The R&D activities developed at the CEA LIST Carnot Institute, within the Research and Technology Direction of CEA, are focused on the development of new technologies for smart digital systems bringing beyond state of the art research results to efficient innovations transferred to industry.

With more than 260 publications in major scientific journals and international conferences, 46 patents applications, 34 PhD thesis defended, CEA LIST continues in 2011 to invest in high quality scientific resourcing in order to create key enabling technologies which will seed innovative solutions answering future industrial needs.

CEA LIST is part of the Paris-Saclay Campus ecosystem and the newly labeled Paris-Saclay Idex. Within the next few years, the Paris-Saclay campus under construction will figure among the most significant campuses in the world. CEA LIST continues to pursue a voluntary strategy to establish privileged partnership through the Digiteo alliance and the Nano-INNOV integration center.

In parallel, in 2011, the number of industrial partnerships has risen quickly. R&D teams supported a growing number of SMEs and startups to strengthen their business identity by integrating in disruptive technologies. As for large corporations, they work side-by-side with the Institute on a long-term basis, often broadening the scope of our research themes and increasing of their competitiveness.

In this context, the 2011 annual research report of CEA LIST translates this balance between high level R&D and technology transfer by presenting an anthology of our best results obtained during the year.
# SUMMARY

## AMBIENT INTELLIGENCE

### SMART MANIPULATION

- Generalized Predictive Control of an Anthropomorphic Robot Arm for Trajectory Tracking
- Compact and Lightweight Hydraulic Mini-Actuator for High Performance Miniature Robots
- Robotic hands: mechatronic design and compliance control of a self-sensing finger prototype
- Modeling and Robust Control Strategy for a Control-Optimized Piezoelectric Micromanipulator
- Design of a new haptic device for maxillofacial surgery
- Design of an actuation system and Modeling of a New Long Range Inflatable Manipulator
- Dynamic virtual manipulator control design for the assessment of the workstation ergonomics
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- Nonparametric estimation of fisher vectors to aggregate image descriptors
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- XRCE and CEA LIST’s Participation at Wikipedia Retrieval of ImageCLEF 2011
- A Weakly Supervised Approach for Large-scale Relation Extraction
- Filtering and Clustering Relations for Unsupervised Information Extraction in Open Domain
- Trajectories based Descriptor for Dynamic Events Recognition
- Using Cross-Language Information Retrieval for Machine Translation
- Error decreasing of background subtraction process by modeling the foreground
- Indoor Pedestrian Localisation Solution based on Anemometry Sensor Integration with a Smartphone
- The Spatial Spectrum of Tangential Skin – Displacement Can Encode Tactual Texture
- Probabilistic Vibrotactile Feedback for Visually-Impaired Gaming
- Accurate and robust 3D object tracking with a single camera
- Designing a Virtual Reality Training Platform for Surgeons: Theoretical Framework, Technological Solutions, and Results

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- Designing complex systems with executable models
- Enabling Scheduling Analysis for AUTOSAR Systems
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- A Model-Driven Framework for the Development of Portable Real-time Embedded Systems
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- Eliciting unitary constraints from timed Sequence Diagram with symbolic techniques: application to testing
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- MIEL: Model Extraction for Concurrent C Programs
- PathCrawler-online.com: A Test Generation Web Service
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- A SystemC TLM Framework for Distributed Simulation of Complex Systems
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The LIST’s 2011 scientific report aims to highlight the main scientific breakthrough of each research team. According to that perspective, the 2011 results are presented by the searchers itself, ensuring thereafter a better readability of the strengths and assets of each laboratory. Therefore, we shall thank all the authors who intended to present the substance of their results, recalling context, state of the art, starting issue, and potential of application.

Because such a business oriented presentation highlights mainly the specificities of the laboratory skills, we must remember to complete that the strategic cohesion of the researches is ensured around three complementary technological axis: (1) ambient intelligence, (2) embedded systems, (3) advanced manufacturing technologies.

These strategic goals have attracted a lot of academic and industrial partnership (technology platforms, joint laboratories...) leading to excellence level researches and industrial applications (security, transport, mobility, health, energy, manufacturing, ambient intelligence...).

In the domain of architectures and embedded software, half a part of the chapter is devoted to research on multi-core architectures. The rest is devoted to work on real-time architectures, safety, memory control, signal processing and information networks.

About ambient intelligence, 50% relate to knowledge sciences, the other part being devoted to human-machine interface software, which are the central skills in robotics or data mining.

CEA LIST also develops software and equipment for embedded systems to ensure their safety, security reliability and performance, especially developed for complex systems or ambient intelligence devices which critical functions require specific researches.

Numerical simulation joined to our means for physical standards of reference experimentation, are complementary forces enabling a real non-destructive testing technological ability in the domain of nuclear applications, for more accurate, safe and secure operations, and in the domain of nuclear medicine for, for more secure, pertinent and fast diagnostics and imaging.

These research works are leading to a lot of new skills and wider capabilities which will be integrated in software innovations and tool-kits developed by the LIST’s laboratory.

One can observe a distribution of the themes of software research along two tendency axis, complexity and versatility. Centralized computers give place to cloud and static devices to mobile ones. With the development of swarm intelligence embedded in the objects, complex systems can be implemented in non-localized and non-centralized systems of production, and interact intelligently with humans, large amount of objects or knowledge repositories that are weakly connected and fast interacting in a fast growing complex evolving world.
OVERVIEW

SMART DIGITAL SYSTEMS

Based in Paris region, CEA LIST Institute focuses its 700 scientists, engineers and technicians’ research on smart digital systems. Building long-lasting relationships with its industrial partners, based on innovation and technology transfer, the institute maintains a high level upstream research through academic partnerships. At the crossroads between physical and digital worlds, CEA LIST Institute focuses its research on embedded systems (architecture, software and system engineering), ambient intelligence (interactive systems), sensors and signal processing (innovative sensors, signal processing, industrial control and metrology).

AN ASSET FOR INDUSTRIAL COMPETITIVENESS

CEA LIST Institute is intended to support industrial competitiveness through innovation and technology transfers. The institute’s ability to create a perennial relationship with its industrial partners allows its researchers to understand and respond to their needs. Often initiated within R&D projects, mainly in business competitiveness clusters as Systematic, these links take shape in strategic partnerships.

To maintain the necessary high level of research for innovation, CEA LIST has also forged a number of academic partnerships, particularly within RTRA Digiteo and the Carnot Institutes network. Such an environment enables CEA LIST to address future societal needs, including more user-friendly human-machine interfaces, more secure and reliable systems, intelligent energy management systems and tools for industrial eco-design processes that take into account environmental issues.

INTEGRATED PROJECTS: FROM IDEA TO INNOVATION

CEA LIST’s research covers several major sectors of activity surrounding our daily life, among which information and communication technologies (ICT), energy, transport, security, health and manufacturing. The Institute’s leading edge is based on its ability to integrate hardware and software using its know-how and technological skills. Designing quality comprehensive systems is made possible thanks to the institute’s strong culture on project building and to the excellence achieved by its researchers, engineers and technicians. The CEA LIST research covers the entire innovation process, from the publication of original results to development of demonstrators and technology transfers.
AMBIENT INTELLIGENCE

SMART MANIPULATION
GENERALIZED PREDICTIVE CONTROL
OF AN ANTHROPOMORPHIC ROBOT ARM
FOR TRAJECTORY TRACKING

RESEARCH TOPICS: ROBOT ARMS, TRAJECTORY TRACKING, PREDICTIVE CONTROL
M. MAKAROV, M. GROSSARD, P. RODRIGUEZ-AYERBE (SUPELEC), D. DUMUR (SUPELEC)
SPONSORSHIP: CEA LIST
PARTNERSHIP: SUPELEC

Over the last few decades, the efficiency of the Model Predictive Control (MPC) has been demonstrated through a large number of industrial applications. A receding horizon control strategy is especially beneficial when a plant model is available and the reference trajectory is known, allowing for prediction (Fig.1), which makes it relevant for precise trajectory tracking by a robot manipulator. However, robot manipulators are characterized by fast and nonlinear dynamics. In this context, a direct application of nonlinear MPC methods would require solving a nonlinear optimization problem at each sampling period, which may not be compatible with the limited computation time in real-time controllers.

Existing MPC approaches for robot motion control therefore tend to avoid the on-line optimization process by providing an analytical solution of the predictive control algorithm. This is usually achieved either by using an approximated model of the manipulator, or by applying linear MPC on a robot first linearized by feedback. The proposed approach relies on the experimentally identified rigid dynamic model of the robot arm, used in an inner linearizing loop (Fig.2).

By this, the multivariable system is not only linearized but also decoupled and can be controlled by linear decentralized controllers. Among different MPC strategies, the GPC (Generalized Predictive Control) algorithm without constraints has been adopted. Its formulation under a polynomial form is especially suitable for real-time implementation, and allows a classical frequency-domain design. This control strategy was experimentally evaluated on ASSIST [1], a 7-dof anthropomorphic robot arm designed at CEA LIST in the context of safe human-robot interaction and co-manipulation. Experimental results with two actuated joints demonstrate the efficiency of this approach when compared with a classical decentralized PID and the model-based CTC (Computed-Torque control) schemes (Fig.3). Better tracking performances and an improved robustness to payload changes were obtained.

References:
COMPACT AND LIGHTWEIGHT HYDRAULIC MINI-ACTUATOR FOR HIGH PERFORMANCE MINIATURE ROBOTS

RESEARCH TOPICS: MINIATURE ACTUATORS, MINIATURE SCALE ROBOTICS, SOFT ROBOTICS

C. ROTINAT-LIBERSA, B. SOLANO

SPONSORSHIP: ANR TECSAN 2007

There is a worldwide interest in ultra-small and lightweight actuation systems that are able to simultaneously generate relatively high force and displacement. Typical fields of application that would potentially benefit from this kind of actuator are, among others: aerospace robotics, medical robotics, personal robotics and military applications. In some cases, these applications demand actuation in confined small space and/or portability. In this context, the design, modeling and testing of a new hydraulic actuation system has been investigated.

Fluidic artificial muscles (or McKibben actuators) are very powerful actuators that consist of an inner flexible tube that is surrounded by a tubular braided fiber mesh sleeve. When the bladder is inflated, the mesh expands in the radial direction and contracts axially, shortening the overall length of the muscle and subsequently producing a pulling force (Fig.1).

As opposed to the usual pneumatic approach (requiring a separate pressurized air source), a compact and lightweight actuation system made of a motorized water-hydraulic closed circuit and a miniature McKibben actuator has been proposed [1]. The system components are shown in Fig.1, and their specifications are given in Table I.

The actuator performances are: a 25% contraction rate (12.5 mm stroke for a 61 mm length muscle), and a 6 N load under 1 MPa fluidic pressure. Compared to similar actuators, our system considerably increases the work density while maintaining an equivalent force-to-volume ratio (Table II).

In order to understand, to optimize and to control such an actuation system, an analytical model able to predict its quasi-static behavior has been developed and validated experimentally (Fig.2) [1]. Unlike the other models found in the literature, which require the exteroceptive measurement of one of the two performance parameters, our analytical model is able to estimate both the force and the contraction of the muscle simultaneously, by using the knowledge of only two proprioceptive parameters of the fluid circuit (imposed piston displacement and pressure measurement). This is particularly interesting, as it gives a reliable estimation of the actuator behavior using only the motor encoder and pressure sensor data, which is crucial to simplify the control strategy and to reduce the instrumentation for compactness.

To conclude, the quasi-static relatively high mechanical performances and the reliable analytical model of this integrated actuator may help spreading its use in an increasing number of applications, where compactness, lightness and high power are needed. Especially, such an actuator is well suited to be integrated in small size portable robotic devices, like dexterous manipulators or surgical instruments [2].

Table I. Specifications of our actuation system

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic closed circuit with motor</td>
<td>2.6 Watt</td>
</tr>
<tr>
<td>Max. length</td>
<td>75 mm, Ø 13 mm</td>
</tr>
<tr>
<td>30 grams</td>
<td></td>
</tr>
<tr>
<td>Nylon braid: Ø 1.5 mm (external)</td>
<td></td>
</tr>
<tr>
<td>Fiber angle of the braid: 17 degrees</td>
<td></td>
</tr>
<tr>
<td>Silicone tube: Ø 0.6 mm (internal)</td>
<td></td>
</tr>
</tbody>
</table>

Table II. Work density (in 10-3 J/mm³) of our actuator compared to actuators from the literature [1]

<table>
<thead>
<tr>
<th>Actuator Type</th>
<th>Work Density (10-3 J/mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air cylinder*</td>
<td>0.18</td>
</tr>
<tr>
<td>Fluidic muscle*</td>
<td>0.15</td>
</tr>
<tr>
<td>NiTi actuator</td>
<td>0.10</td>
</tr>
<tr>
<td>PZT actuator</td>
<td>0.07</td>
</tr>
<tr>
<td>Human muscle</td>
<td>0.69</td>
</tr>
<tr>
<td>This work*</td>
<td></td>
</tr>
</tbody>
</table>

*hydraulic/pneumatic pumps are not included

References:
ROBOTIC HANDS: MECHATRONIC DESIGN AND COMPLIANCE CONTROL OF A SELF-SENSING FINGER PROTOTYPE

RESEARCH TOPICS: FLEXIBLE STRUCTURE, ROBOTIC HAND, MECHATRONIC DESIGN
J. MARTIN, B. HUARD, M. ROBERT AND M. GROSSARD
SPONSORSHIP: EU HANDLE PROJECT (FP7)
PARTNERSHIP: UPMC, SHADOW ROBOT COMPANY

This work presents the first steps towards the development of an anthropomorphic and dexterous hand with adjustable compliance. Our design approach is based on the backdrivability of a cable-driven actuator and the use of backlash-free, frictionless compliant structures. High-performance mechanics improve the level of dexterity related to the mechanical structure; control-wise, minimum friction and zero backlash leads to an enhanced stability and fine manipulation capability. Thus, an optimized linear actuator based on a DC motor along with a ballscrew component, cables, and two flexible structures, has been designed (Fig.1).

The first flexible structure has been specifically designed to accomplish the anti-rotation function without introducing additional friction and backlash. It is a protruded planar three-link serial mechanism, where each joint has been substituted by a compliant notch joint. The first link is linked to the ground and the last link is linked to the nut. As shown in Fig. 2 (left), it allows the linear displacement of the nut along the ball-screw axis by deformation of the flexible structure, while preventing the nut rotation around the ball-screw axis. As an additional advantage, the proposed anti-rotation system can be machined as a monolithic structure. This simplifies the assembly and minimizes the number of parts. Simultaneously, the anti-rotation device allows the nut to slightly displace and rotate along any transversal direction, which absorbs angular oscillations and avoids hyperstatic constraints. Without this freedom, there would be a variable friction that would depend on the screw rotation angle and the nut travel. This would diminish mechanical performance of the actuator. In the perspective of high efficient mechanics for fine manipulation, it has been adopted the strategy of substituting contact-based joints by compliant joints. This removes friction, backlash and wear, as the motion of such joints is achieved by the elastic deformation of a solid material.

A second flexible pivot structure with large angular range and minimum axis drift has been designed to be implemented on the structure (Fig.2-right).

These flexible structures have been used as mechanical components in the actuation mechanism represented in Fig.1. Forces applied to the force transmitting cable are directly translated into a resistive torque on the motor shaft thanks to the backdriveability mechanism. This torque, in turn, can be calculated from the motor current. Since the behavior of the spring and the flexible joint is known, its contribution to the torque can be estimated, as well as the contribution of the phalanx inertia and weight. Then, by subtraction of these terms from the overall torque measurement, the contribution of the external forces applied to the finger can be calculated. This calculation gives to the actuator the capability of self-sensing the external forces applied to the finger, and this is possible by virtue of the actuation mechanism backdrivability and the overall mechanical efficiency. Forces above 0.5 N are experimentally detected by motor current measurement.

Figure 1. Prototype of the self-sensing actuated joint with flexible structures.

Figure 2 Left: monolithic frictionless anti-rotation system of the self-sensing linear actuator: canceling of the effects caused by the angular oscillations and the hyperstatic constraints. Right: Novel flexible pivot with large angular range and small center shift for the inter-phalangeal joints.

References:
MODELING AND ROBUST CONTROL STRATEGY FOR A CONTROL-OPTIMIZED PIEZOELECTRIC MICROGRIPPER

RESEARCH TOPICS: FLEXIBLE STRUCTURE, HYSTERESIS, PIEZOELECTRIC ACTUATOR, ROBUST CONTROL

M. GROSSARD, M. BOUKALLEL, N. CHAILLET, C. ROTINAT-LIBERSA

SPONSORSHIP: CEA LIST
PARTNERSHIP: FEMTO-ST

Recently [1], we developed a prototype of a new compliant piezoelectric monolithic gripper (see Fig. 1). It has been designed using a global systematic approach, based on the multidisciplinary topology optimization of the flexible structure. This method is based on the flexible building block method called FlexIn ("flexible innovation"), which uses a multidisciplinary genetic algorithm to optimize flexible structures. Details on the design procedure can be found in [1]. When the active beams of the symmetric jaws of the microgripper are supplied by voltage, it results in a deformed shape that produces a symmetric stroke of $\delta = \pm 10.51 \, \mu m$ and a gripping force of about $0.84 \, N$ along $x$-axis under $\pm 100 \, V$. These static mechanical characteristics of our device are of the same order of magnitude of other well-known actuation schemes, such as unimorph or bimorph PZT actuators, widespread in the design of microrobotic manipulators [1].

It has been previously designed with an emphasis to control strategy, using a new topological optimization method. For the design of our microgripper, both purely mechanical criteria (i.e., stroke and force at the tip) and innovative frequency-based criteria have been used. These last criteria are useful tools to ensure the efficient control of flexible structures afterward. These criteria allow taking into account resonance amplitude modulations and optimal pole/zero placement in the frequency spectrum of the device, so that the designer can fit its open-loop frequency response function (FRF) in a desired way. As a consequence, because our device has been frequency-optimized, it appears that the synthesis of simple robust regulators is easy afterward. They can guarantee interesting stability margins and lead to low-order regulator compared with classic robust pole placement approaches.

A complete nonlinear model relating the voltage and the resulting deflection is established, taking into account hysteresis as a plurilinear model subjected to uncertainties. The approach used for controlling the actuator tip is based on a mixed high authority control (HAC)/low authority control (LAC) strategy for designing a wideband regulator (Fig.2). It consists of a positive position feedback damping controller approach combined with a low-frequency integral controller, which is shown to have robustness performances as good as a RST-based robust pole placement approach for the microgripper. Rejection of the vibrations, naturally induced by the flexible structure, and the control of the tip displacement have been successfully performed. Because we had taken into account frequency-based criteria from the first designing step of our device, we demonstrate that the tuning of the HAC/LAC can be easily performed and leads to low-regulator order.

Figure 1. 3-D CAD model of the piezoelectric device with top face electrode patterns ($V_{left}$ and $V_{right}$ are the controlled inputs for actuating the left and right arms).

Figure 2. Experimental step responses of the HAC/LAC compensated microactuator.

References:
Virtual Reality (VR) technologies offer promising opportunities for the training of skilled activities. If properly designed, multimodal VR platforms allow reproducing a compelling illusion of reality. Moreover, in VR, the environment is fully controlled and can be adapted to the performances and progress of the user. It is possible to break up the trained tasks in subtasks in order to favor the comprehension and training. Multimodal helps can also be provided, e.g., semi-transparent objects to help understanding blind tasks, active haptic guidance to help performing well. Non-dominant senses like haptics can also be emphasized in order to avoid relying only on vision. Finally, quantitative data can be recorded, analyzed, and used as feedbacks which are crucial in training.

These advantages make multimodal VR training platforms efficient complements to traditional teaching methods. Several such systems already exist, e.g., to train handwriting, sport, or surgery. The first results obtained tend to support the hypothesis that they can help learning new tasks, and maxillo-facial surgeons expressed the wish to benefit from these advances. To answer these needs, CEA LIST developed such a platform in close collaboration with the Departments of Oral and Maxillofacial Surgery (MFS) of several University Hospitals in France with the financial support of the European Commission (SKILLS Project).

MFS is however particularly demanding. While most of the existing commercial systems (e.g., Lap Mentor from Symbionix, Hystsim from Virtamed, LapVR from CAE Healthcare) concentrate on MIS procedures, allowing a simplified platform design with 3 or 4 DOFs robots, MFS requires 6 DOFs haptic interfaces with a high quality force feedback to allow interacting with both the soft and hard tissues (bones) of the face. The efficiency of this approach depends indeed on the ability to realistically reproduce the situations encountered in the real world. If not, users could develop false perception-action loops. This would be detrimental for the transfer of the training to the real world.

MFS requirements were obtained from interviews with surgeons and on site activity analysis complemented with quantitative data obtained with specifically equipped surgical instruments during a data acquisition campaign on dead bodies in the Anatomy Laboratory of the Rouen University Hospital with three expert surgeons. The specifications emphasize a large workspace, large forces and a high stiffness. As no commercially available haptic device fits these requirements, we specifically developed a new interface, as illustrated by Fig.1.

This robot makes use of a 6 degrees of freedom (DOFs) hybrid architecture composed of two 3 DOFs robots connected by a link carrying an additional DOF in series. This architecture combines the advantages of serial (large workspace in orientation) and parallel robots (good transparency in orientation). Further additional DOFs are introduced to reject the singularities outside the workspace and to avoid collisions between the links. High performances actuation is obtained with DC actuators and optimized cable capstan reducers. The performances, i.e. up to 400x600x700mm and 140° workspace, more than 50N force and more than 10000N/m stiffness [1], are beyond the state of the art.

To render the high frequency vibrations of the surgery drill, an active prop is added in the handle. It makes use of a piezoelectric stack actuator whose movements are amplified by lever arms and bending beams introduced at the surface of the handle. This design allows handle’s surface displacements under the fingertips up to 100µm up to 600Hz [2].

The device was integrated within a multimodal VR platform and training campaigns were performed in several University Hospitals. Thanks to the unique capabilities of the haptic interface, the platform was judged very realistic by expert surgeons. Indeed it shows very similar force positions patterns as those encountered in real surgeries. Moreover, it allows distinguishing novices from experts before training. Finally, after training, novices performed quicker and more precisely on simulator.

References:
DESIGN OF AN ACTUATION SYSTEM AND MODELING OF A NEW LONG RANGE INFLATABLE MANIPULATOR

RESEARCH TOPICS: MECHANICAL DESIGN, ROBOTICS, INFLATABLE STRUCTURES
S. VOISEMBERT
SPONSORSHIP: CEA LIST
PARTNERSHIP: ARTS ET MÉTIERS PARISTECH

The CEA has developed numerous remote handling systems for inspections in cluttered or complex environments. Very often, the access hole diameter does not exceed 200mm and cannot be enlarged. Moreover, the space is filled with critical installations, machines, tanks, pipes… that must not be damaged by the robot. One vital requirement is to inspect hidden parts of the remotely located equipments with a camera, or another sensor.

That is why long-range snake-like articulated cantilever arms have been developed. They are long, stiff, and made of high performance materials such as titanium or carbon fibers. But the risk of damaging essential parts of the plant is too high to authorize any contact between the arm and its environment. As the arm is only supported by its base, the maximal length of the arm is limited by its proper weight. The research of a dramatic weight reduction led us to consider inflatable structures[2].

In fact, inflatable structures can be stiff, lightweight and articulated so they are suitable for a long range application. Moreover, they are harmless for the environment and we can imagine that this kind of robot could touch the installations and even be supported by them on some points. Thus the length of the arm could be theoretically unlimited. The cost of such a robot would be far lower than the cost of an AIA robot and the inflatable part could even be disposable.

The benefits in terms of storage and manipulation are obvious: when deflated the robot could be easily folded and transported. The foreseen design is presented in Fig.1, the robot is composed of stiff inflatable links and constant volume joints based on space-suit joints.

This kind of joint best suits our application because its torsion stiffness is the same as the links and the actuation torques are low [2].

In 2010 this concept was proposed and a flexible model in order to predict the deflections of the inflated arm was presented[3].

In 2011 we have designed an actuation system based on tendons and pulley-blocks. The coupling between the joint is avoided by making the tendons follow the middle lines of the joints (Fig.3).

We have also focused our work on the manufacturing process of the joints and the integration of the actuation system. Fig.2 presents some of the numerous prototypes we have built in order to test different processes and joints structures.

The concept of a long range inflatable arm is now validated and in our future works we will motorize the joints and design the modeling for control.

**References:**
Physical risk factors assessment is usually conducted by analysing postures and forces implemented by an operator during a work-task performance. A basic analysis can rely on questionnaires and video analysis, but more accurate comprehensive analysis generally requires complex expensive instrumentation, which may hamper movement task performance.

In recent years, it has become possible to study the ergonomic aspects of a workstation from the initial design process, by using digital human model (DHM) software packages such as Pro/ENGINEER Manikin, JACK, RAMSIS or CATIA-DELMIA Human. However, a number of limitations concerning the use of DHM have been identified, for example biomechanical approximations, static calculation, description of the probable future situation or statistical data on human performance characteristics. Furthermore, most common DHM used in the design process are controlled through inverse kinematic techniques, which may not be suitable for all situations to be simulated.

A dynamic DHM automatically controlled in force would therefore be an important contribution to analysing ergonomic aspects, especially when it comes to movement, applied forces and joint torques evaluation. Such a DHM would fill the gap between measurements made on the operator performing the task and simulations made using a static DHM.

In [1], we introduce the principles of a new autonomous dynamic DHM, and then describe an application and validation case based on an industrial assembly task adapted and implemented in the laboratory. An ergonomic assessment of both the real task and the simulation was conducted based on analysing the operator/manikin’s joint angles and applied force in accordance with machinery safety standards (Standard NF EN ISO 1005-1 to 5 and OCcupational Repetitive Actions (OCRA) index). Given minimum description parameters of the task and subject, our DHM provides a simulation whose ergonomic assessment agrees with experimental evaluation.

The workstation (Fig.1) comprised a force platform assembled on a lift table fitted with a row of ten insert supports arranged at 45° from back to front in the sagittal plane. A ten camera Motion Analysis System was implemented to record the whole body position and posture. Eleven healthy right-handed subjects (nine males and two females) took part in the study.

In our study, the human body (Fig.2) was kinematically modeled as a set of articulated rigid bodies branches, organized into a redundant tree structure, which is characterized by its degrees of freedom (DoF). Our DHM comprises 39 joint DoF and 6 root DoF, with 8 DoF for each leg and 7 for each arm. The root is not controlled. The dynamics of the robot is described as a second order system [2].

The optimization framework is a force control approach based on the idea of a Jacobian-transpose (JT) control method [2]. The controller is formulated as a (quadratic programming) QP problem, which deals with a great number of DoF solving simultaneously all constraint equations.

Force control is introduced in order to achieve different objectives. The goal of the control system is to compute joint torques based on given tasks.

We used this model to simulate an experimental insert clipping activity in quasi-real-time and applied the simulated postures, time and exertions to an OCRA index-based ergonomic assessment. Given only scant information on the scenario (typically initial and final operator positions and clipping force), the simulated ergonomic evaluations were in the same risk area as human data.

References:
INTERACTIVE DYNAMICS AND BALANCE OF A VIRTUAL CHARACTER DURING MANIPULATION TASKS

RESEARCH TOPICS: DIGITAL CHARACTERS
M. LIU, A. MICAELLI, P. EVRARD, A. ESCANDE, C. ANDRIOT
SPONSORSHIP: CEA LIST

A great challenge for virtual characters is to be able to interact with human operators by performing tasks in physics-based virtual environments (Fig.1).

This research work is particularly interested in the interaction with operators by using a simple motion capture of the hands. Motion capture has become an essential technique in the control of virtual characters. It is traditionally used to guide the motions of a virtual character by virtual springs. Many existing motion correction techniques are based on prerecorded motions, whereas our work studies real-time interactions where an operator can interact in an unpredictable way.

This involves endowing the virtual character with the ability to accomplish tasks required by operators in real-time by trying to follow their motions as best as it can, and to adjust its postures autonomously to handle multiple constraints due to interactions with virtual environments.

There are two main difficulties in this research topic. First, captured motions should be adjusted to handle external contact forces during interactions with the environment. As a virtual character’s body is under-actuated, it needs to use contacts with the environment to perform desired motions and to maintain its balance. However, the operator’s postures can be inappropriate for the character. This is because in order to simplify the interaction system and to make the operator more comfortable, it is preferable to use a minimum of equipments for the interaction. To achieve a low-immersion virtual reality environment, we choose to use only a motion capture system for the interaction without using force sensors. As a result, the character should be endowed with the ability to improve its performance automatically to compensate for the fact that the operator is not completely immersed into the virtual environment and cannot adjust his postures according to force feedback.

Consider a character pushing an obstacle for example, the operator just sends out the intention of pushing by reaching out his hands, but the character has to automatically lean toward the obstacle to push it while the operator cannot, because the virtual obstacle does not exist in the world of the operator. Second, a virtual character’s body has many degrees of freedom. They can have many postures that can accomplish the same task. The controller must find the best posture solution.

To handle these problems, we propose a new framework of online hybrid control for virtual characters [1], which combines multi-objective control and motion capture techniques. The block diagram is shown in Fig.2. At each time step of simulation, the control system computes joint torques from a motion capture sequence, given tasks, and constraints. The wrench bound module is developed to handle conflicting motion tasks [2]. The joint torques are used to drive the virtual character.

Our controller can work fast enough for real-time interactions. It can control a virtual character to perform a variety of manipulation tasks (Fig.1); and it can improve task performance by enhancing the character’s ability to handle interaction forces.

References:
HUMAN MOTIONS ANALYSIS AND SIMULATION BASED ON A GENERAL CRITERION OF STABILITY

RESEARCH TOPICS: BALANCE, DIGITAL HUMAN MODEL, STABILITY MARGIN, ERGONOMICS
Z. QIU, A. ESCANDE, A. MICAEILLI, T. ROBERT (IFFSTAR)
SPONSORSHIP: CEA LIST - IFFSTAR
PARTNERSHIP: IFSTTAR (LBMC)

A DHM (Digital human model) that moves in an environment can be represented by a simplified mass point model (as shown in Fig. 1) that interacts with the environment at some supports (contacts and grasps) [1]. External wrenches applied on the DHM are constrained by some physical limits for ensuring support feasibility (e.g. no-slipping, no-tipping, force limit). Accordingly, these constraints result in an admissible subspace for the DHM’s dynamics.

This admissible subspace depends only on the support configuration and is defined as:

\[ \mathcal{P}_{ad} = \left\{ \mathbf{w}_p \in \mathbb{R}^6 \mid \text{contact or grasp constraints are satisfied}\right\} \]

A DHM is in dynamic balance if its pseudo-wrench, \( \mathbf{w}_p \), is inside its admissible subspace, \( \mathcal{P}_{ad} \). The stability margin (the smallest distance from \( \mathbf{w}_p \) to all facets of \( \mathcal{P}_{ad} \)) can thus be used for evaluating quality of the balance when facing perturbations.

The above-mentioned balance criterion can be first used for analyzing a real human motion in terms of dynamic balance [1]. A recorded motion in MoCap (motion capture) experiments has been reconstructed with a kinematic DHM, as shown in Fig. 2. A sequence of support configurations as well as the human subject’s motion data in this recorded motion, have been estimated from the reconstructed motion data. Accordingly, one can compute for each instant: the human’s pseudo-wrench, its admissible subspace and the stability margin.

In a second step, based on the stability margin previously presented, we developed a method for generating a 3D CoM trajectory based on MoCap data only at key frames (instants at which the support configuration changes) (see [1]). The CoM trajectory is parameterized as a 3d B-spline whose control points are solved by optimization technique.

The optimization solver computes the CoM trajectory by minimizing velocity and jerk of the trajectory at some sampling instants while respecting the balance constraints, namely a set of admissible subspaces for \( \mathbf{w}_p \) that are computed based on a pre-defined sequence of support configurations. CoM positions are imposed at the key frames and some geometric constraints are also defined for the optimization problem.

The generated CoM trajectory as well as trajectories of end-effectors (feet, hand, head) extracted from the reconstructed motion have been used as tracking references for the dynamic controller which actuates a 39 dofs DHM to realize its motion using XDE, the CEA LIST real-time simulation software (see Fig. 3).

References:
Recent events have placed the debate on nuclear energy on the front of the stage. In this difficult context, it is more necessary than ever to work for the safety of the nuclear world operators, following the ALARA (As Low As Reasonably Achievable) principle of precaution applied to the nuclear sphere. Among others, and this is the subject of the research presented in this paper, it is essential to ensure minimal exposure to operators working in irradiated sites.

For a long time, the preparation of interventions in irradiated environments was made empirically. Since the 80s, calculation codes appear to model these environments, and calculate the radiation doses received by an operator. It then became possible to plan in advance the movements of the operator on the site to minimize the received dose.

However, these simulations require a computation time which makes their use impossible in real time. Thus, the impact of shields addition or removal during operation cannot be accounted for instantly.

CEA LIST worked on the development of algorithms to perform these calculations in real time. To do this, we chose radiation propagation methods. In particular, we relied on a method of attenuation in straight line with build-up factors, which considers radiation from radioactive sources moving in a straight line, without bouncing, and their intensity being a function of the thickness and the nature of the encountered materials.

This method provides an accurate estimate as long we strive to efficiently calculate the thickness penetrated by the rays from the source to the operator.

To do this, we must first reproduce the real scene by computer. This is done by modeling it using geometric primitives, in our case triangles (see Fig.1). This modeling generates 3D scenes whose complexity is around one million triangles. However, to ensure a good accuracy, our method should cast about one million rays. If we use a brute force approach to calculate the intersections between a million triangles and a million rays the method requires $10^{12}$ tests!

Despite the steady increase in computing power at our disposal, interactivity is still far away. We must therefore resort to an acceleration structure that allows us to quickly discard rays and triangles having no chance to intersect. We determined after comparison with other types of structure, that the perspective grid structure was best suited to our problem.

In this structure, shown in Fig.2, we first project triangles, whose indices are stored in the covered cells. Next, the rays are in turn projected. Knowing for each cell, the rays as well as the triangles belonging to this cell, it only remains to compute the intersection of these few triangles and rays. Computational complexity is thereby considerably reduced.

Nevertheless, this method is still too slow to be used interactively. However, it seems possible to treat rays independently of each other, so that a parallel implementation is possible. Especially, it is possible to adapt this method to a GPU architecture.

This is the solution that we have adopted, developed and presented in [1]. The GPU architecture is very different from the CPU architecture, and we had to rethink the algorithm, including reversing the phase of projection rays and triangles, and adapting to the constraints imposed by memory accesses. This method allowed us to treat scenes containing 600,000 triangles and 800,000 rays at a frequency of several Hertz, thus making interactive simulation possible.

References:
Machine to Machine (M2M) environment is considered as an advanced type of network referring to data communication between physical devices without human intervention. M2M networks inherit resource-limited, un-guarded and mass deployed nature of sensors networks but also ensure more intelligence and self-organization. Considering this large number of M2M devices, deployed in potentially hazardous environment and communicating together over unsecure radio links, high security measures have to be taken in order to provide adequate transmission of sensitive information. The major requirements related to security concern authentication, confidentiality and data integrity. In turn, these security services require an initial key establishment process that must fit to the low capabilities and cost constraints of M2M components, most of which cannot implement complex security schemes.

In the M2M scenario envisioned in this work, the low-resource nodes are considered as a part of internet and are therefore to interact with nodes that do not belong to the same network without prior knowledge of each other. However, highly resource-constrained nodes unable to support public key cryptography are not capable to communicate with a powerful remote server that would precisely require that level of security. Unfortunately, among existing key establishment solutions, none adapts use of asymmetric cryptography primitives for ensuring a strong security level to highly resource-constrained nodes. Hence, new key establishment solutions become a necessity in order to make their communications successfully set up.

In this work, we proposed to exploit the heterogeneity of M2M systems by delegating cryptographic computational load to less resource-constrained nodes in a distributed and collaborative scheme. A novel key establishment protocol was presented in which a highly resource-constrained node obtains assistance from more powerful M2M nodes in neighborhood in order to securely establish a shared secret with a remote server. Each assistant node, called “proxy”, is to encrypt a part of the shared secret sent from the highly resource-constrained to the distant server.

Our solution requires that assistant nodes contact the server and send it messages on behalf of the constrained node. Hence authorization and authentication questions arise at the proxy side, since these nodes must prove on one hand the integrity of the sent messages and on the other hand their representativeness of the constrained node.

For this purpose, we propose to assign each proxy an ephemeral pair of private and public keys, using the lightweight one-time signature scheme explained in [1] in order for the proxy to sign messages on behalf of the constrained node. The computational load of generating those pairs of keys is moved from these proxies to the sensor network trusted entity T, which is also the only entity able to assert that a proxy is authorized to sign on behalf of constrained node. Once retrieving their key material, proxies are prepared to participate to the key exchange. The constrained node applies an error correction scheme to the secret key, splits it into multiple parts and sends each part to the correspondent proxy. The error correction scheme aims to make possible the recovery of the secret key at the server even if some parts are lost or undelivered during the phase of transmission. Independently, each proxy processes (encrypt and sign) the received share of the secret key and delivers it to the server. Once receiving a sufficient number of shares from proxies, the server checks their integrity and finally reconstitutes the secret key.

We provided at part of this work a security analysis to prove the effectiveness of our solution. Next steps in the validation of this protocol will consist in carrying out simulations, in order to precisely quantify the energy savings at the constrained node.

Figure 1. Considered topology
ANCHOR-BASED ROUTING OPTIMIZATION EXTENSION FOR PROXY MOBILE IPv6 IN FLAT ARCHITECTURES

RESEARCH TOPICS: ROUTING OPTIMIZATION, PROXY MOBILE IPv6, IP CELLULAR NETWORKS, LTE
M. BOC, A. PETRESCU, C. JANNETEAU
SPONSORSHIP: MEVICO CELTIC-PLUS PROJECT
PARTNERSHIP: AALTO UNIVERSITY, EXFO NETHAWK, NOKIA SIEMENS NETWORKS OY, VTT (FI), ALCATEL-LUCENT, ARTELYS, FRANCE TELECOM (FR), CHEMNITZ UNIVERSITY, DEUTSCHE TELE-COM (DE),…

The growing number of mobile users and bandwidth demand has led mobile network operators to consider flattened, distributed architectures, and even cloudification of their infrastructures. The idea is to localize mobility management operations and, if possible, to perform rapid data offloading. Although flat and distributed architectures do not prevent IP anchored mobility management protocols to operate, the impact of the anchor location is increased however. Optimized mobility management procedures are therefore crucial to ensure optimal resources usage, limited congested areas, and higher throughput.

In a network-based IP mobility management protocol like Proxy Mobile IPv6 (PMIPv6), routing optimization is an open problem. PMIPv6’s signaling and mobile node’s data flows are anchored to a central location, i.e., the local mobility anchor (LMA). Within a domain, the LMA’s location is fixed by the operator and is not related to the current point of attachment of a Mobile Node (MN) nor its corresponding nodes (CNs). Mobile access gateways (MAGs), i.e., the first IP routers from MNs, ensure MNs registration with the LMA and route MNs data flows in bidirectional tunnels towards the LMA. This generic operation is conceptually not optimized and causes drops in flows performance (throughput, jitter, packet loss, etc.).

Our contribution in this document [1] is the design of an extension to PMIPv6 to perform data routing optimization. The idea is to give to the LMA the ability to control the data path of each flow by selecting a set of intermediate data anchor(s) (IAs) to be traversed. We consider that anchors are needed in a mobile context for two main reasons: (1) to support the medium handover procedures delays, which sometimes cause packets dropping and (2) because the operator may need to apply flow treatments it is responsible for (content filtering, lawful interception, etc.). Note that those concepts are close to Software defined networking (SDN) and OpenFlow. Routing optimization is hence resolved by considering the optimal anchor’s location. With this principle in mind, the idea is to dissociate signaling and data path by using the LMA as signaling anchor and intermediate anchors (IAs) as data anchors.

Basically, the LMA would be responsible to select the most appropriate IAs to determine the path one flow or all flows from a MN have to pass through with regards to the destination. This means that data flows may not traverse the LMA in some situations.

By selecting IA(s) for a data flow, the extension aims at enabling new functionalities such as 1) improving flows performance by avoiding bottlenecks, 2) obtaining a MAG-IA-MAG path length close to the shortest path (MAG-to-MAG), and 3) offloading to other networks. Therefore, we define an intermediate anchor as an IP entity able to route data packets, to establish tunnels, and to apply a set of services on a flow. In a distributed and flat architecture, an IA can be any IP entity.

New forwarding paths and tunnels are pushed from the LMA to MAGs and IAs through a new signaling message: the localized routing initiation (LRI) messages. MAGs and IAs acknowledge new rules through localized routing acknowledgement messages (LRA).

When the LMA initiates a routing optimization procedure, it first sends an LRI message to the IA. This LRI message provides 1) the IPv6 addresses of MAG1 and MAG2 for tunnels establishment and 2) the MN and CN prefixes.

When the IA accepts the request with a LRA, the LMA sends LRI messages to both MAGs. In the case where there is more than one IA, LRI messages are sequentially transmitted to each IA before MAGs. In this way, we limit the probability to lose data packets. As soon as both MAGs have accepted the initiation request, the data traffic between CN and MN is optimized and traverses the IA. There is no more traffic passing through the LMA.

References:
CONSTRUCTION OF NEW DELAY-TOLERANT SPACE-TIME CODES

RESEARCH TOPICS: COOPERATIVE COMMUNICATIONS.
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SPONSORSHIP: IEEE TRANSACTIONS ON INFORMATION THEORY.
PARTNERSHIP: TELECOM PARISTECH. UNIVERSITY OF WATERLOO, CANADA.

During the last decade, cooperative communications have been widely investigated for wireless networks, especially cellular systems and ad-hoc sensor networks. In such cooperative networks, a transmitter can act as a relay, with some processing, assisting another transmitter (source) to convey its messages to a destination as described in Fig.1.

Among several cooperation strategies, distributed Space-Time Coding (STC) techniques have been designed to transmit the information symbols at different time instants on the distributed antennas belonging to independent relay terminals. These STC schemes showed to improve the system performance by providing maximum cooperative diversity and high data rates. Recently, research studies have been interested in asynchronous communications. In fact, since the distributed antennas are dispersed on different relay terminals, they are not sharing the same timing reference, resulting hence in asynchronous transmission. Therefore, when delays are introduced between transmitted symbols from the distributed antennas, the space-time codeword rows are shifted. This matrix misalignment can cause rank deficiency of the code. Thus, the distributed STCs basically achieving full diversity are no more efficient. In order to address this problem, new STC designs that satisfy the full-diversity order for any delay profile have been lately proposed, leading to the so-called Delay-Tolerant distributed Space-Time Codes (DT-STCs).

In our study [1], we propose a general construction of new MxM delay-tolerant codes. The main idea consists in transmitting from each of the M antennas (M relays) at each transmission time a different combination of all the information symbols. Then, it is ensured that for any delay profile, a combined symbol sent from the relays arrives at the destination in at least 2 different times, hence guaranteeing the STC full-diversity order. The new construction is based on the Perfect Space-Time Codes algebras that are optimal codes in synchronous transmission. It is obtained from the tensor product of the perfect code field extension with another field extension of the same order M over the same base field and which Galois extensions have coprime discriminants. In this way, we build rotated lattices in higher dimension in order to construct the new MxM DT codes. We prove that these codes maintain the optimal performance in synchronous transmission, achieving thus full-rate and full-diversity. In addition, unlike the perfect codes, the new codes preserve their full-diversity for arbitrary delay profile in asynchronous transmission.

In Fig.2, we show the performance of the proposed DT-STCs in synchronous as well as asynchronous transmission. For instance, we consider a cooperative system where 3 relays each with one antenna are cooperating to transmit the information to a destination that has 3 receive antennas. The relays are using 3x3 space-time codes. The performances are represented in terms of codeword error rate CER versus signal-to-noise ratio per receive antenna.

We can observe that both the perfect code and the new DT code have the same performance for synchronous relays. For the asynchronous case, we assume that we have a maximal delay of 2 symbols on the first relay (antenna) transmission, and 1 symbol delay on the second relay. We can see in this case that the 3x3 delay-tolerant code preserves the diversity and provides a gain of 5 dB over the 3x3 perfect code at CER=10^-4.

References:
MIXED-STATE PARTICLE FILTERING
FOR SIMULTANEOUS TRACKING AND
RE-IDENTIFICATION IN NON-OVERLAPPING
CAMERA NETWORKS

RESEARCH TOPICS: COMPUTER VISION, PEOPLE TRACKING, IDENTIFICATION.
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SPONSORSHIP: CEA LIST. PARTNERSHIP: CNRS-LAAS

We present a novel approach to person tracking within large-scale indoor environments monitored by non-overlapping field-of-view camera networks. We address the image-based tracking problem with distributed particle filters using a hierarchical color model. The novelty of our approach resides in the embedding of an already-seen people database in the particle filter framework. Doing so, the filter performs not only position estimation but also establishes identity probabilities for the current targets in the network. Thus we use online person re-identification as a way to introduce continuity to track people in disjoint camera networks. We demonstrate the performance of our approach on a 5 camera-disjoint network and a 16-person database.

PEOPLE REPRESENTATION.
The tracking is conducted in the image plane, with a rectangular Region Of Interest. The descriptor is built from slicing ROI into regular horizontal stripes and each stripe is described by its color distribution (color histograms). Identities are learned in a first camera seen as an entrance point of the network. Key frames are extracted from the tracks and relative descriptors are related to identities. The network is seen as a closed system with a collection of identities.

MIXED STATE PARTICLE FILTER.
A bayesian tracking filtering process begins with the choice of a reference region in an image, and then proceeds to a recursive search of similar regions in the remaining of the sequence.

Given the identity database, we have got here another reference descriptor to compare with. We use the Mixed State Condensation particle filter framework, to estimate in a unique state vector $X$, composed of both continuous parameters $u$ (target’s coordinates) and a discrete parameter $w$ (target’s identity) in the filter loop. The sampling process density at frame $t$ can be written as:

$$P(\mathbf{x}_t|\mathbf{x}_{t-1}) = T(w_t, w_{t-1}) \cdot P(u_t|u_{t-1})$$

where:

- $T(w_t|w_{t-1})$ is a transition probability matrix regarding the Identity parameter. $T$ is built over the key frame set with $T(i,j)$ representing the similarity between identities $i$ and $j$ built from key frames of the database.
- $p(u_t|u_{t-1})$ is the probability distribution of the continuous part of the state.

THE NON-UBIQUITY CONSTRAINT.
Our distributed approach provides a strategy for re-identification, allowing identity concurrency in the process. There is no interaction between filters, which means that nothing constrains filters from choosing the same identity. Thus we add to the approach a light supervising procedure that gather re-identification probabilities thanks to the online identity characterization and assign each filter its most likely identity respectively to the other filters. When a filter receives an identity, this identity becomes no more available for the remaining filters.

EXPERIMENTAL RESULTS AND CONCLUSION.
Table I. Re-identification rates for camera comparison with the trivial approach “track then ID”

<table>
<thead>
<tr>
<th>Approach</th>
<th>Site #0 to #0</th>
<th>Site #0 to #1</th>
<th>Site #0 to #2</th>
<th>Site #0 to #3</th>
<th>Site #0 to #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track then ID</td>
<td>0.96</td>
<td>0.40</td>
<td>0.66</td>
<td>0.65</td>
<td>0.30</td>
</tr>
<tr>
<td>Track + ID</td>
<td>0.98</td>
<td>0.46</td>
<td>0.81</td>
<td>0.71</td>
<td>0.34</td>
</tr>
</tbody>
</table>

We propose here a new approach for people tracking in camera networks. The main novelty of this work is to embed re-identification into the particle filter framework to estimate simultaneously the target’s position and its ID within the camera network. Distributed filters make this approach independent of the camera number. We also provide a way to constrain ubiquity of identities. Further work will investigate on an online construction and updating procedure of the identity database.

Figure 1. The particle cloud is divided into 3 subclouds. The strongest identity will take the lead, thanks to the combined likelihood and the transition matrix $T$.

Figure 2. Identity DB and network configuration.

References:
NONPARAMETRIC ESTIMATION OF FISHER VECTORS TO AGGREGATE IMAGE DESCRIPTORS

RESEARCH TOPICS: AUTOMATIC IMAGE RECOGNITION.
H. LE BORGNE, P. MUNOZ-FUENTES.
SPONSORSHIP: I2S – ANR – DGCIS.
PARTNERSHIP: I2S.

Visual concept detection, also known as image classification, consists in assigning labels to an image or a video keyframe based on its semantic content. The generic term “visual concept” can refer to objects (radio, mug, zebra...), a general atmosphere of the scene (indoor/outdoor, beach, cityscape, landscape, day/night...), technical facts on the image quality (illumination level, whether the image is blurred or not...) or even more abstract impression on the picture (aesthetic, fancy...), as showed on Fig. 1.

Technically, visual concepts are usually learned from an annotated image or video database with a machine learning algorithm, posing this problem as a multiclass supervised learning task (Fig 2). The first step of such a process consists in extracting the relevant visual features from the images in order to reflect their content. The state of the art technologies rely on the use of local features that are aggregated into a vector of given length, such that it can feed a machine learning algorithm.

The core of the proposed method consists in a new approach to aggregate local features, based on a non-parametric estimation of the Fisher vector that results from the derivation of the gradient of the loglikelihood. For this, we need to use low level local descriptors that are learned with independent component analysis and thus provide a statistically independent description of the images. These local features are band-pass oriented filters, similar to simple cells of the primary visual cortex (Fig. 3).

The main contribution of this work is to propose a non-parametric estimation of the Fisher kernel principle then derive an image signature that can be used for image classification. By using a non-parametric estimation of the Fisher kernel principle, our approach circumvents classical issues of parametric approaches, and provides a more accurate model of the loglikelihood.

The resulting signature has a quite intuitive interpretation, since it can be regarded as the “standardizing” transformation (remove the mean, divide by the standard deviation) of the raw description of the image given by a polynomial activity. We proposed a set of heuristic to choose the most relevant polynomial, leading to an efficient implementation of the algorithm.

We conducted an experiment on the Scene15 benchmark, composed of 4485 images with 200 to 400 images for each category. A given image belongs to one category exactly. The original sources of the pictures include the COREL collection, personal photographs and Google image search. We followed the standard experimental setup using 100 images per class for training and the rest for testing. Using the global image only, the best results reported were 76.7% of mean average precision (MAP) while our method reached 78.4%.

In future work we would be interested in applying the non-parametric Fisher vector estimation presented in this paper on local features that only partially verify the property of statistical independence or not at all. Another research direction is concerned with application of signature compression to image retrieval.

References:
MINING SOCIAL MEDIA TO CREATE PERSONALIZED RECOMMENDATIONS FOR TOURIST VISITS

RESEARCH TOPICS: COLLABORATIVE FILTERING, RECOMMENDATION, PERSONALIZATION, TOURISM.
A. POPESCU, G. GREFENSTETTE (EXALEAD).
SPONSORSHIP: ANR. PARTNERSHIP: EXALEAD.

The availability of increasing amounts of personal data on the Web opens the way for creating a wealth of personalized services. Tourism is one of the domains that can benefit from the existence of such data. However, in spite of significant shifts in tourist practices induced by the proposition of free Web-based services, personalized tourist recommendation remains a hot research topic.

When describing a destination, classical tourist guides usually favor the most popular tourist attractions in this area. If a visitor follows their recommendations, he will see these popular spots but may miss attractions more suited to his tastes. Mass printed guide books, for obvious economic reasons, describe the average tourists’ experience. This model, once acceptable, now becomes obsolete, as many Web 2.0 platforms containing user data about their travels become available. Past research on tourism personalization focused on explicit user preference elicitation but this approach has two important drawbacks: the users are reluctant to provide detailed information and the complexity inherent to one’s tourist preferences is so high that it is very difficult to synthesize.

Alternately, user’s interest can be mined from her trip records, such as tourism photo annotations or blogs [1]. We show how to apply collaborative filtering, which consists in structuring data from a large community to then discover like-minded users, to visit personalization. To do this, we combine data from Flickr, one of the most popular photo sharing platforms, and a pre-existing geographical gazetteer that was extracted from different data sources, notably Wikipedia [2].

The first step toward user trip record structuring is to find a list of relevant points of interest (POIs) for given locations and to rank them by popularity, a measure based on their occurrence in social networks. Cities are base units for most of our trips and POIs are structured within cities. To illustrate the results of our POI extraction algorithm, in Table 1 we present the most representative elements from three large cities from different continents. We notice that, although we apply a simple POI ranking algorithm, extracted elements are close to one’s intuition and to most popular tourist attractions that are found in classical tourist guides.

Each user’s trip record is extracted by comparing his photo annotations to POIs available in the gazetteer. To overcome ambiguity problems generated by POIs that share the same name, disambiguation heuristics based either on geotags or on the POI + city name associations are introduced. User similarities are then discovered by computing the overlaps trip records, using either the intersection of elements or a normalized version of it called Dice’s coefficient. Visits are personalized by exploiting the user similarity matrix. When a tourist reaches a new destination, we extract all other users that already visited that destination from the matrix and propose potential points of interest to visit by retaining only the top k most similar users.

Table I. Top POIs extracted for three large cities.

<table>
<thead>
<tr>
<th>City</th>
<th>POI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangkok</td>
<td>Grand Palace, Wat Phra Kaew, Wat Pho, Wat Arun</td>
</tr>
<tr>
<td>Paris</td>
<td>Louvre, Eiffel Tower, Arc de Triomphe, La Défense, Notre Dame de Paris</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Golden Gate Bridge, Golden Gate Park, California Academy of Sciences, Conservatory of Flowers, Dolores Park</td>
</tr>
</tbody>
</table>

The personalization algorithm was evaluated against two classical tourist guides, the first based on the top POIs extracted as described above (Table I) and second based on POIs proposed by TripAdvisor, a popular Web-based tourism platform. The evaluation metric was the ability to predict POIs that were really visited by tourists during their trips. We computed the total number of landmarks visits in the 30 large cities we tested (23850). A classical tourist guide approach predicts that 11187 landmarks out of 23850 will be visited. As for the personalized approach, the prediction accuracy varies from 8133 items when k = 1 to 14335 for k = 45 similar users. The number of correctly predicted landmarks is almost constant for values of k equal to or higher than 20. This result shows that the method is robust to parameter changes and that a small community of similar users is sufficient to propose relevant POIs. When compared to a classical tourist guide, the additional number of correctly predicted landmarks is 28.1% higher and this shows that personalization outperforms the baseline by a large margin, offering a wider and more correct set of choices to users.

These positive results encourage us to create more complete trip record models, including attention given to individual POIs, recognition of POIs from image content only and to use more complex methods for predicting interesting items.

References:
XRCE AND CEA LIST’S PARTICIPATION AT WIKIPEDIA RETRIEVAL OF IMAGECLEF 2011

RESEARCH TOPICS: DATA MINING, MULTIMEDIA FUSION, LANGUAGE MODELS.
A. POPESCU, G. CSURKA (XRCE), S. CLINCHANT (XRCE).
SPONSORSHIP: ANR. PARTNERSHIP: XEROX RESEARCH CENTRE EUROPE (XRCE).

With the wide adoption of social networks, the information available on the Web is becoming prevalently multimodal while existing search capabilities, such as Google, were primarily designed for text retrieval. In this context a consistent research effort was recently devoted to adapting retrieval tools to multimedia information. The evaluation of such tools is mainly performed through shared evaluation campaigns, such as ImageCLEF whose Wikipedia Retrieval task was specifically devoted to the access to multimedia information retrieval (IR). An image collection and a set of topics that are not known in advance were distributed to all participants who were free to use any automatic method in order to retrieve the best results for each topic.

Prior to 2011, XRCE and CEA LIST had good results through their separate participations to Wikipedia Retrieval and decided to form a consortium in order to explore the complementarity of their approaches. Each team’s text- and content-based retrieval had shown good performances in earlier years and, in 2011 [1], the focus was put on finding efficient fusion methods that would improve the final results. For text modeling, XRCE explored information based IR and lexical entailment based models. The former starts from the hypothesis that the difference in the behaviors of a word at the document and collection levels brings information on the significance of the word for the document. The latter are inspired from methods originally applied to statistical translation and are based on the well-known noisy channel model. CEA LIST [2] focused on designing query models based on heterogeneous information available on social networks. Flickr and Wikipedia, whose content is complementary given that they address respectively the photographic and the general language, were mined and models were produced for each of these two sources. For Flickr, an adaptation of the classical TF-IDF model to the social space in which related terms were discovered based on their usage by different users was proposed. Wikipedia was exploited in order to find semantically related concepts that are relevant to the topic but not present in the original query.

Visual content was represented using Fisher Vectors (FV) that are an extension of classical bag of words models. Instead of characterizing an image with the number of occurrences of each visual word, Fisher Vectors characterize the image with the gradient vector derived from a generative probabilistic model. FVs were used on top of low-level features such as SIFT-like Orientation Histograms and local color statistics that capture different properties of an image.

Text and image description are combined using a Late Semantic Combination approach in which the two modalities are processed separately and then combined. The intuition behind this technique is that since different media (here text and image) are semantically expressed at different levels, we should not combine them independently as most of information fusion techniques so far do, but on the contrary, we should consider the underlying complementarities that exist between these media. A textual filter formed of the combination of techniques developed by XRCE and CEA LIST is applied to retrieve an initial list of images that share a common semantic defined by the query and its extensions. Visual reranking is then applied within this semantically constrained space defined by text retrieval. The strength of image reranking is to realign the visual system to search in a relevant subset with respect to the semantic viewpoint, while the strength of late fusion relies on a well performing text expert.

Table I. Top results at ImageCLEF Wikipedia Retrieval 2011. Metrics: Mean Average Precision (MAP) and Precision @ 10 top results (P@10).

<table>
<thead>
<tr>
<th>Participant</th>
<th>MAP</th>
<th>P@10</th>
</tr>
</thead>
<tbody>
<tr>
<td>XRCE_CEA_TXT</td>
<td>0.3141</td>
<td>0.516</td>
</tr>
<tr>
<td>XRCE_CEA_MM</td>
<td>0.3880</td>
<td>0.632</td>
</tr>
<tr>
<td>UNED_TXT</td>
<td>0.3044</td>
<td>0.5060</td>
</tr>
<tr>
<td>UNED_MM</td>
<td>0.3405</td>
<td>0.5420</td>
</tr>
</tbody>
</table>

Both text and multimodal runs were submitted in 2011 and results are presented in Table 1. We present the best results for textual and multimedia runs for our consortium as well as for other reported results. In both cases, our results are ranked first and they are consistently better for the multimodal (MM) run. The application of multimodal fusions has a significant effect on result quality (MAP 0.388 vs. 0.314) and this result validates our assumption that textual and visual information are highly complementary and should be associated to improve the overall quality of results.

References:
A WEAKLY SUPERVISED APPROACH FOR LARGE-SCALE RELATION EXTRACTION

RESEARCH TOPICS: INFORMATION EXTRACTION
L. JEAN-LOUIS, R. BESANÇON, O. FERRET
SPONSORSHIP: CEA LIST - DGA

INTRODUCTION.
In the context of information extraction, relation extraction is dedicated to find, from a textual corpus, if two entities are semantically linked and determine the nature of this link. One purpose of this task is to automatically build or enrich large-scale knowledge bases. The idea of “large-scale” extraction actually covers several aspects: the large number of relation types considered, which implies that a manual rule-based approach is hardly possible; the large number of existing relations in a pre-existing knowledge base (that can be acquired from semi-structured data such as the DBPedia project), which give a good starting point for machine learning techniques; the large size of the collection of documents in which new relations are searched, which implies the use of information retrieval techniques to retrieve good candidates.

APPROACH.
In such a context, using fully supervised machine learning techniques is not tractable due to the large number of relations considered. Instead, we consider a paradigm of distant supervision, where examples of relation instances are known (characterized only by the entity pairs) but not their occurrences. These instances are used, along with an unannotated corpus, to learn a model for identifying new relations.

More precisely, in a first step (see Fig.1), existing relations are extracted from a predefined knowledge base (KB) as pairs of named entities. These pairs are then mapped onto a given corpus using information retrieval techniques, which provides a set of contextualized relation examples. From these examples, extraction patterns are learned using a linguistic generalization of the expressions of the relations.

In a second step, illustrated in Fig.2, starting from an incomplete relation, we look for candidate occurrences of the relation using information retrieval techniques. Extraction patterns are then applied on these candidate relations to extract entities that are possible answers and a final filtering selection is applied to select the best entity.

EVALUATION.
An evaluation of this approach has been conducted on the data from the Knowledge Base Population (KBP) 2010 evaluation campaign, in the framework of the Text Analysis Conference (TAC), which goal was to search for 42 different relations related to persons (date_of_birth, residence…) and organizations (location, founder…) for 100 entities in 1.8 million documents, based on an existing knowledge base extracted from Wikipedia. With the method described, we achieve 17.7% of F-measure on the extracted relations, which corresponds to an average score compared to the participants. In fact, we did not tackle some of the problems of this extraction such as the possibility of finding relations in different sentences (co-reference resolution): compared to the systems dedicated to only in-sentence relation extraction (see Fig.3), our system is in the top 3.

References:
FILTERING AND CLUSTERING RELATIONS FOR UNSUPERVISED INFORMATION EXTRACTION IN OPEN DOMAIN

RESEARCH TOPICS: INFORMATION EXTRACTION
W. WANG, R. BESANÇON, O. FERRET, B. GRAU (LIMSI-CNRS)
SPONSORSHIP: ANR (FILTRAR-S PROJECT)
PARTNERSHIP: LIMSI-CNRS

Information Extraction has recently been extended to new areas by loosening the constraints on the strict definition of the extracted information and allowing to design more open information extraction systems. In this new domain of unsupervised information extraction, we focus on the task of extracting relations between target entities or types of entities without any a priori knowledge concerning the type of the extracted relations. Furthermore, these relations are clustered according to their similarity to be structured into meaningful sets.

Fig. 1 illustrates both the kind of relations we extract from texts and the way we cluster them. As the type of relations is not fixed a priori, their definition is semi-structured: one part — the pair of related entities — refers to existing knowledge structures while the other part, the relation itself, appears under its linguistic form. For instance, the second relation in Fig. 1 is defined both by a pair of entities known as organizations — University of Florida and the Institute of Pharmacy Entrepreneur — while the relation is expressed by the verb establishes. More globally, the cluster of Fig. 1 gathers relations expressing that one organization creates another organization.

Fig. 2 shows the results of the evaluation of various kinds of statistical classifiers on this task compared to the reference work of (Banko et al., 2008).

Filtered relations are clustered according to their similarity to characterize their type. The similarity of two relations is defined more precisely by applying a “bag-of-words” similarity measure to their linguistic definition. Once again, a specific emphasis is put on the ability to process a large amount of relations by using the All Pairs Similarity Search (APSS) algorithm for computing efficiently the most significant similarity values between pairs of relations. The Markov Clustering algorithm is applied for the final clustering of relations.

The interest of our filtering procedure of relations from the viewpoint of their clustering is illustrated by Fig. 3. at the level of clusters with Purity (what is the overlap between result and reference clusters?) and at the level of pairs of relations with F1-measure (are two relations part of the same cluster both in the reference and result clusters?).
TRAJECTORIES BASED DESCRIPTOR FOR DYNAMIC EVENTS RECOGNITION

RESEARCH TOPICS: DYNAMIC EVENTS RECOGNITION IN VIDEOS
N. BALLAS, B. DELEZOIDE, F. PRÊTEUX
SPONSORSHIP: CEA LIST
PARTNERSHIP: MINES-PARISTECH

In this work, we propose a solution to automatically annotate video based on their contents.

Recent years have witnessed an explosion of multimedia contents. In 2010 the video sharing website YouTube announced that 35 hours of videos were uploaded on its site every minute, whereas in 2008 users were “only” uploading 12 hours of video per minute. Due to the growth of data volumes, human analysis of each video is no longer a solution; there is a need to develop automated video analysis systems.

Automated concepts annotation systems aim at detecting various topics of interest such as scenes characteristics (indoor, outdoor, beach, forest . . .), objects (human, car, plane, cat . . .) [1] and dynamic events (running, driving, eating, smoking . . .) in unconstrained multimedia videos. Videos can then be resumed by “high-level” conceptual descriptions. This problem has large implications: video digital archiving and data mining, video surveillance and human-computer interaction.

To challenge the automated concept annotations problem, works have been done on inter-disciplinary detection algorithms using both machine learning and computer vision. Concept detection algorithms consider the videos data through the extraction of low-level features that capture spatial and/or temporal videos patterns. These features aim summarizing a video into a small signature. The video signatures are then used by higher-level machine learning models to detect the presence or absence of concepts in them.

In this work, we focus on the annotation of dynamic events. We extract video signatures focusing on discriminative motion through local point trajectory features and apply a Multiple-Kernel classifier to detect events.

Motion information is primordial for this type of events. Indeed, it is difficult even for a human to differentiate the activity of running and walking, solely based on video static keyframes. Therefore, we propose to study low-level video signatures based on interest point’s trajectories as figure 1 shows.

Our contribution at the signature level is threefold:
– We propose a new filtering scheme that emphasizes trajectories having a non-negligible motion.
– We extend a state-of-the-art descriptor to model both motion distribution and motion transition in a trajectory.
– Finally we propose a new trajectory descriptor capturing the motion velocity. A multi-kernel classifier is then used to fuse the different point trajectories information: motion, velocity and appearance.

Our signature proposal is evaluated on the publicly available dataset HOHA, a challenging dataset composed by videos extracted from Hollywood movie with significant camera motion. As shown in table 1, our signature outperforms previous state-of-art performances by 11%.

<table>
<thead>
<tr>
<th>State-of-art</th>
<th>Our approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.1 (mAP)</td>
<td>52.3 (mAP)</td>
</tr>
</tbody>
</table>

Table 1: Comparison with state-of-art on HOHA dataset; results are reported using the mean Average Precision measure (mAP).

References:
There are mainly two approaches for Machine Translation (MT): rule-based and corpus-based. Rule-Based Machine Translation (RBMT) systems such as Reverso and Systran analyze first the input sentence and then apply syntactic rules which will match the lexical and grammatical data between source and target languages. These systems require manual development of bilingual lexicons and linguistic rules, which can be costly, and which often do not generalize to other languages. Statistical Machine Translation (SMT) systems such as Google Translate and Moses try to generate translations using statistical methods and their performance depends on the quantity and the quality of the bilingual text corpora involved in building translation and language models. However, finding relevant parallel corpora poses a real challenge for the current SMT systems.

The main idea of our machine translation approach is to use only a monolingual corpus in the target language collected from the Web [1]. This corpus is linguistically analyzed and the results stored in the database of a cross-language search engine. For each sentence to translate, the search engine returns a set of sentences in the target language with their lemmas, part-of-speech tags, gender, number and syntactic dependency relations. These linguistic properties are used with a statistical language model learned from the target language corpus to find the correct translations. The English-French machine translation prototype (WebCrossling) implementing our approach is composed of a cross-language search engine and a text generator (Figure 1).

To evaluate the performance of our machine translation approach, we indexed 1 million French sentences of the Europarl corpus and we used a subset of Arcade-II corpus composed of 1000 sentences in English and French. These English sentences which are aligned to their French counterparts are considered as the translation reference. Our translation approach obtained a BLEU (Bilingual Evaluation Understudy) score of 31.33%. This score is acceptable taking into account that only 1 million sentences are used to train the language model, which can only cover a small part of the French language. In order to show the impact of using linguistic resources (the bilingual lexicon and results of morpho-syntactic analysis) on the machine translation quality, we used WebCrossling and Google Translate to translate into French the English sentence “Social security funds in Greece are calling for independence with regard to the investment of capital.” (Table v1). Google translate proposes the word “Administrations” as a translation for the word “funds” and the segment “sont appelant” as a translation for the expression “are calling for”. As we can see, our translation prototype proposes the word “fonds” as a translation for “funds” and the expression “appellent à” as a translation for “are calling for”. These two translations are better than those provided by Google Translate.

We are currently adapting the WebCrossling prototype to the new language pair English-Arabic and future work will focus on achieving a large scale evaluation of our machine translation approach.

References:
ERROR DECREASING OF BACKGROUND SUBTRACTION PROCESS BY MODELING THE FOREGROUND

RESEARCH TOPICS: BACKGROUND SUBTRACTION, IMAGE ANALYSIS
C. GABARD, L. LUCAT, C. ACHARD (ISIR), P. SAYD
SPONSORSHIP: CEA LIST

Background subtraction is one key component in video-surveillance applications. Conventional methods are based on statistical background modeling, and involve, for each part (pixel or block) of the image, computing a distance criterion to the corresponding element in the model.

This approach suffers from two drawbacks. First, determined threshold detection does not take into account the information available in the “foreground” (targets such as moving objects); secondly, threshold is often empirically determined while optimal value depends on the scene content as well as targeted error tradeoff between false alarm and detection miss.

The proposed method [1] addresses both drawbacks. Foreground statistical modeling is added to the segmentation process of fore- versus back-ground. Furthermore, detection threshold is differentiated for each part of the image and is expressed as a function of the model parameters and the desired performance criterion such as a targeted correct detection ratio.

Benefit of the proposed approach is illustrated in Fig. 1. Fore- and back-ground pixels are synthetic data following Gaussian distributions. The represented surface illustrates the gain of the proposed method w.r.t. the well-known Stauffer & Grimson algorithm, which only involves background modeling.

This gain is always positive and clearly depends on the difference between FG and BG models. The higher the variance difference (left axis) between FG and BG models (e.g. target having a well-defined color while background being unpredictable, thus associated to heavy-spread distribution), or the higher the difference between FG and BG mean colors (right axis), the more the proposed method outperforms Stauffer & Grimson.

Denoting $\gamma$ and $T_+\gamma$ the detection threshold and the true positive detection rate, respectively, setting a targeted $T_+\gamma = \gamma$ leads to resolve:

$$\beta = \underset{\beta}{\arg\min}\{\gamma - (K + F_{BG}(x_1) - F_{FG}(x_2)) = 0\}$$

with:

$$F_{BG}(x) = \frac{1}{2} \left( 1 + \text{erf}\left( \frac{x - \mu_{BG}}{\sigma_{BG}} \right) \right)$$

denoting the error function.

$(\mu_{FG}, \sigma_{FG})$ are the FG (target) model parameters, and $x_1, x_2$ are polynomial roots, as expressed in [1].

A fast routine allows finding $\beta$. Since FG and BG models only slowly evolve along the time, $\beta$ computing can be reduced to simple value update through optimal local search.

In the same manner, the approach allows finding $\beta$ which maximizes

$$\left( (T_+\gamma)^2 + \alpha (T_+\gamma)^2 \right)$$

with $\alpha=1$ as a typical case.

Illustration of the benefit of the method for BG subtraction on a real sequence is presented in Fig.2.

Figure 1. Performance gain of the proposed method.

Figure 2. Dynamic sequence: ROC curves (top), original image (Left), Stauffer & Grimson result (center), our method involving targeted detection ratio (right).

References:
INDOOR PEDESTRIAN LOCALISATION SOLUTION BASED ON ANEMOMETRY SENSOR INTEGRATION WITH A SMARTPHONE

RESEARCH TOPICS: INDOOR PEDESTRIAN LOCALISATION WITH INFRASTRUCTURE-LESS SOLUTION
M. BOUKALLEL, G. TREHARD, F. PERIQUET AND S. LAMY-PERBAL
SPONSORSHIP: CEA LIST

During the last decade, we are experiencing an increasing interest for indoor pedestrian localisation services. In fact, the rapid growth of Localisation Based Services (LBS) is motivated on one hand by the recent technological progress involved in smartphones design and in the other hand by the added value provided by LBS for urban mobility. The LBS use commonly the location of nomadic devices to deliver appropriate services to the user. Thus, the accurate determination of the user localisation is the key features of an efficient technological solution. Ultimately, indoor localisation based technologies have to be ubiquitous, fading into the background, cost effective and naturally supported by all nomadic devices.

According to literature, the indoor pedestrian localisation has been initially addressed by pre-installed infrastructure solutions (GNSS, UWB, WIFI, Cell Id, RFID). Even if these solutions are smartphone oriented with sub-meter accuracies, they require large amounts of infrastructure to be installed into the environment or an extended and reliable calibration process to ensure accurate location determination. The cost and constraints introduced by those approaches may limit the frame of usability to specific applications. In the light of those observations, recent research efforts have been put in the development of infrastructure-less solutions based on range of technological solutions including inertial, camera and magnetometry [1]. From first results stressed in the literature, infrastructure-less solutions can achieve indoor localisation with a meter accuracy. A common solution consists in equipping the user or the smartphone with additional sensors in conjunction to dedicated computation resources in order to catch the dynamics of walking experienced by the pedestrian. Even if encouraging results are presented, developed solutions remain computationally expensive and suffer from the lack of scalability limiting the capacity for applications involving mobility.

PROTOTYPE DESCRIPTION
We have addressed the issue of indoor pedestrian localisation based on an infrastructure-less solution by a novel technological approach aiming to bring new solutions to this field. It consists of a smartphone augmented sensors with hybridisation approach involving anemometer and gyroscopic sensors. In fact, a differential pressure-based MEMS anemometer is integrated to an Android smartphone by means of a dedicated Microchip PIC 32 bits microcontroller. Hence, the instantaneous pedestrian velocity along the walking direction is measured according to air flow dynamics experienced by the anemometer. Since drift errors are reduced with the MEMS anemometer, speed signals could be easily computationally manipulated for estimating the walking distance, without the need of the step length as required in podometry techniques. As a matter of fact the anemometer delivers measurements along the walking heading and achieving 2D pedestrian localisation requires orientation measurements. Consequently, sensor fusion technique is implemented between the anemometer and the gyroscope (IDG300 dual-axis from InvenSens). Dedicated computational algorithm has been developed in the PIC 32 platform in order to ensure signal processing, sensor fusion and position estimation. Extensive indoor experiments have been conducted in order to validate the efficiency and the robustness of the adopted approach.

THEORETICAL AND EXPERIMENTAL VALIDATION
Theoretical modeling from Navier-Stokes equations has been conducted in order to catch the fluid dynamics experienced by the anemometer. A dedicated embedded computational algorithm has been developed in order to ensure accurate signal processing, sensor fusion and position estimation. The proposed prototype was tested in a straight corridor for different distance paths in order to validate the measurement concept. In situ experiments along complex paths demonstrate that the sensors coupled with a smartphone achieve pedestrian localisation with average accuracy of less than 6 % of the total travelled distance.

Figure 1. Overview of the system.

References:
THE SPATIAL SPECTRUM OF TANGENTIAL SKIN – DISPLACEMENT CAN ENCODE TACTUAL TEXTURE

RESEARCH TOPICS: TACTILE INTERFACES, TACTILE PERCEPTION, TEXTURE
J. LOZADA, M. WIERTLEWSKI, V. HAYWARD (ISIR, UPMC)
SPONSORSHIP: ANR TECSAN
PARTNERSHIP: REACTIVE

A new device that is capable of accurate measurement and reproduction of a surface-finger interaction with a sufficient bandwidth and dynamic range (already briefly described in [1]) is used for perception experiments.

The device (Fig.1(a)) comprises a multi-layer, 40-mm piezoelectric disk bender (CMBR07, Noliac Group A/S, Kvistgaard, Denmark) connected to a 20-mm-wide tray that can hold a texture sample. The bender is clamped vertically by two epoxy ridges of semicircular section that apply uniform pressure on the bender. A threaded rod connected to the hollow center of the bender transmits motion to the tray that is linearly guided by a flexure made of two leaf springs. Connection to the bender is realized by two Delrin washers that can tolerate ± 0.5° of misalignment. The texture samples are bonded to the tray using double-sided adhesive tape.

The device can operate both as a sensor and as an actuator. During sensor operation, the interaction between the finger and the texture induce flexural deformations of the blade along x and in the piezoelectric element (Fig.1(b)). The instrumentation amplifier measures then a voltage proportional to the deformation. When used as an actuator, a voltage is applied to the electrodes of the bender; the piezoelectric effect causes the transducer deformation and thereby a displacement of the tray. Deformations can be imposed in the fingertip resting on it.

The transducer uses causality-inversion process [1] recording the interaction force and displaying the displacement. We conduct a perception experiment asking two groups of five participants to identify different textures. Five real textures were first recorded using the experimental device. The first group of participants has to compare the stimulus of a real surface picked randomly from a set of three surfaces with the standard stimuli of the five real textures. The second group has to compare a simulated stimulus of one of the same three surfaces picked randomly with the standard stimuli of five real textures (noted A to E).

In order to ensure that the matching of virtual and real textures were performed under conditions that were as similar as possible, a test bench was constructed where the simulated and the real surfaces had to be touched under the same constraints (Fig.2).

The overall results can be summarized by the confusion matrices shown in Fig.3. When the real textures were used as comparison stimuli, identification was nearly perfect, which showed that it was possible to identify the samples. There was some confusion regarding the A and B textures. After the experiment, the participants reported that they felt the need to detect them, even though they were never presented. All noticed, however, that some samples were missing. When the comparison textures were simulated, the pattern was similar, and the identification rate high, but there was noticeably more confusion between samples A and E.

The results suggest that the texture-recognition task can be adequately performed.

References:
Haptic interaction is one way of enhancing game accessibility for gamers with visual impairments. However, to design easy-to-use, attractive and accessible haptic and tactile games for this user base, there are a number of issues to overcome. Two main approaches to the provision of haptics in games have emerged. The first approach is sensory substitution. In this case, cues that would normally come from the visual channel are replaced by haptic or audio stimuli that both enables the design of new games as well as the augmenting of already existing games designed for users with no visual impairment. Vi-Tennis and Vi-Bowling are examples that enable eyes-free game play by adding simple vibration and audio cues to existing games for the Nintendo Wii console. The Wii controller allows players to detect key events (e.g. a ball bouncing) in the game play.

This research was developed using a custom built mouse instrumented with a lateral vibrator built in to the left mouse button, as shown in figure 1 [1]. This vibrator, designed to aid the reproduction of surface texture sensations, when driven by a pink noise signal enables the perception of very subtle tactile cues.

Building on the idea of adding feedback to existing games our ViPong example application enables visually impaired players to play a classic game of pong using a probabilistic approach to the generation of haptic feedback. Previous research has developed a method of improving user audio feedback through the display of time varying probabilistic information. In a similar manner we use a particle filter simulation to predict future positions of the game ball dictated by a fusion of all the external influences on the ball. The only influence in this case is the rather simple physics involved, meaning that the prediction of future positions is relatively easy. Our particle filter predictions are thus only influenced by the randomness injected to the initial angle or direction of travel and velocity of the ball before the simulation begins. Figure 2 shows predictions of the ball’s possible future positions, with larger circles indicating predictions further into the future, given two initial uncertainty levels (figure 2 – left for high initial uncertainty and figure 2 – right for low initial uncertainty). It is hypothesized these initial conditions will have an effect on the feedback detected by the user and hence on the overall difficulty, enjoyability and adaptability i.e. on the overall user experience of the game.

Haptic feedback is generated directly from the particle simulation as each of the particles virtually collides or ‘impacts’ with the user’s paddle, illustrated in figure 2. Newer particles, i.e. particles closer to the pong ball impart more energy to the paddle, which is correlated to the amplitude of a pink noise signal, used to drive the vibrator of the mouse. The user feels the vibration increase as the ball gets closer to the paddle and the certainty of the paddle being in the correct location increases. The user also hears the typical pong audio sounds to confirm that the ball was successfully hit. Future user studies will aim to prove that adapting the level of uncertainty in the feedback displayed, by altering only one parameter of the algorithm, does have an effect on the user’s perceived difficulty of the game. More complex games will then be developed in order to test to what extent this kind of feedback generation can be used to increase game accessibility for visually-impaired users.

Figure 1. The ViTouch mouse with integrated vibrator.

Figure 2. Pong ball future position simulation with high uncertainty (left) and low uncertainty (right). The ball moves from right to left.

References:
ACCURATE AND ROBUST 3D OBJECT TRACKING WITH A SINGLE CAMERA

RESEARCH TOPICS: COMPUTER VISION, AUGMENTED REALITY
M. TAMAAZOUSTI, S. Bourgeois, V. GAY-BELLILE, S. NAUDET-COLLETTE, M. DHOME (CNRS)
SPONSORSHIP: DIOITASOFT
PARTNERSHIP: LASMEA

While the need of 3D environment perception is boosted by many emerging technology (robotic, augmented reality, visual inspection,...), real-time 3D object tracking still remains a technological bottle-neck. In this work, we focus on solution based on computer vision since video camera is currently the most widespread sensor that provides good tracking results for a low amount of money.

Until now, two separate approaches were developed in the computer vision community. The first one is known as Visual Simultaneous Localisation and Mapping (VSLAM) and consists in estimating simultaneously the motion of a camera in and a 3D feature map of an unknown surrounding environment. Such approach is usually robust to large motion and occlusion since all the features of the image are used to estimate the camera trajectory. Nevertheless, since the environment is unknown, the camera location is expressed in an arbitrary reference frame with an arbitrary scale factor and is subject to error accumulation. The second approach is known as model-based object tracking, and relies on the a priori knowledge of a 3D model (or CAD model) of an object of interest. It consists in matching 2D features of the video stream with their respective 3D features in the 3D object model to estimate the position and orientation of the camera. While this approach provides an accurate and drift-free localisation expressed in a known reference frame with a correct scale factor, it remains far less robust than VSLAM. Indeed, when the object is small in the image or occluded, the process is unable to estimate correctly the camera location.

To cope with these issues, we proposed to merge these two approaches in a unique framework. Our solution consists in extending the VSLAM solution by integrating the constraints provided by a 3D object model. A first solution [1] consists in initializing the 3D feature map of the VSLAM process with 3D features extracted from the CAD model. On one hand, if the VSLAM process still reconstructs features of the environment, the quality of their reconstruction is improved since the features extracted from the CAD model provide a reference frame, a scale factor, and prevent error accumulation. On the other hand, when the object is small in the image or occluded, features of the unknown environment can still be used to estimate and accurate localisation. Therefore, the resulting tracking process is both accurate and robust.

To still improve the robustness of our tracking process, an extension of this first solution was introduced in [2]. This second solution improves the environment mapping by constraining the reconstruction with the CAD model. For example, the 3D points that belong to the object are constrained to lie on the surface of the CAD model.

These solutions were also integrated in a system of selling-aid developed by the Diotasoftware company. This system provides tools for customizing virtually a kitchen in augmented reality or a car (cf. Fig.1).

In conclusion, this work explores the benefit of merging VSLAM and model-based tracking approaches. Our evaluations demonstrated that our approach is more robust and accurate than other state of the art solutions. Moreover, it provides a unique framework to handle different kinds of objects or CAD models. This flexibility allows to handle more domain of applications than our competitors.

Figure 1 – Kitchen (a,b) and car toy (c,d,e,f) customization through Augmented reality.

References:
DESIGNING A VIRTUAL REALITY TRAINING PLATFORM FOR SURGEONS: THEORETICAL FRAMEWORK, TECHNOLOGICAL SOLUTIONS, AND RESULTS

RESEARCH TOPICS: SIMULATION AND TRAINING PROTOCOLS FOR SKILLS ACQUISITION IN BONE SURGERY APPLICATIONS
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SPONSORSHIP: SKILLS PROJECT - EU 6TH FRAMEWORK PROGRAM
PARTNERSHIP: CEA LIST, TECHNION (ISRAEL), AALBORG UNIVERSITY (DENMARK)

Many socio-economic factors influence the way in which surgical education is given to junior residents. Public consideration for patient safety has raised attention to the risks of residents practicing their skills on patients, and recent policies on workload limitations have increased the challenge of healthcare education by reducing the time available for teaching. To address these problems, new structures dedicated to postgraduate residency education are appearing at a fast pace. New protocols are being developed to build the theoretical framework for the assessment of basic skills in surgery in which the role of surgical simulation can be addressed.

Within the SKILLS project unified framework, we have developed a surgical training platform following a user-centered approach along with strong technological developments. The goal was to evaluate the benefits of features commonly available in VR surgical simulation to the training of skills in maxillofacial surgery (MFS), especially in the case of bone drilling procedures. Our methodology provided qualitative and quantitative description of major subskills constituting the MFS surgery. Observational methodologies and analysis from human science successfully obtained information on surgeons’ routine procedures and helped them to elaborate meta-knowledge of their procedures and skills [1].

The novelty of our work is in the design principles of the training platform, where the priority was given to the way sensory feedbacks are combined when presented to the subject. Such a dissociation and control of sensory-motor features is impossible in a real environment, where sound, vibration, and stiffness naturally come together as a complex input, originating from the same physical source during the bone drilling procedure. We showed that in discrimination tasks, bimodal performance was always better than uni-modal performance regardless of order of experience. The discrepancies between the results on vibration and stiffness studies may reflect the inherited physiological differences in perception of these two aspects of touch: stiffness is commonly sensed without vision; however, vibration of a tool is always accompanied by sound, where the very same vibratory stimulus simultaneously activates receptors on the basilar membrane in the cochlea and the skin of the fingers. Experiments with surgeons revealed that expertise in complex skill strongly relies on enhanced bimodal touch perception, as measured in reaction times and discrimination ability in vibro-auditory conditions. These results suggest that acquisition of bone-drilling surgery skill has brought an enhanced representation of vibro-tactile modulations in relevant stimuli ranges.

These studies were translated into a training system specifically designed to reach the needs of a maxillofacial surgery in terms of workspace, force, torque, and stiffness while implementing training accelerators following from the experiments described above and taking benefit from the possible dissociation of modalities provided by virtual environment [1]. The training program focuses on mastering drilling procedures. The exercises consist of either performing a punctual drilling or drilling a line into a virtual bone. The system was tested during summer 2011 in two university hospitals involving 20 residents and 4 experts.

Preliminary results have shown that the platform successfully reflects the expertise of a subject (Fig.1), as expertise in the operating room, is directly correlated with performances on the platform’s training protocol [2]. The performance is defined as a correlation between the efficiency (the duration of the drill) and its accuracy (the penetration depth into a critical zone inside the bone). Future work will include a more detailed evaluation of the transfer to the real operating room of the skills acquired on the platform.

![Figure 10. Performance for a basic drilling procedure performed on the platform. Triangle: novices, square: intermediates and diamond: experts.](image-url)

References:
EMBEDDED SYSTEMS
SOFTWARE & SYSTEMS ENGINEERING
The World Wide Web has evolved from a place where we share and find data to a place where we share and find dedicated functionalities. Such functionalities, called Web services, can be assembled to build new systems, where the Web services are usually developed and offered by different parties, and are physically stored in different places on the Internet. The process of building systems by combining Web services is known as Web service composition. In [1], we focus on orchestration architectures: systems where there is a central component (orchestrator) which serves as an interface for users and is responsible for coordinating Web services.

In order to build orchestrations, the first step is to find required Web services: this activity referred as (Web) Service Discovery (Figure 1). Web services must be published and accessible on some known repositories, and must be associated with descriptions allowing the designer to select them. Those descriptions contain usually only functional aspects: founds are made by matching orchestration requirements with descriptions of candidate Web services.

In [1], we aim at completing those existing matching procedures based on static analysis by techniques exploiting Web service executions. Provided that the system designer produces a behavioral description of the orchestrator before the Web service selection phase, we aim at taking benefits of the knowledge of the orchestrator to select Web services.

Since the orchestrator is responsible of Web service invocations, orchestrator executions mainly contain sequences of Web service invocations conditioned by Web service reactions. Therefore, an orchestrator greatly constrains the set of acceptable behaviors of Web services to be selected. Our proposal is to use that set of acceptable traces to guide a selection procedure based on testing techniques.

Orchestrators are specified by means of Timed Input/Output Symbolic Transition Systems (TIOSTS), that we define as an extension of Input/Output Symbolic Transition Systems [2] to deal with timing issues. Taking time into account in our work is mandatory because defining timers and reasoning about them is very common in orchestrator descriptions. Typically, one of the most well known ways to describe orchestrators is the WS-BPEL specification language. Operations that can be made on clocks in TIOSTS reflect the common usage of timers in WS-BPEL: take decisions in the absence of reactions of Web services. Advantages of using TIOSTS are twofold: first, we can take benefits of the formal testing framework that we previously defined [2, 3] by extending it to timing issues. Secondly, we use symbolic execution techniques to analyze the orchestrator description: from a tree-like structure symbolically representing all possible executions of the orchestrator and by means of projection and mirroring techniques, we transform those behaviors into intended Web service behaviors from which we extract test purposes to be used in a testing algorithm (Figure 2). A Web service conforming to the test purpose extracted from the orchestrator becomes a good candidate to be integrated in the orchestration. The testing algorithm is a timed extension of the one we defined in [3] and further adapted to the test of orchestrators in context in [2].
DESIGNING COMPLEX SYSTEMS WITH EXECUTABLE MODELS

RESEARCH TOPICS: EXECUTION SEMANTICS, CONCRETE SYNTAXES, SIMULATION

A. CUCCURU, S. GERARD, F. TERRIER

SPONSORSHIP: THALES

PARTNERSHIP: THALES, AIRBUS, INCOSE, NASA JPL

Model Driven Engineering helps in managing design complexity of modern real-time systems through models specified at appropriate abstraction levels. Being able to execute such models naturally contributes to management of complexity. By observing an execution, engineers can more easily figure out the constraints that models place on the runtime structure and behavior of the final system. Observations can be used to make relevant decision choices, from the very early steps of the system design flow.

Executing models not only requires non ambiguous execution semantics. Precise and compact notations are also needed to ensure a convenient representation. In year 2011, the LISE has conducted R&D activities on these two aspects of executable modeling, resulting in several scientific publications. As compared to existing work, one of the innovative aspects of our approach is that it relies on well-established standard specifications. It also tries to contribute to their evolution and convergence, or even promotes new complementary specifications when needed.

In [1], a joint work between the LISE and THALES RT has highlighted limitations and semantic ambiguities of the standard MARTE (Modeling and Analysis of Real-Time Embedded systems) component model, regarding its usage for modeling of heterogeneous systems. The work includes a detailed analysis of the flaws as well some proposals for changes in the specification in order to address them. Nevertheless, the given formalization is not precise and operational enough to enable execution of resulting models.

Work published in [2] rather concerns syntactic aspects of model execution. The main motivation for this work comes from the fact that among existing OMG specifications, several textual syntaxes for typed expressions are defined, namely the Value Specification Language (VSL, defined in MARTE) and the Action Language for Foundation UML (Alf). The article highlights the intersection between the two languages, and motivates the idea of defining VSL as an extension of Alf. Alf has formal semantics, while VSL does not currently have. From the model execution standpoint, it means that VSL expressions could be unambiguously interpreted at execution time. An evolution proposal for VSL is detailed; it demonstrates how VSL could be defined as an extension of Alf.

Ideas described in these two publications have contributed to the emergence and clarification of a need for more precise execution semantics of the MARTE component model. In a joint effort with Thales, Airbus, INCOSE or NASA JPL (among other participants), the LISE took the initiative to formalize the need for a new standard specification that would address this subject [3]. In order to keep homogeneity and ensure complementarity with existing standards, the RFP requires that the new specification extends fUML (Foundation UML, for which Alf is a concrete textual syntax), which defines execution semantics of a UML subset with a formal execution model. The extension strategy of fUML, as required by [3] and illustrated in Figure 1, consists in extending the UML subset in order to include UML Composite structures (on which the MARTE component model relies) and then extend the execution model accordingly.

Currently, the LISE is strongly involved in the preparation of a response for this RFP. While primarily focused on UML composite structures, the resulting proposal will also include precise semantics of the MARTE component model.

In order to validate this work, the LISE develops Moka, a model execution environment integrated in the UML/SysML Papyrus modeler (also developed by the Lab). Moka includes an implementation of the fUML execution model, and already enables simulation of systems modeled with the fUML subset.

Figure 1. Extension of fUML required by [3]

References:

ENABLING SCHEDULING ANALYSIS FOR AUTOSAR SYSTEMS

RESEARCH TOPICS: MODEL-DRIVEN DEVELOPMENT, SOFTWARE ARCHITECTURES, TIMING ANALYSIS. (S. ANSSI), S.TUCCI-PIERGIOVANNI, (STEFAN KUNTZ), S.GERARD, F.TERRIER

SPONSORSHIP: SYSTEMATIC. PARTNERSHIP: CONTINENTAL

In the automotive industry we are witnessing a shift from hardware-centric to software-centric architectures. This shift comes with several new opportunities and challenges for manufacturers and OEMs. Massive software introduction helps delivering complex functionality to customers while increasing profitability, but results in large-scale component architectures that are difficult to design, verify, maintain, reuse. AUTOSAR (Automotive Open System Architecture) is a consortium created to face these new challenges in automotive domain.

Main goal of AUTOSAR is to provide an open software architecture that includes different layers (application, middleware, OS, hardware) and define standard interfaces. At the beginning AUTOSAR was meant to facilitate smooth integration of third party software, easier reuse of software/hardware components and seamless application of diverse development tools. During the process of improving AUTOSAR, other requirements were added beyond initial objectives. The seamless integration of timing verification tools was a new requirement for AUTOSAR. To satisfy this requirement a new version of the standard (AUTOSAR 4.X) was issued. The main novelty was the introduction of the Timing Extension. The timing extension allows enriching AUTOSAR design models with timing information, which includes: timing properties and constraints.

Our contribution [1] defines a method to build AUTOSAR models in order to enable schedulability analysis. The minimal set of needed concepts to enable schedulability analysis is firstly defined. This set includes (1) application timing behaviour, i.e. chains of activations functions/operations, frequency of activation and deadlines (2) resource platform information, i.e. resource topology and resource management control algorithms (3) resource usage definition: mapping of functions/operations to platform resources and their worst case execution times.

We show then how to use AUTOSAR concepts in order to build AUTOSAR models containing schedulability-enabling concepts. The Timing Extension is used to build the application timing behaviour model. Other AUTOSAR concepts (not coming from the Timing Extension) are used to define the resource platform model and the resource usage model.

The proposed method is applied to a Continental case study. The case study is a cruise control system (see Figure 1). This system consists of a switch sensor that acquires the driver inputs and a control system that processes the inputs and maintains the vehicle speed according to a given speed set point. The cruise control system is composed of several functions distributed over two ECUs: the Body Controller ECU and the Engine Management ECU communicating via CAN bus.

Table 1 summarizes the timing information of the cruise control functions, task allocation and task priorities.

Schedulability-enabling information has been translated in AUTOSAR models following our method. AUTOSAR models have been then translated again in readable format for an open source schedulability tool called MAST. As schedulability results show, the system is schedulable (see Figure 2).

Table 1 Timing information of control functions

<table>
<thead>
<tr>
<th>Functions</th>
<th>WCET (ms)**</th>
<th>Period (ms)</th>
<th>Deadline (ms)</th>
<th>Allocated to Task</th>
<th>Task priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input acquisition</td>
<td>2.5</td>
<td>10</td>
<td>20</td>
<td>Acquisition</td>
<td>1</td>
</tr>
<tr>
<td>Input interpretation</td>
<td>2.32</td>
<td>40</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagnosis</td>
<td>1.52</td>
<td>10</td>
<td>20</td>
<td>Failure Management</td>
<td>4</td>
</tr>
<tr>
<td>Speed setpoint</td>
<td>3.5</td>
<td>40</td>
<td>80</td>
<td>Setpoint</td>
<td>2</td>
</tr>
<tr>
<td>Limp home</td>
<td>1.03</td>
<td>10</td>
<td>20</td>
<td>Control</td>
<td>3</td>
</tr>
<tr>
<td>Application condition</td>
<td>3.92</td>
<td>40</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controller</td>
<td>1.4</td>
<td>40</td>
<td>80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Timing information of control functions

Function | Worst response time (ms) | Deadline (ms)
---------|-------------------------|-------------
Input acquisition | 4.84 | 20 |
Input interpretation | 34.84 | 80 |
Speed setpoint | 49.82 | 80 |
Controller | 59.29 | 80 |
Diagnosis | 1.52 | 20 |
Limp home | 10.95 | 20 |

References:

MODEL-DRIVEN DEVELOPMENT OF SELF-DESCRIBING COMPONENTS FOR SELF-ADAPTIVE DISTRIBUTED EMBEDDED SYSTEMS

RESEARCH TOPICS: MODEL-DRIVEN ENGINEERING, ADAPTIVE SYSTEMS, SELF-DESCRIPTIONS.
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SPONSORSHIP: PROJET RT-DESCRIBE.
PARTNERSHIP: FRAUNHOFER ESK

Many software systems lack the ability to react automatically on internal or external changes at runtime. Self-adaptive software systems provide a promising approach to deal with this problem, in order to reach a higher degree of flexibility, reliability, extensibility and efficiency. The application of self-adaptation within the field of distributed embedded systems seems very promising, but these systems imply specific characteristics which need to be addressed sufficiently. In this paper, we present a new model based methodology approach to develop self-adaptive software for embedded distributed real-time systems.

We investigate ways to enrich the software components of the design model with self-descriptions and information about their adaptability. The self-descriptions are traced at runtime to provide self-awareness and support adaptation decisions with necessary information about the software components. In order to create these enrichments, we investigate a new self-X profile and a model transformation engine. The profile has an orthogonal aspect: besides self information, it provides information about the use of certain features in given modes.

Figure 13 shows an example of the approach – partial network operation: when the allocation is chosen in a suitable way, parts of the system may be shut down (here, all except ECU4) in some situations in order to save energy. The allocation can be automatically determined based on the information which functions are required in which mode.

Figure 14 shows an overview of the approach (see also [2]): we start with a UML design model enriched with the self-X profile. This design model complies with the eC3M toolchain [1, 3] which is used to transform the design model into an intermediate model. From the latter, we derive a simulation model that is fed into the DynaSim simulator. The simulations provide a feedback to the initial model. The gained information helps us in two ways: (1) it verifies whether specified self-X information about resource-consumption and execution times are valid on a given platform and (2) it helps tuning the application e.g. by changing allocation information and thus optimizes the initial application configuration.

Future work within this project will be the refinement of the methodology and the integration of the automatic simulation feedback for the iterative model refinement.

Figure 13: use case – partial network operation

Figure 14: Overview of the approach

References:
A MODEL-DRIVEN FRAMEWORK FOR THE DEVELOPMENT OF PORTABLE REAL-TIME EMBEDDED SYSTEMS

RESEARCH TOPICS: MODEL-DRIVEN ENGINEERING, REAL-TIME, PLATFORM-INDEPENDENCE.
W. EL HAJJ CHEHADE, A. RADERMACHER, F. TERRIER, B. SELIC (MALINA SOFTWARE CORP.), S. GÉRARD

An important aspect of Model-Driven Development for real-time embedded software is the separation of concerns between application model and target platform. This requires the definition of model transformations realizing the mapping of the application model onto the target platform. Real-Time and Embedded Systems design means coping with different target platforms and with heterogeneous constraints related to time synchronization and memory footprint. However, different target platforms have APIs and implementation patterns that vary significantly. Thus, it is necessary to develop several dedicated model transformations in order to achieve portability between them. Although this is one way to achieve portability we show in this paper that the cost of portability can be reduced by providing domain-independent model transformations while still ensuring that performance requirements are satisfied.

Figure 15 shows an overview of our approach. Instead of a transformation that is specific for a certain platform, a generic transformation is executed. This transformation takes not only the application model (a component based model complying with [3]) as input, but also a detailed platform description and a correspondence model [1, 2] that links additional information on the application model (e.g. annotations with MARTE’s HLAM model) with platform elements.

The porting effort is given by the following formula:

\[ \text{DoP} = 1 - \frac{\text{cost to port}}{\text{cost to redevelop}} \]

In this equation, “cost to redevelop” represents the cost to redevelop a software unit for an environment starting from its requirements. And, “cost to port” is the cost to develop an original portable design plus an implementation or adaptation for a given environment.

In the context of our approach, we want to compare the effort to change/extend the generic transformation (NGT) with the effort to change or extend a specific transformation (NSP). The results are shown in Table 1. The cost to develop the generic transformation is initially higher. However, when additional platforms are added, only concepts that are unique to this platform and have not yet been treated in the generic transformation need to be added (we neglect the creation of a new platform description). Thus, when RTSJ is added, only concepts that are specific to RTSJ need to be treated. C++/POSIX did not require the treatment of concepts already present in the other platforms (this is a slight simplification, some POSIX concepts were not mapped).

Table I. Comparison of Porting efforts

<table>
<thead>
<tr>
<th>Platform</th>
<th>NSP</th>
<th>NGT</th>
<th>DoP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Java</td>
<td>350</td>
<td>454</td>
<td>-0.3</td>
</tr>
<tr>
<td>RTSJ</td>
<td>250</td>
<td>20</td>
<td>0.92</td>
</tr>
<tr>
<td>C++/POSIX</td>
<td>320</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>920</td>
<td>474</td>
<td>0.48</td>
</tr>
</tbody>
</table>

In this paper, we have described a new model-driven framework for the development of real-time embedded applications that achieves a separation of concerns for its internal transformations.

References:
Automotive software applications are characterized by increasing complexity, safety requirements and timing constraints. To face these challenges, major OEMs and tier-1 suppliers founded the AUTomotive Open System Architecture (AUTOSAR) development partnership. The main goal of this project is to create an open standard for automotive architectures. AUTOSAR defines a development methodology that aligns to model-driven architecture (MDA) principles which is an engineering approach that decouples the software application from the computing platform. Interestingly, AUTOSAR aims also at addressing the upcoming ISO 26262 standard which provides a general framework for functional safety handling in automotive EE systems.

Our contribution [1] helps AUTOSAR to further exploit MDA principles in compliance with ISO 26262 recommendations. Our goal is to provide a methodological framework to support schedulability analysis of embedded automotive applications at the earliest possible stage, including in the analysis the fact that some components have to comply with safety levels demanding software redundancy. The framework allows obtaining replication assessment: schedulability predictions injecting possibly different replication mechanisms.

We envisage a replication assessment starting with a set of software components identified as safety critical and for which software redundancy should be provided. The specification of software redundancy in has the objective of declaring the strategy the designer wants to follow for replication, considering all the aspects that can have an impact on schedulability analysis, i.e. type of failures to be tolerated, replication styles, replicas placement, platform properties. Figure 1 shows an excerpt of the meta-model used to declare the replication strategy.

The proposed approach is applied to a Continental case study. The case study is a cruise control system. This system consists of a switch sensor that acquires the driver inputs and a control system that processes the inputs and maintains the vehicle speed according to a given speed set point. The cruise control system is composed of several functions distributed over two software components: the Body Controller SW and the Engine Management SW. The two components are allocated on two different ECUs connected via CAN bus. The system is initially schedulable. The safety critical component to make redundant for the case study is the EngineManagementSWC software component, which actually encapsulates the throttle control function.

The replication strategy we want to evaluate for our system considers: the active replication style, two initial component replicas, and a threshold of one replica’s crash. The injected replicated architecture is shown in Figure 2.

Schedulability results have been then obtained. The worst-case results show that ECU now in charge of executing the set of replicated tasks exceeds its capacity. Two different schedulable alternatives are then proposed. The first alternative considers having a more powerful ECU (increasing its speed-factor by 1.5). The second alternative considers a different software architecture in which EngineManagementSWC software component is split in two smaller components. Only the smaller component containing the throttle function is replicated, as required. Other alternatives can be considered, but this simple analysis already shows how redundancy can affect system schedulability and that schedulability and replication considerations can lead to the refactoring of the system architecture at design level.

Interestingly, analysis results are also related to the size of software components, which should be small to easily place replicas by exploiting residual computational capacity of existing resources. Small component size is also a desirable property from ISO26262.

Figure 1. UML Stereotypes for Replication

Figure 2. Replicated Architecture

References:
REQUIREMENTS EXCHANGE: FROM SPECIFICATION DOCUMENTS TO MODELS [1]

RESEARCH TOPICS: REQUIREMENTS TRACEABILITY INTO A MODEL-BASED APPROACH.
M. ADEDJOUMA (CEA, DELPHI), H. DUBOIS, F. TERRIER
PARTNERSHIP: DELPHI

As illustrated in Figure 1, requirements management focuses on analyzing and eliciting customer needs and documenting requirements. All along a system design process, requirements management techniques are then used for different goals: requirement validation, requirement verification, documentation generation adapted to the different steps of the process to document specific or general acceptance of the system.

Various methods are used to handle these goals. Among them, graphic representations have the benefit to help to easily understand a complex problem and communicate a system’s functional and data requirements for performing requirements engineering activities. Examples include the Unified Modeling Language (UML) or, more specifically, the specific modeling language for system engineering widely used in industry: Systems Modeling Language (SysML), “which supports the specification, analysis, design, verification and validation of a broad range of complex systems” [2].

Nevertheless, in practice, the customer needs are provided in text documents formats like MS Excel™ or MS Word™, whereas the graphic representations are used in modeling environments. Given the large number of requirements that may be represented, the challenge is to have a simple process to easily document the customer needs from source specifications in the required environment as well as requirements models without specifying them manually.

Our proposal uses the new Requirements Interchange Format (ReqIF) [3] (see Figure 2) to perform this task, from MS Excel™ specifications documents to the Papyrus tool [4].

Requirement engineers can work with their specification documents with any regard on system architecture or a modeling environment. They can then generate a requirements document in XML format compliant with ReqIF standard. On the other hand, the integration of ReqIF with SysML enables system architects who use the Papyrus tool to visualize requirements defined in a requirements authoring tool in SysML. They can trace design artifacts to requirements in standardized form to establish seamless traceability. The result is that we can use modeling and text based approaches to specify requirements and integrate them in a standardized way.

**Process input: requirements & needs**

**Process output: documentation**

![Figure 1. System Engineering Process & Requirements Management.](image)

**Figure 2. Usage of ReqIF format between different Requirement Management Tools.**

References:
Industrial systems are often designed and implemented as a collection of basic functional units interacting by means of communication mechanisms. These functional units, called components in the sequel, are pieces of software or hardware. They may be developed specifically to implement the system of interest or built out of reused e.g. “off-the-shelf”) components. Once such basic components exist, implementing a system amounts to build the communication architecture to glue them: the system exhibits behaviors which result from the interactions of basic components (and user inputs by means of interface components) through the communication architecture. In the earliest design phases, one has to specify the system behaviors in order to adequately choose or implement components that together will realize them. Among the classical graphical specification standards that can be used for that purpose, we can cite UML sequence diagram (sequence diagram for short) with timing properties which can be used as guidelines to implement or elicit constraints on the behaviors of their components. Such constraints can be used as guidelines to implement or choose the components of the system and are the basis of the definition of fitness for a component with respect to a sequence diagram. That fitness relation relies on a timed conformance relation which makes it evaluable by testing techniques. We ground our approach on symbolic execution techniques based on Input/Output Symbolic Transition Systems (IISTS) which extend IOSTS with timing constraints on transitions and particular variables to store dates according to sequence diagram semantics. We show how to translate sequence diagrams into TIOSTS. The TIOSTS automata are similar to Timed Automata except that they constrain timed input/output symbolic actions and by variable assignments which capture state evolutions. To formalize sequence diagrams, we define Transition Systems (IOSTS) [Gaston2006] which extend IOSTS with timing constraints on transitions and particular variables to store dates according to sequence diagram semantics. We then extend the symbolic execution rules in [Gaston2006] to capture the specific features of TIOSTS. The symbolic execution of such TIOSTS results in a tree-like structure that characterizes all possible executions of the system specified by the sequence diagram. We then show how to project those symbolic behaviors on the interface (i.e. the set of ports) of any component of the system: that results on the definition of an execution tree characterizing all the constraints on the intended behaviors of a specific component. This projection operation is an extension to the TIOSTS of the one defined in [Faivre2007]. Finally, we define our fitness relation as the central element of a testing framework based on the TIOSTS-conformance relation [Schmaltz2008] to evaluate the conformity of components to their associated constraints. The following figure summarizes the approach.

References:


A virtual platform is a software tool, often called simulator, that mimics the behavior of an electronic system so that software can run on it before silicon or FPGA implementation of that electronic system is available. The simulated electronic system can include lots of microprocessors and devices. Indeed a full system simulator, not only executes the microprocessor instruction set, like an instruction set simulator, but also simulates buses, I/O devices, sensors, actuators, so that real application workloads and operating systems can run on them. UNISIM [1] provides several such virtual platforms and a framework to ease the development of new virtual platforms.

Simulation speed has a critical impact on the design process: low simulation speeds mean fewer design options can be explored, resulting in potentially less efficient designs. There are multiple approaches for tackling the simulation speed issue, such as parallel simulation, statistical simulation, synthetic benchmarks, and sampling. Among these, sampling, i.e., running a small portion of a program while still accurately predicting its overall performance, has demonstrated the capability of improving simulation speed by several orders of magnitude with little losses in simulation accuracy. Tools such as SimPoint and SMARTS have successfully demonstrated the potential of sampling; yet while they are being extensively used in academia, sampling techniques are not mature yet for typical usage scenarios.

What is a typical usage scenario? The architecture designer explores several variations of the architecture; therefore the sampling technique should transparently adjust to architecture variations, with reasonably constant accuracy across them. Otherwise, the performance comparison of architecture designs is skewed, leading to wrong design decisions. In the embedded world, the designer also modifies the hardware and the software simultaneously, so that the sampling technique should additionally accommodate frequent software modifications across design iterations. Finally, the designer wants to invest no time in supporting or implementing sampling itself, so the technique should require no simulator-level modifications. All three constraints should be met for the sampling technique to be practical.

Yet in spite of a large number of proposed sampling and warm-up techniques, there is no technique yet that a designer can safely and easily use for a large range of architecture and software design modifications. In [2], we propose a method for combining together on-line sampling and adaptive warm-up, resulting into an integrated technique that is transparent to the target architecture design, tolerates frequent software modifications, and is almost entirely simulator neutral as it only requires generic modifications of the functional simulator (in the form of calls to a clustering library).

We have demonstrated the simulation speed and accuracy of this technique on a set of embedded benchmarks and an embedded architecture, and implemented it using SystemC.

Figure I shows the percentage of simulated instructions over the aforementioned set of benchmarks. Most programs require to perform simulation less than 1% of all their instructions. The fraction of instructions increases with the cache size, due to the larger warm-up required by the larger SRAM structure, but the increase is very moderate. There are two singular points: susan corner and susan edge which exhibit very high performance simulation ratio, 14% and 12% respectively. However, these two programs are the smallest of all benchmarks, so that even a few intervals account for a large fraction of the overall simulation. It is interesting to note that the same type of algorithm (susan smooth; susan is an image recognition package with several image processing algorithms), with a larger instruction count, has low error and low performance simulation ratio. This is illustrated by the wtd average, which is the average of the percentage of simulation time weighted by the total number of dynamic instructions in the program: 0.13% for the 4KB and 8KB caches, and 0.2% for the 64KB cache.

Figure I. Detailed simulated instructions

References:
MIEL: MODEL EXTRACTION FOR CONCURRENT C PROGRAMS

RESEARCH TOPICS: SOFTWARE VERIFICATION
R. BONICHON, L. CORRENSON, B. YAKOBOWSKI, S. LABBE (EDF R&D)
PARTNERSHIP: EDF R&D

In critical embedded systems, such as in the power generation industry, digital control systems may play an important role in plant safety. These systems are therefore the object of rigorous analyses and safety assessments. In particular, the quality, correctness and dependability of control systems software need to be justified. Some of these systems make heavy use of concurrent programming techniques. This can render the analysis particularly difficult, even if it is computer-assisted.

We propose to leverage tested and proven model-checking techniques by providing a user-assisted model extractor for C (MIEL) focused on handling concurrent code. This model extractor was implemented as a plug-in for Frama-C, a framework for static analysis of C programs, which is developed at the Software Safety Lab of CEA LIST. The MIEL tool has been built in to allow multiple outputs, even though the initial work was focused on using ALCOOL [1], a geometric model-checker developed at the LMEASI Lab of CEA LIST.

Let us detail the general use case. Given a C source program, a user first specifies their points of interest (mutex locks and releases, thread creations, etc.) as in the following example:

MIEL is then fed the specification file along with the source code to extract a model from it for a target model-checker (here ALCOOL). In order to do that, it uses a set of features provided by Frama-C such as syntactic loop unrolling and constant propagation. The extracted model contains the details the user has chosen but otherwise follows the control-flow of the original program. The model-checker is then responsible for providing the results of its analysis back to the user. A summary of this process is displayed in Fig.1.

The extension of MIEL’s current features can be envisioned mostly along two paths. First, one could make a better use of the semantic analyses from Frama-C (mostly its value analysis plug-in [3]) to get more precise results for the model construction and to lift some of the restrictions of the plug-in. Second, MIEL could be able to support other model-checking tools such as the industry standard SPIN model-checker to benefit from a wider range of available provers, each one with its strengths and weaknesses.

References:

Figure 1. Using MIEL with ALCOOL as a backend. Experimental results on a relevant case-study provided by EDF R&D - a digital control system for an energy plant - show evidence of the feasibility of the approach on real-world systems [2]. The extraction of the model and its analysis by the model-checker can take place in a matter of minutes on relatively substantial inputs to return useful results.
Structural testing is widely used in industrial verification processes of critical software. Automation of test case generation brings obvious benefits. In critical systems processes where structural testing is required by the development norm, manually creating tests from the specification fails to achieve complete satisfaction of the coverage criterion. In this case, automatic methods help to reach the objectives which are not covered and provide corresponding path conditions that may be used to refine the specification if needed. They may also determine whether the objectives which are not yet covered are really infeasible. Even when the development process does not impose any structural testing activity, the use of a structural test generation tool is a way to increase the quality of the software with a very low cost overhead.

PathCrawler [1] is a structural test generation tool developed at the Software Safety Lab of CEA LIST that may be used to automate structural testing. PathCrawler generates tests for C functions respecting the all-paths criterion, or the k-path criterion (for a given $k \geq 0$), which restricts the generation to the paths with at most $k$ consecutive iterations of each loop.

We present a new version of PathCrawler developed in an entirely novel form: that of a test-case server which is freely accessible online [2]. The user uploads the C source code to be tested and the server displays the test-cases generated by PathCrawler (see Fig.1) and a detailed justification of the coverage. The user can define the test context and browse the results using specialised interfaces in the form of web-pages. The server allows many test-case generation sessions to be run in parallel in a completely robust and secure way.

The advantage of making the tool available online is that it does not have to be downloaded and installed. Instead, it can be immediately run either on the programs which are provided, or on the user’s own code. The user can easily try out different test contexts, as to appreciate their significance, and can also upload an oracle and see the verdict of each test.

Indeed, in order to successfully perform automated structural unit testing, the user must pay particular attention to the definition of the test context and the oracle. This demands a different “mindset” from that used for informal functional-style manual testing. PathCrawler-online provides a convenient way to try out automatic testing for the first time. We have used PathCrawler-online as a teaching aid for university students at several French universities [3] and as a way for our industrial partners to evaluate the PathCrawler tool.

The PathCrawler-online service has become a reference in automatic test generation and has been used for tutorials on structural testing at several international events, such as TAP 2012, TAROT 2012, QSIC 2012 [4] and ASE 2012.

References:
Automatic analysis of programs from their
executable files has many potential appli-
cations in safety and security, for example:
automatic analysis of mobile code and mal-
ware, security testing or worst case execu-
tion time estimation.

We address in [1] the problem of (safe) CFG
reconstruction, i.e. constructing a both safe
and precise approximation of the Control
Flow Graph (CFG) of an unstructured pro-
gram (typically: an executable file). CFG
reconstruction is a cornerstone of safe un-
structured program analysis: if the recovery
is unsafe, subsequent analyses will be un-
safe too; if it is too rough, they will be blurred
by this initial imprecision.

Such an approximation is difficult to obtain
because of dynamic jumps, i.e. jump instruc-
tions whose target expression is resolved at
run-time and may vary from one execution
to the other. Unfortunately, dynamic jumps
are ubiquitous in native code programs
since they are introduced at compile-time
(return statements, function pointers in C,
virtual methods in C++, etc.). As a conse-
quence, industrial analysis tools targeting
binaries are either unsound or rely on users’
annotations.

The main technical problem here is that CFG
recovery must be both efficient and pre-
cise, which is well-known to be impossible
for most program analyses. In the method
proposed in [1], we take advantage of the
very specific nature of dynamic jumps found
in most programs to design an original
static analysis technique matching these
objectives. We rely on a very precise (but
potentially expensive) domain to compute all
potential values of the program at each pro-
gram point, controlled by a precision param-
eter allowing to focus the analysis on some
parts of the program only. Finally, a lazy
refinement mechanism adjusts automatically
and continuously the precision, resulting in
precise CFG recovery at moderate cost.

First experiments, including an industrial
case study from aeronautic and small rep-
resentative embedded programs, show that
the method does scale to realistic problems,
largely outperforms standard industrial
analyses in terms of precision, and beats ac-
ademic state-of-the-art techniques either in
terms of precision, efficiency or robustness.
Table I illustrates the results of the aircraft
case study.

Table I. The aircraft case study

<table>
<thead>
<tr>
<th></th>
<th>Dynamic Jumps (DJ)</th>
<th>Targets (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32,000 instr.</td>
<td>51 dyn. jumps</td>
<td>461 targets</td>
</tr>
<tr>
<td>Time</td>
<td>Resolved DJ</td>
<td>Recovered T</td>
</tr>
<tr>
<td>20 seconds</td>
<td>51/51</td>
<td>503 (10% false)</td>
</tr>
</tbody>
</table>

These results are part of a larger effort on
binary-level program analysis, including
automatic test data generation [2] and for-
mal semantics of binary-level programs [3].
Future works comprise improving perfor-
mance, conducting wider experiments and
exploring other domains of application, for
example binary-level security analysis.

References:
54, 2011.
165-170, July 2011.
ACCELERATION OF THE ABSTRACT FIXPOINT COMPUTATION IN NUMERICAL PROGRAM ANALYSIS

RESEARCH TOPICS: STATIC ANALYSIS OF NUMERICAL PROGRAMS.
O. BOUISSOU, Y. SELADJI, A. CHAPOUTOT (ENSTA PARISTECH)
PARTNERSHIP: ENSTA PARISTECH

One of the challenges of static analysis is to automatically and efficiently compute range of values for the variables of a program. In this way, one can detect potential run time errors such as division by zero or overflows. The most used technique for that is to use Kleene iteration: it is an iterative process that accumulates at each step new values that the variables can take. When the process stops, we know that we collected all the possible values. This technique is correct and simple to implement, however it may be very slow on simple, numerical programs as the number of steps that are required before Kleene iteration reaches its limit may be very high. Known techniques to reduce this number such as widening often introduce a large over-approximation that may lead to false alarms. Other techniques use different kind of accelerations but are not very well adapted to programs with floating point computations (see the work by Gonnord or Jeannet for example).

Our work on the acceleration of the fixpoint computation aims at reducing the number of steps in Kleene iteration while keeping a good precision. To do that, we adapted a technique used in numerical analysis to compute the limit of converging sequences, called sequence transformation. A sequence transformation transforms a converging sequence $x_n$ into another sequence $y_n$ that converges faster towards the same limit. For example, Aitken $\Delta^2$ process defines $y_n$ as: $y_n=x_n-(x_n-x_{n+1})^2/(x_n-2x_{n+1}+x_{n+2})$

On Fig.1, we show the sequence $x_n=0,(-1)^n$ and the transformed sequence obtained with $\Delta^2$: we can see that the transformed sequence reaches the limit much faster.

In [1], we presented the first ideas to use such sequence transformations in the context of static analysis of numerical programs. We modified Kleene iteration so that it extracts, at each step, one (or more) numerical value that represents the current range of values. Then, we apply sequence transformation on the obtained numerical sequences and insert it back into Kleene iteration once we have the limit.

In [1] this was done on the interval abstract domain only, in [2] we extended this work to the octogon and template polyhedra abstract domains. This work creates a link between the field of static analysis and numerical analysis: Kleene iteration computes a sequence of abstract values (intervals) that order-theoretically converge towards the solution, while numerical analysis is interested with numerical sequences that metrically converge towards its limit.

We showed that both notions can actually be used together to reduce the number of steps required by Kleene iteration. In Table 1, we present the result of our prototype analyzer for different programs: we give the number of steps used by Kleene iteration (column named Kleene), and the number of steps used with our technique for different acceleration process (Aitken $\Delta^2$, the epsilon algorithm and the Vector Epsilon Algorithm). Results show that we greatly reduce the number of required steps, while keeping a very good precision.

Table 1. Comparison of the number of iteration steps for various methods

<table>
<thead>
<tr>
<th></th>
<th>Kleene</th>
<th>$\Delta^2$</th>
<th>$\varepsilon$</th>
<th>VEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>butter1.c</td>
<td>346</td>
<td>6</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>butter2.c</td>
<td>180</td>
<td>33</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>gauss-seidl.c</td>
<td>24</td>
<td>14</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>nonlin-ear1.c</td>
<td>-</td>
<td>17</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>nonlin-ear2.c</td>
<td>1929</td>
<td>-</td>
<td>7</td>
<td>-</td>
</tr>
</tbody>
</table>

In a more recent work [3], we started to apply these ideas to the more general polyhedra abstract domain by using support functions, which are an efficient yet precise way to represent convex sets. This is very promising and we could compute precise invariants for high order numerical filters, which are known to be hard to analyze.

Figure 1. Effect of sequence transformation.

References:
A NON-STANDARD SEMANTICS FOR KAHN NETWORKS IN CONTINUOUS TIME

RESEARCH TOPICS: HYBRID SYSTEMS, SEMANTICS, NON-STANDARD ANALYSIS.
R. BEAUXIS (TULANE UNIVERSITY), S. MIMRAM
SPONSORSHIP: ANR PANDA
PARTNERSHIP: TULANE UNIVERSITY

Processes acting in a physical environment (such as a speed controller for car) are often modeled as hybrid systems which involve numerical quantities, called streams, varying both continuously over time (the speed of the car) and at discrete instants (the controller is a processor which operates at a given frequency). They are often described by graphs connecting various operators, such as the one below:

Over the links of the graph are propagated streams, on which the operators perform operations at every instant.

Since those are widely used, it important to define clearly their behavior by formalizing their semantics in order to be able to study their mathematical properties. However, this task is far from being straightforward because infinitesimal quantities are involved and these are rarely mathematically defined. Integrating or derivating a continuous stream for instance consists in considering the variations of the stream over a period of time $dt$ which is arbitrarily small. Another problem is that the graphs themselves are not usually precisely defined. The purpose of the article is to addresses both of these issues.

We have first formalized the graphs describing hybrid systems using a construction that we call nets, of which we have studied the algebraic properties in order to characterize the structure of their models. Since those nets can be composed and put in parallel, they are naturally structured as a monoidal category, and this category can be shown to have finite products and be traced with the cartesian product. Moreover, we have actually shown that it is the free such category, that we call a fixpoint category, on a set of generators corresponding to the operators. This result is of great interest in order to construct models for nets since any interpretation of the generators in a fixpoint category canonically induces a functorial model in this category for all the nets by the freeness property.

The semantics of the discrete part of the hybrid systems, where streams are simply infinite sequences of values, had been extensively studied as Kahn domains, modeling the systems as Scott-continuous functions between complete partial orders of prefix-ordered sequences (which form a fixpoint category). We have managed to extend these works to the continuous case, thus capturing all the hybrid systems, by using non-standard analysis. This theory introduced by Robinson develops an extension of real numbers, the hyperreals, which contains infinitesimal numbers (quantities are strictly positive elements smaller than any other real). Their construction is performed by considering sequences of reals quotiented by an ultrafilter: two such sequences are identified when they coincide on a “large” set of indices, that belong to a given ultrafilter on natural numbers. A real number can be seen as a constant sequence hyperreal and infinitesimals are simply (equivalence classes of) sequences converging towards zero. Inspired by this construction, we have shown that the category of sequences of Kahn domains quotiented by an ultrafilter is a fixpoint category and can thus form a model for nets. The interest of this construction lies in the fact that the elements of these sequences are hyperreals, thus containing a notion of infinitesimal, which can be used to interpret all the usual operators (such as the integrators and derivators in particular).

We have proved that, in the same sense that an infinitesimal is a sequence of successive approximations of zero, the semantics of a net in this model is a sequence of successive approximations of the idealized semantics that we take intuitively in account when manipulating these networks. This was done by relating the two on simple networks on which this idealized semantics is actually defined. However the present semantics is compositional and thus defined for every net, even in the presence of Zeno effects, which is the traditionally difficult case to handle.

This works lays mathematical foundations for the study of hybrid systems. In particular, we plan to use it to elaborate methods for their guaranteed simulation and abstract interpretation, in order to mechanically verify them for sensitive applications (cars, aeronautics, etc.).
EMBEDDED SYSTEMS
ARCHITECTURES & EMBEDDED SOFTWARE
DYNAMIC ROUTING STRATEGY FOR EMBEDDED DISTRIBUTED ARCHITECTURES

RESEARCH TOPICS: EMBEDDED DISTRIBUTED MANYCORES; ROUTING
C. AZAR, S. CHEVOBBE, Y. LHUILLIER AND J.P. DIGUET (UBS/LABSTICC)

SPONSORSHIP:
PARTNERSHIP: UNIVERSITÉ BRETAGNE SUD

Manycore architectures gained a large interest over the years but the problem remains in scaling the control fabric and the interconnection network. In this work we present CEDAR, a Configurable Embedded Distributed ARchitecture, and its adaptive routing strategy based on ACO (Ant Colony Optimization). Routing paths for remote data transfers are defined at runtime and allow a homogeneous distribution of traffic.

The number of cores of parallel architectures is expected to scale rapidly and the issue of the interconnection network is a serious threat that jeopardizes their usability. One of the major problems arises from non-scalable global wire delays. To overcome this issue, designers have introduced a communication-centric approach based on Network-On-Chips (NoCs), favoring short communication links.

While NoCs constitute a fair solution for nowadays interconnection architectures, we believe that, in exceeding thousands of cores on chip in future designs, more efficient interconnection strategies may be proposed. We make a step from communication-centric approach towards PE-centric approach, letting the PE (Processing Element) be in charge of the communication management.

We thus introduce CEDAR, a Configurable Embedded Distributed ARchitecture, and its adaptive routing strategy. In order to achieve such an adaptive system, we developed a swarm intelligence algorithm, based on Ant Colony Optimization (ACO), to handle dynamic communication. The CEDAR platform consists of an array of homogeneous PEs. Each PE is an embedded RISC processor having a 5-stage pipeline and operating at 0.9V and 300 MHz. It includes a local data and instruction memories, I/O and co-processor interfaces, and has a total area impact of 16 K Gates. The interconnect is a mesh like network, connecting each PE to its four nearest neighbors via distributed shared memories. No control host is settled down. Communication and synchronization between remote tasks are handled automatically and dynamically at the routing PEs by an implemented ACO algorithm.

We have developed an ACO algorithm specifically designed to map to the hardware modules of CEDAR. The ACO algorithm finds optimal paths between remote tasks, sources and destinations, while ensuring a homogeneous distribution of created paths between routing nodes. It releases artificial ants in the network to explore all possible paths, and chooses the one that assembles the least loaded crossed nodes.

To study the scalability of the proposed routing strategy, we consider a grid which dimensions grow gradually from a 3x3 to a 24x24 array of PEs. Remote tasks are mapped to corner PEs and the sources communicate with each of the destinations. The variation of the paths exploration and data transmission stages with respect to the total execution time are plotted in Fig. 1.

The path exploration first increases to reach then a peak of 32%. This rise is due to the growing system dimensions, which increases the number of possible paths and therefore the waiting at the routing nodes due to the sequential path checking. As for data transmission, it remains at a constant rate, around 65% of the total execution time.

Results are encouraging in terms of performance. Despite considering a sequential PE and not bringing hardware optimizations, the overhead due to path exploration at runtime remains little compared to the overall communication process. We intend in the near future to implement hardware optimizations for the ACO routing strategy to decrease the path exploration and the data transmission execution times.

References:
AHDAM: AN ASYMMETRIC HOMOGENEOUS MANY-CORE ARCHITECTURE

RESEARCH TOPICS: MULTITHREADED PROCESSOR, MANY-CORE, DYNAMIC APPLICATIONS.

C. BECHARA AND N. VENTROUX / D. ETIEMBLE (UNIVERSITÉ PARIS-SUD LRI)

PARTNERSHIP: UNIVERSITÉ PARIS-SUD

In this work, we designed a many-core architecture named AHDAM. This architecture uses a specific control unit to dynamically balance the workload on different tiles. Each tile is composed of a master processor and a set of secondary VLIW processors to process OpenMP loop nets. The 136 many-core architecture reaches 140Gops on 51.92 mm² (40nm) i.e. 2.69GOPS/mm².

The AHDAM chip architecture uses a specific control unit to dynamically load balance tasks on different tiles, through a control bus, to master processors (MPE) [2]. A tile is composed of an MPE and a set of secondary processors (LPEs) to process net loops. Each task has serial and parallel regions. The parallel regions are the parallelized loop implemented by using a fork-join programming model such as OpenMP. The MPE executes the serial regions of the tasks. When it encounters a loop region using OpenMP pragmas, the MPE executes a scheduling algorithm that uses a heuristic to fork the exact number of child threads in the appropriate Tiles’ Thread Context Pool. The local MPE can fork child threads in others Thread Context Pool by verifying their availability using the shared TCP state memory. The master thread who forks the child threads, waits to join until all the child threads have finished their execution. All tiles share a DDR access to handle data and a local instruction memory through a multibus. MPEs are implemented as monothreaded MIPS32 24K with FPU, while LPEs are implemented as 2-threaded 3-way VLIW processors. The CCP is the AntX 32-bit 5-stage RISC processor.

To study its performance, we used a radio spectrum sensing application from Thales Communication France. On a simulation framework, we evaluated sequential and parallel versions of the application on two platforms: single processor, and AHDAM with a variable number of processors (up to 136). Our architecture meets the real-time deadline of the application and reaches 140 Gops, while occupying 51.92 mm² at 40 nm technology. This represents a transistor efficiency of 2.69GOPS/mm², compared to 0.11GOPS/mm² for a MIPS24K.

References:
INTERLEAVED MULTITHREADED PROCESSOR FOR EMBEDDED SYSTEMS

RESEARCH TOPICS: MULTITHREADED PROCESSOR, EMBEDDED SYSTEMS.
C. BECHARA, A. BERHAULT, N. VENTROUX, S. CHEVOBBE, Y. LHUILLIER, R. DAVID, D. ETIEMBLE (LRI)
PARTNERSHIP: UNIVERSITÉ PARIS-SUD

In this work, we designed a small footprint interleaved multithreaded processor based on the AntX 5 stage RISC processor. This processor can support two virtual threads and uses only 13.97 Kgates. The performance gain is 17% when compared to the monothreaded core for a 73.2% area increase.

With the increase in the design complexity of MPSoC architectures and the need for more transistor/energy efficient processor architectures, designers are exploiting the parallelism at the thread level (TLP) through the implementation of embedded multithreaded processors. Moreover, future manycore architectures tend to use small footprint cores. In this work, we present a small footprint, scalar, in-order, 5-stage pipeline, interleaved multithreaded processor with two hardware thread contexts for embedded systems and SoC integration [1].

Recent small multi-threaded processors for embedded systems have been designed. The figure below shows the main existing works among interleaved multithreaded (IMT) and blocked multithreaded embedded (BMT) processors.

The monothreaded core, on which we have based our study, is called AntX. It has lot of similarities with MIPS-I R3000 but has been designed to ease the specialization of the core with dedicated extensions. AntX is a 5-stage pipeline mono-threaded RISC core. It is a mix 16-32-bit instruction set with 32-bit wide datapath. It is well-suited for low-cost control in MPSoC environment. Therefore, there are no complex units such as a branch predictor, FPUs and multipliers. Its register file is composed of 16 32-bit registers. AntX comes along with a dedicated GNU tool chain. The ISA supports a variable instruction size (16/32 bit) in order to reduce the instruction memory footprint. So, some basic arithmetic/logic/comparison/jump instructions are coded in 16-bit, while other more complex instructions are coded in 32-bit.

Synthesis results in 40 nm TSMC shows that the multithreaded core area is only 19800 µm² and 13.97 Kgates, which is almost equal to a 4KB direct mapped cache memory according to CACTI 6.5 tool. The IMT core area increase is 73.2% compared to the monothreaded core. The IMT RTL model is validated by executing 2 instances of a simple bubble-sort application concurrently, while varying the L1 D$ size. The extracted pipeline statistics showed that the IMT model is able to hide all the pipeline stalls due to data dependencies between instructions and branch penalties. The IMT core gives an average performance gain of 17% compared to the monothreaded core as shown below.

References:
SYNCHRONOUS REACTIVE FINE GRAIN TASKS MANAGEMENT FOR HOMOGENEOUS MANY-CORE ARCHITECTURES

RESEARCH TOPICS: EMBEDDED SOFTWARE, MANY-CORE ARCHITECTURES
M. OJAIL, R. DAVID, K. BEN CHEHIDA, Y. LHUILLIER, L. BENINI (UNIVERSITY OF BOLOGNA, STM)
PARTNERSHIP: UNIVERSITY OF BOLOGNA, STM

Embedded computing architectures are increasingly shifting towards multi- and many-core designs to achieve high performance and low power consumption. This work presents a hardware-assisted reactive tasks management (RTM) technique enabling the efficient exploitation of the different resources in such many-core architectures.

Current embedded computing architectures are moving toward many-core concepts in order to sustain ever growing computing requirements within complexity and power budgets. Programming many-core architectures not only requires parallel programming skills, but also efficient exploitation of the parallelism at both the architecture and runtime levels. Our work [1] presents a reactive tasks management (RTM) technique that is suitable for fine grain parallelism. Exploiting fine-grain parallelism eases the work of the developer since, most of the time, it is a form of parallelism which is naturally present in applications and doesn’t require heavy algorithm rewriting.

Development and performance evaluation of the proposed RTM API is done on Platform 2012 (P2012); a many-core architecture, designed by CEA and STM, which aims at moving a significant step forward in dealing with the issues related to exploiting the increasing amount of on-chip resources.

The RTM API leverages both hardware and software support to efficiently exploit fine-grain parallelism at the lowest possible cost. The hardware acceleration resources, as well as other resources not used for the programming model presented here are encapsulated in a single IP in P2012 developed by CEA LIST and named HWS (Hardware Synchronizer).

The Parallelism expression in the RTM framework presented in this work is based on forking and duplicating tasks. When the forked or duplicated tasks have finished their execution, the core that has expressed this parallelism joins the tasks in order to continue sequentially. Thus, programming with the RTM API is very simple and consists in using only two functions. The programming model reflected by this RTM API is a synchronous one, in a sense that forking (or duplicating) and joining tasks is done in the same function and by the same processing element. This leads to a simple API that presents the lowest possible overhead as well as the easiness of programming. The figure bellow depicts an example of the task graph that this API supports. Multiple nesting levels can be implemented using this API but no asymmetric fork-join operations are allowed due to the synchronous nature of the implemented model.

Performance estimation was conducted on two versions of the TLM platform: an untimed version, and a timed version taking into account hardware access latency and serialization. Results are summarized in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Timed TLM</th>
<th>Untimed TLM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruction count overhead</td>
<td>9%</td>
<td>7%</td>
</tr>
<tr>
<td>Overhead per scheduled task</td>
<td>58 cycles</td>
<td>46 cycles</td>
</tr>
</tbody>
</table>

The instruction count overhead is partially masked by the waiting time for the critical path. In fact, simulation on the VC-1 decoding application showed that only 3.5% cycle count overhead is induced by this API which makes it truly suitable for fine grain tasks scheduling.

Nevertheless, due to the fact that the fork-join operations are done synchronously, it is not possible to join a subset of the forked tasks. Thus implementing asynchronous fork-join operations is a must to model more complex task graphs and will be done in future work.

References:
A SYSTEMC TLM FRAMEWORK FOR DISTRIBUTED SIMULATION OF COMPLEX SYSTEMS

RESEARCH TOPICS: SYSTEMC – DISTRIBUTED SIMULATION – PDES – MPI
J. PEETERS, N. VENTROUX AND T. SASSOLAS

Increasingly complex systems need parallelized simulation engines. Existing distributed SystemC solutions require predicting communication in the simulated system. However, this is often unpredictable.

This work presents a novel parallelization approach that deals with unpredictable communication. Experimental results show a 13 fold speed-up on 16 processors.

Application requirements are getting more and more complex. Systems executing these applications have to evolve to support new execution models, new memory hierarchies or new communication schemes. This pushes such systems to grow in size and in complexity. SystemC is a C++ library that offers to model mixed software/hardware systems. Such a model can be described at multiple levels of accuracy depending on the system designer’s needs. SystemC simulations may have very different purposes, such as design space exploration, verification or validation. Nonetheless, facing the continuously increasing complexity of current and future systems and considering that SystemC gets to be used by a large number of industrials and academic groups, there is a real and pressing need for efficient and scalable implementation of SystemC simulations.

One promising approach to achieve this goal is to parallelize the evaluation of SystemC simulations. Existing distributed SystemC solutions require knowing the frequency of communications in the simulated system so as to offer good performance. However, communication cannot be predicted in real complex systems since their computing load is highly dynamic. We propose a novel method [1] based on distributed computing that consists in cutting up the SystemC model of the simulated system into clusters. All clusters are evaluated in parallel on separate computing nodes. Communication between clusters is asynchronous on top of a Message Passing Interface (MPI) library. The simulation consistency is kept using a distributed and cooperative algorithm derived from the Parallel Discrete Event Simulation (PDES) theory.

Figure 1 shows the result of the distribution process of a SystemC model using our approach.

Compared to previous approaches, the system designer can tune the synchronization period between clusters to reduce the control overhead and therefore to increase the simulation speed.

The value of the synchronization period is a trade-off between accuracy and speed depending on the requirements of the simulation.

We evaluated our implementation using a small grid of 4 nodes, each composed of 2 Intel Xeon W3550 cadenced at 3.07 GHz. We demonstrated that our approach can be scalable and meet the requirements of an efficient SystemC simulation tool with a speed-up up to 13 fold with 16 clusters. Figure 2 shows the results for a random communication period following a uniform probability law.

References:
DESIGNING PROCESSORS USING MAss, A MODULAR AND LIGHTWEIGHT INSTRUCTION-LEVEL EXPLORATION TOOL

RESEARCH TOPICS: MULTI CORE ARCHITECTURES, DESIGN TOOLS, ILP
MATTHIEU TEXIER, ERWAN PIRIOU, MATHIEU THEVENIN AND RAPHAËL DAVID

This study proposes an algorithm analysis approach that eases Design Space Exploration (DSE) for programmable processors. The originality of the method comes from its capacity to generate operator level simulators allowing a quick code analysis from real data sets. MAsS is demonstrated in designing two original parallel processors.

The increasing complexity of applications and computational demand dictates the need for highly efficient processors. Therefore, an efficient task mapping over control and processing elements is required, in order to sustain high execution speed performance as well as efficiency in electrical power and silicon area utilization.

The aim of the MAsS tool [1] is to provide a flexible way to design an embedded programmable solution in order to optimize the execution of specific kernels within a set of defined applications.

MAsS provides execution statistics and instruction-level profiling about the execution of a program on a real data set and so helps the architecture Design Space Exploration (DSE). Moreover MAsS allows to measure the impact of resources specialization (special instructions, heterogeneous computing ways, etc.) in order to make the system more efficient for specific applications.

Usually an application is written in a high level language such as C. Prior using MAsS, an application profiling is needed to extract the main computing parts (kernels) to be analyzed in MAsS. An initial transformation translates the kernel code into an intermediate representation (IR). This IR is used to generate simulators which allow the execution of the code using a real data set. This is done through the generation of an annotated C code that replaces the original kernel. The generation is driven by a configuration file which defines the processor model. Thus MAsS enables to obtain information on a specific kernel running both in its original context with the real data set and on different hardware architecture. For example it can give the usage of the operators of each computing way of a Very Long Instruction Word (VLIW) processor. Figure 1 shows the operator usage and the code length of a convolution kernel compared to the numbers of computing ways of the targeted architecture.

An Explicit Parallelism Instruction Computing (EPIC) processor devoted to multimedia applications has been designed using MAsS. The targeted application is an MPEG2 encoder and especially its most compute intensive kernel the full search algorithm. MAsS has been used to measure the impact of sub-word parallelism, loop management and the impact of specific operators on a processor with heterogeneous computing ways on the performances.

A complete architecture for image processing [2] has also been designed using MAsS. The targeted image processing algorithms have been simulated in order to define the required operators and the appropriate data access mode. MAsS showed a data level parallelism. Finally a Multiple Single-Instruction Multiple-Data (MSIMD) architecture that is designed from mass results is presented.

The MAsS approach is an original approach that is especially relevant for Application Specific Instruction Set Processors (ASIP) design. MAsS can generate fast and accurate instruction level simulators. The simulator runs in the original application context and with the real data sets.

Two different architectures have been successfully profiled and optimized for media and low-level image processing applications.

Figure 1: Results of the ILP Study on a VLIW processor using MAsS: average ILP and length versus number of ways.

References:
GRAPHIC RENDERING APPLICATION PROFILING ON A SHARED MEMORY MPSoC ARCHITECTURE

RESEARCH TOPICS: MULTI-CORE, SIMULATOR, GRAPHIC RENDERING, LOAD BALANCING

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PARTNERSHIP: UNIVERSITY OF RENNES

This work is about the implementation of a graphic rendering application for an MPSoC architecture initially devoted to the dynamic management of static task graphs. It exhibits a highly non-stationary workloads of the application domain. It provides a first feedback on the design of future embedded architectures that will face multiple computation domains like graphics, multimedia and telecommunications.

Embedded devices have to handle an increasing amount of applications. Each has different computing requirements and is dedicated to a specific domain. To efficiently handle this variety of applications, embedded systems usually use different hardware accelerators.

Current embedded devices are based on system on chips made of several cores like general purpose processors, multimedia processors (video and audio encoding and decoding) and others IPs that can be dedicated to imaging or telecoms for example. More and more mobile systems also embed a Graphic Processing Unit (GPU).

In this work [1] we look at a different approach consisting in extending current MPSoCs to support graphic applications. We study the ability of standard execution models devoted to multi-domain multi-core architectures to sustain performance for graphic applications.

The main Graphic Processing Unit job is to render a three-dimensional scene to a two-dimensional screen. The input data is a set of points (vertices) defined in a three-dimensional space. These points define triangles and the gathering of triangles can make a form like a sphere, a cube, etc. A complex triangle mix can draw any kind of synthetic or real forms. This rendering process is done in three main stages: the geometry, the setup (rasterizer) and the fragmentation. All these stages are handling different kinds of data as shown in Figure 1.

The rendering pipeline has been implemented as a five stage pipeline. Each has its own parameters that are set at runtime. The implementation has been done in the SESAM simulator [2]. We show that the application uses two types of parallelism: thread and data parallelisms. In order to leverage all the processing, the application has been parallelized by duplicating the entire pipeline or only parts of the pipeline, for example the geometry or the fragment stages.

Different scenes have been chosen as execution scenarios to analyze the workload, each having different computing requirements. We show in [1] that the different stages have very different computing needs depending on input data (Figure 2). According to the scenario, different parallelization schemes must thus be applied. Considering only average case scenarios may lead to lower by two the performance with respect to the optimal parallelization scenarios. On the other hand the worst case scenario leads to over-dimension the architecture and huge power wasting.

This study demonstrates the need for MPSoC architectures to support dynamic task graph so that to be able to sustain performance in complex applications like graphics, and paves the way for further MPSoC architectures improvements.

References:
SESAM/PAR4ALL: EXPLORATION OF MPSOC ARCHITECTURES

RESEARCH TOPICS: MPSOC SIMULATION, EXPLORATION, PERFORMANCE ANALYSIS
N. VENTROUX, T. SASSOLAS, A. GUERRE / B. CREUSILLET, R. KERYELL (HPC PROJECT)

In this work, we associated a semi-automatic parallelization workflow based on the Par4All retargetable compiler, to the SESAM environment. This new framework can ease the application exploration and help to find the best tradeoffs between complexity and performance for asymmetric homogeneous MPSoCs and dynamic streaming processing.

Due to the increasing complexity of new multiprocessor systems on chip, flexible and accurate simulators become a necessity for exploring the vast design space solution. In a streaming execution model, only a well-balanced pipeline can lead to an efficient implementation. However, with dynamic applications, each stage is prone to execution time variations. Only a joint exploration of the application space of parallelization possibilities, together with the possible MPSoC architectural choices, can lead to an efficient embedded system. In this work, we associated a semi-automatic parallelization workflow based on the Par4All retargetable compiler from HPC Project, to the SESAM environment [1,2,3]. This new framework can ease the application exploration and find the best tradeoffs between complexity and performance for asymmetric homogeneous MPSoCs and dynamic streaming application processing.

As shown on the figure above, Par4All generates the control task, which is a CDFG graph, and all computation tasks source codes based on the SESAM Hardware Abstraction Layer (HAL) corresponding to the application pipeline, including kernel and server tasks. The computation task executables are generated using a C cross-compiler corresponding to the computing resource type. A specific compiler provided by the SESAM framework is used for the control task. Depending on the execution results and user defined scenarios, it is then possible to change the kernel tasks by only modifying the pragmas used in the input application, and run it again through Par4All, to optimize the load balancing on the application pipeline on computing resources.

The efficiency of our framework was studied through the simulation of a complete asymmetric MPSoC architecture running a radio sensing application from Thales Communication France.

We demonstrated that SESAM can bring to the designer the possibility to guide the application optimization with Par4All, and that Par4All brings a very convenient way to generate multiple parallelized version of the application in order to find the right balance between the tasks, with a moderate impact on performances. (figure below).

To our knowledge, this is an original work on a complete simulation tool chain that supports the exploration of asymmetric MPSoC architectures and associates a semi-automatic code generation for streaming applications. It enables the exploration of new computing paradigms to face future embedded application needs.

References:
PROBABILISTIC PARAMETERS OF CONDITIONAL TASK GRAPHS

RESEARCH TOPICS: PARALLEL COMPUTING, CONDITIONAL TASK GRAPH, TASK SCHEDULING
S. CARPOV, J. CARLIER (UTC HEUDIASYC), D. NACE (UTC HEUDIASYC), R. SIRDEY
PARTNERSHIP: UTC

This work deals with the problem of determination of probabilistic parameters for tasks in a series-parallel conditional task graph. Such problematic is encountered in the context of parallel computing when dealing with conditional precedence constrained parallel tasks on a multi-core machine. We focus on the calculation of two probabilistic parameters: the release dates and the delivery times. An algorithm for computing these parameters is proposed.

A task graph model, also known as directed acyclic graph (DAG), is used to represent algorithms which have to be executed on a parallel computing system. A multitude of methods have been proposed in the literature to deal with the DAG scheduling on multiprocessor systems having as objective the completion time minimization. The above methods use different parameters which are defined for the DAG’s tasks. Two important parameters are the release date (head or top level) and the delivery time (tail or bottom level) of a task. These parameters are used in task selection rules of list scheduling algorithms.

Another important parameter for a task graph is the minimal execution time (or the critical path) which is the completion time obtained when no constraint is imposed on the number of available processors (i.e. when the number of processors is considered to be unlimited). The minimal execution time is a lower bound for the completion time of the general multiprocessor scheduling problem and it is used in tree search algorithms (e.g. branch and bound methods) to reduce the search space.

The task graph model lacks of expressivity which limits its use in many practical situations. A first drawback is the hypothesis that task execution times are constant. In reality, they are variable and depend on several factors (caching, branch prediction mechanisms). A second disadvantage is the absence of tools for modeling conditional branches which are widely employed in programs. A conditional branch is a special task, such that only one of its successors is executed (in function of a condition depending on the input data for example). The case of variable task durations is known in the literature on probabilistic PERT scheduling and on stochastic DAG scheduling. The literature on task graphs with conditional branches is scarce and mainly consists in methods for allocating and scheduling them onto multiprocessor systems. The goal of this study is to define probabilistic parameters for task graphs with conditional branches.

Roughly speaking, a conditional task graph (CTG) is a DAG in which certain edges have an execution probability. In Fig.1 a CTG is illustrated. In this CTG the probability of tasks 5, 7, 8 and 9 execution is 0.6 for example.

An algorithm for finding probabilistic heads and tails for each vertex of a series-parallel CTG is proposed. The algorithm has a pseudo-polynomial complexity.

The execution time of the algorithm depends on the sizes of the domains of definition of the discrete random variables used to represent the heads and the tails. At the price of less precise results the execution time of the algorithm can be reduced in order to be able to use it for graphs encountered in practice. For the example illustrated in Fig.1 the critical path value (head of task 11) is 13 with probability 0.32, 14 with prob. 0.08, 17 with prob. 0.48 and 18 with prob. 0.12.

References:
This study is devoted to the problem of estimating the achievable degree of parallelism for a parallel algorithm with respect to a bandwidth constraint. In a compiler chain for embedded parallel microprocessors such estimation can be used to fix an appropriate target for parallelism reduction “tools”.

In this work [1], we investigate a series of problems related to efficient memory bandwidth management in embedded parallel processor architectures. In particular, we are interested in estimating the memory bandwidth required for the sequential execution of a parallel algorithm so as to estimate the number of tasks which may execute in parallel with respect to an external memory bandwidth constraint. In a compiler chain proceeding by parallelism reduction, such estimation can be used to fix an appropriate target for the degree of parallelism. This estimation can also be used within an Algorithm-Architecture Adequation framework to perform an initial assessment.

Let us consider an embedded parallel processor architecture which consists of many processing cores which share a common memory space. The system, in which this processor is used, has an external memory for storing application data and instructions. External memory locations are accessed without direct core involvement, i.e. if only initiates and finishes the data transfers. In this context, a typical bottleneck for many algorithms is the external memory access bandwidth, which must be carefully managed in order to keep the processing cores busy enough. An algorithm is composed of a set of tasks that are using external memory data. The data loading time is variable because several data could be loaded two or more times in function of the caching strategy.

In this study, we propose a method to estimate the achievable degree of parallelism for an algorithm constrained by the external memory bandwidth, which is the ratio \( \frac{\Lambda}{\lambda} \) between the external memory bandwidth \( \Lambda \) to the average bandwidth \( \lambda \) required by an optimal sequential execution of the algorithm. We suppose that we are dealing with parallel algorithms, thus their intrinsic structure in terms of parallelism is not an issue, only the limitations of the chip (here, in terms of external memory bandwidth) influence the estimation.

The average bandwidth \( \lambda \) is defined as the total amount of data divided by the total execution time. It is straightforward to see that the average bandwidth is proportional to the amount of data loaded from the external memory, thus loading less data will reduce the bandwidth.

Informally, our problem consists in task ordering and memory management for an algorithm, so as to minimize the number of memory accesses. We prove the NP-hardness of this problem and introduce a polynomial special case. We propose a branch and bound procedure for the general case along with computational results interpretation demonstrating its practical relevance.

An example optimal task processing order which minimized the total number of external memory accesses is represented in Fig.1. The used application is an M by N image convolution with 3x3 kernel.

References:
EXACT SOLUTION OF A DIFFICULT COMBINATORIAL OPTIMIZATION PROBLEM USING PARALLELISM

RESEARCH TOPICS: PARALLELISM – COMBINATORIAL OPTIMIZATION – OPERATIONAL RESEARCH
FRANÇOIS GALEA, BERTRAND LE CUN (UNIVERSITÉ VERSAILLES SAINT-QUENTIN)
PARTNERSHIP: UNIVERSITÉ VERSAILLES ST-QUENTIN

We implemented a branch-and-bound-based exact algorithm for the Three-Index Quadratic Assignment Problem (Q3AP) on multicore processors. Our parallel implementation has two levels of parallelism: the tree search procedure uses the Bob++ parallel search framework. The lower bound computation uses the SIMD extensions of modern processors.

Q3AP is an extension of the Quadratic Assignment Problem (QAP), which is well known in the combinatorial optimization community. While QAP is considered a difficult problem, Q3AP is even more difficult.

Different industrial problems can be formulated as a Q3AP problem, in fields such as wireless networking.

The Q3AP may be described as follows: consider a facility-location problem with N facilities and N locations, where in addition to assigning facilities to locations we also want to assign N managers to the N locations. A solution to this problem is a set of N triplets (manager, facility, location), where all the managers, facilities and locations are assigned one-to-one. The cost of a solution is the sum of Lijk linear costs for each of the chosen (i, j, k) assignments (i.e., the sum of the Lijk*xijk products for placing manager i and facility j to location k), plus the sum of Cijklmn quadratic costs for each ((i, j, k), (l, m, n)) pair of assignments (i.e., the quadratic cost Cijklmn*xijk*xlmn for placing manager i and facility j to location k, and manager l and facility m to location n).

The problem was exactly solved [1] using a parallel branch-and-bound procedure in the Bob++ parallel search framework we developed [2]. Multi-core parallelism is used to accelerate the tree spanning by exploring different subtrees in parallel. Table #1 shows typical run times depending on the number of used cores.

The SIMD extensions of the processor (Intel SSE2) were used to accelerate the lower bound computations in the tree nodes. Table #2 compares the run times of the bound procedure implemented with and without SSE.

These parallelization techniques are suitable for use on a large variety of problems. We are currently developing a heuristic solver for a place and route problem on a 48-cores server.

Table #1: run times (in seconds) of our solver using different numbers of cores on a multi-core workstation.

<table>
<thead>
<tr>
<th></th>
<th>2 cores</th>
<th>4 cores</th>
<th>8 cores</th>
</tr>
</thead>
<tbody>
<tr>
<td>nug10</td>
<td>23.7</td>
<td>7.8</td>
<td>4.5</td>
</tr>
<tr>
<td>tail10a</td>
<td>7.9</td>
<td>4.3</td>
<td>2.9</td>
</tr>
<tr>
<td>inst10a</td>
<td>19.1</td>
<td>10.0</td>
<td>5.6</td>
</tr>
<tr>
<td>12 1</td>
<td>77.3</td>
<td>42.0</td>
<td>42.0</td>
</tr>
<tr>
<td>had12</td>
<td>533.0</td>
<td>261.7</td>
<td>186.3</td>
</tr>
<tr>
<td>nug12</td>
<td>862.7</td>
<td>562.9</td>
<td>347.7</td>
</tr>
<tr>
<td>inst12a</td>
<td>249.0</td>
<td>121.6</td>
<td>105.1</td>
</tr>
</tbody>
</table>

Table #2: run times (secs) and speedups for the lower bound implementation using SSE (vector) vs. a scalar implementation.

References:
NEW EXECUTION MODEL FOR CHIP MULTI-PROCESSORS

RESEARCH TOPICS: EXECUTION MODEL, PARALLELISM, OS ACCELERATORS
S. LOUISE, V. DAVID

As multi-core architectures become the standard for embedded systems, it is widely acknowledged that parallelism management for parallel architecture and for embedded application is difficult. We present a new approach to heterogeneous multi-core systems to provide a simple multi-task, multi-threaded execution model for such an architecture, by introducing an execution unit specialized in parallelism management on the front-end core.

The era of ever increasing single-core performance is over, the new Moore’s law nowadays roughly translates as: the number of available cores on an up-to-date chip double every 18 to 24 months. Nonetheless, programming multicore architectures is a difficult task for the embedded programers, because usual HPC programing scheme like MPI or OpenMP do not fit well with the usual applications of the embedded world: these application require a very light-weight OS and library support and a very dynamic execution scheme in order to fit performance with execution time requirement and optimizing power consumption within these constrains.

The main principle of our approach is to start from a simple observation: parallel programing is difficult, whereas the dynamic parallel execution of instructions with superscalar architectures was a very efficient way to keep a simple programing model (sequential programing), with the processor using dynamical knowledge of the execution to optimize the parallel issue and execution of single instructions. Our approach involves a single core processor with several Auxiliary Processing Unit cores (APU) (fig. 1), to execute dynamically tiny processing kernels. The APU are execution units for High-Performance Computations and are limited mostly by the limits of Amdahl’s Law, hence the parallelism exploitation is better if a wide range of parallel kernel coarsening level is possible. That means that if fine granularity parallel kernel can be used efficiently, then the kernel and core management time must also be tiny, by at least an order of magnitude with regards to the minimum execution time of the parallel kernel executed on an APU [1].

We showed how to define a specialized execution unit —called Auxiliary Control Unit (ACU) — of the front-end processor that manage the APU and act as an OS accelerator for dynamic parallelism optimization.

References:
EXTENSION OF CMOS ACTIVE PIXEL SENSORS LIFESPAN UNDER RADIATION

RESEARCH TOPICS: HARDENED SYSTEMS, RADIATION EFFECTS
J.M. ARMANI, P. BARROCHIN AND F. JOFFRE

The possibility to extend the lifespan of Active Pixel Sensors under gamma rays irradiation has been demonstrated. The procedure involves high temperature heating cycles applied to the sensors. Such thermal annealing results in improving the sensor tolerance to total ionizing dose.

In the nuclear industry, video cameras are widely used to allow equipment operators to have an accurate view of their work. However, in high radiation level areas the current CCD based cameras may exhibit a lifespan of only a few weeks. The use of deep-submicron CMOS image sensors could be an interesting alternative to the CCD technology paving the way for a potential breakthrough in this field.

This work explores the possibility of extending lifespan of CMOS image sensors, by using thermal regeneration of components during their exposure to radiation. At present few studies have addressed the thermal regeneration of components during their exposure to radiation. Although heating can induce aging of components, it could help extend the lifespan of certain components such as CMOS image sensors used in video cameras.

The CMOS Active Pixel Sensor (APS) used for the study is the MT9V131 produced by Aptina (formerly Micron). It is a digital 1/4-inch VGA-format sensor with a pixel size of 5.6 mm x 5.6 mm.

In order to determine the temperature and duration of the heating period that would allow a good regeneration of the sensors, preliminary isochronal annealing experiments were performed in the range 80°C-200°C. It was found that sensors had to be heated at 200°C for 30-40 minutes to restore their functionality.

Four sensors have been irradiated up to a total dose of 130 kGy with a dose rate of 200 Gy/h. Three sensors have been heated cyclically during the experiment to allow their regeneration and one was never heated.

The effectiveness of sensor thermal annealing was evidenced with the heating cycles applied during irradiation. Fig.1 shows the images provided by a heated sensor just before and after a regeneration period of 30 minutes at 200°C. There is a clear improvement in image quality, color rendering and noise level.

Fig.2 shows the images delivered by heated and unheated sensors after a cumulated dose of 2700 Gy. While the heated sensor gives a still usable image, the unheated sensor generates an image showing a phantom test chart hidden behind a very important horizontal band noise. It is clear that thermal annealing can extend the lifespan under gamma radiation of MT9V131 imager.

This work was presented at the RADECS 2011 Conference in Sevilla [1].

References:
MEMORY CONTROLLER FOR GLOBALLY UNCOORDINATED AND LOCALLY COORDINATED CHECKPOINTING

RESEARCH TOPICS: MEMORY CHECKPOINTING – BACKWARD ERROR RECOVERY
Y. CONGAL, M. CARTRON

For dealing with soft errors in the logic of multiprocessors, a new backward-error-recovery-capable architecture is proposed. The cornerstone of this architecture is an innovative memory controller that realizes a hybrid checkpointing for reducing the performance overhead. This enhanced memory controller was designed for minimizing the performance overhead for error-free scenarios.

The multiprocessor strategy for enhancing performance consists in parallelizing the code of an application. The presence of efficient mechanisms for synchronization and data exchange are crucial for good performance, and a local and fast shared memory is often used for this purpose.

Backward Error Recovery (BER) approaches consist in combining an error detection mechanism with a roll-back mechanism for restoring error-free states. Every BER protected system has a limited recovery perimeter inside of which the errors can be undone by the recovery action, which is impossible outside this perimeter. If the recovery perimeter is small, the recovery will be simpler, but the error containment induces performance loss for preventing unrecoverable error propagation. If the recovery perimeter is large, the error containment will be less harmful to the performance, but the recovery actions are more complex and costly.

Our proposal [1] uses a large recovery perimeter in order to limit the impact of BER on performance for parallel applications: the recovery perimeter includes processors (including caches) and the shared memory. Errors in the processors are allowed to propagate in resources belonging to the current process and processes that interact with it. We call this group of interacting processes a Data Dependency Sphere (DDS). Inside a DDS, the checkpoints (CPs) are taken in a coordinated way [2] (for bounded CP storage), and between DDSs, the CPs are taken in an uncoordinated way [3] (for smaller and less frequent CPs).

The architecture is divided into several CP components and a CP master. Every CP component must implement CP functions and recovery actions. The fault containment is provided by MPU control.

The most critical part of our BER capable architecture is the memory controller (Fig. 1), because the recovery of memory is more complex. For this component, we used the following design priorities: a) minimize the performance overhead while reading, b) minimize the performance overhead while writing, c) minimize the recovery time.

For satisfying these constraints, we have designed a dedicated memory for CP storage (the CPSM) for better read and write operations performances. The CPs are log-based for limiting the write penalties for some of the write operations. The CPSM is a unique buffer for balancing the CPSM resource between many different applications and avoiding oversizing problems. Then, the CPSM is a circular buffer for avoiding searching for a free line during write operations for minimizing the performance overhead. Then, the CPSM is ordered by DDS. The recovery to the CP of a DDS requires parsing the CPSM and the ordered property allows parsing the CPSM only once. Some write operations require saving data to the CPSM and some do not. In order to determine the need to save the data, a parsing of the CPSM should be necessary. However, we introduced a new module called Write Resolution Accelerator (WRA) for determining this in only one clock cycle.

As a perspective, we are interested in finding efficient solutions for processes that would interact rarely with each other.

References:
STUDY OF THE IMPACT OF SOFT FAULTS ON MULTICONDUCTOR TRANSMISSION LINES

RESEARCH TOPICS: CODING – ELECTROMAGNETISM, REFLECTOMETRY, FAULT DIAGNOSTIC
M. FRANCHET, N. RAVOT, O. PICON (LABORATOIRE ESYCOM, MARNE-LA-VALLÉE)
PARTNERSHIP: ESYCOM

In the context of wiring networks, diagnostic tools such as reflectometry work well to detect hard defects (short or open circuits). It is now very important to devise methods for detecting soft defects (shallow contacts) which requires a better understanding of their effects on multiconductor lines. This is the purpose of this work.

As electronic devices are more and more present and complex, attention has been raised on monitoring the health of their wiring networks. Consider this simple fact: there is a probability of 66% that a wiring defect appears in a plane of more than 20 years. This makes more obvious the need of developing efficient methods of detection, all the more than their consequences can be costly and even tragic.

One method commonly used is called Reflectometry (see Figure 1). It is based on the injection of a probe signal into the wiring network and the analysis of the reflected ones measured at the injection point. This works well for severe faults (open or short circuits).

Unfortunately, no method seems to be efficient enough for detecting faults at their early age in bundles. Although the use of time frequency tools in the case of one single coaxial line (Wavelet transform, Wigner Ville transform) show some improvement, a better understanding of the effects of soft faults on the electrical parameters (RLCG) of multiconductor transmission lines (MTL) and on reflectometry signals is of crucial need in order to develop systematic and efficient methods. This is the purpose of our contribution.

In order to characterize the electromagnetic properties of the cables, we used the CST Microwave studio software tool. A Laplace code was used to extract the electrical properties of the cables (RLCG parameters). Two kinds of soft faults were considered: In the first one only the dielectric coating is damaged (see Figure 2), in the second the dielectric and the conductor are both degraded (see Figure 3).

We have obtained qualitative results concerning the impact of two kinds of soft faults on the characteristic parameters of MTL's structures. Considering the per-unit-length capacitance and inductance parameters and the characteristic impedances, one can observe the similarity between results for 2 and 6 conductors. This enables us to extend the observed trend to any kind of structure composed of n coated transmission lines.

References:
THE USE OF THE PSEUDO WIGNER VILLE TRANSFORM FOR DETECTING SOFT DEFECTS IN ELECTRIC CABLES

RESEARCH TOPICS: CODING – ELECTROMAGNETISM, REFLECTOMETRY, FAULT DIAGNOSTIC
M. FRANCHET, N. RAVOT, O. PICON (LABORATOIRE ESYCOM, MARNE-LA-VALLÉE)
PARTNERSHIP: ESYCOM

Recently a reflectometry method called JT-FDR (Joint Time Frequency Domain Reflectometry) has been proposed to improve the detection of soft faults in cables. It is based on the use of the Wigner Ville Transform. This work proposes to use the Pseudo Wigner Ville Transform in order to attenuate the cross-terms effect and therefore enhance the diagnosis quality.

Nowadays automotive systems are asked to perform multiple tasks. One consequence is an increase in complexity of their networking. In order to ensure a good quality of service, the interconnect system has to be safe and reliable. As the trend is towards X-by-Wire systems, a special attention has to be paid on their wiring networks. In order to prevent electrical failures, which can have heavy consequences, defects in cables have to be detected as soon as possible.

For monitoring the health of cables, several wiring diagnostic techniques exist. Reflectometry is among the most popular one. A solution based on the Wigner Ville transform (WVT) and a normalized time frequency cross-correlation function has already been proposed. It is part of a wiring diagnostic method called Joint Time Frequency Domain Reflectometry. It has been applied to a coaxial cable and shows interesting results concerning soft faults. However one problem has not been raised yet: the possible presence of cross-terms resulting from the use of the quadratic WVT. This problem can arise if the characteristic impedance of the cable has several discontinuity points (multiple faults, impedance mismatch at near and far end, interconnections, etc.). As these terms can lead to false-positive results or mask real faults, it is important to reduce them.

We propose to use the Pseudo Wigner Ville Transform (PWVT) which is a windowed version of the WVT. The PWVT smoothes the cross terms in the frequency plane. As a consequence the frequency resolution is degraded but the time resolution is kept intact.

In this work, the PWVT has been applied on two different cases. First, it has been tested on results obtained from a simulated wire. The performance of the method has been verified against experimental results obtained for a damaged coaxial cable as can be seen on figure 1 and 2.

This work has proposed a method to detect incipient faults (soft faults). A time frequency cross-correlation function, using the WVT, was applied on TDR results. The problem of cross-terms emerging from the quadratic nature of this transform has been raised. It has been shown that the use of PWVT instead of the simple WVT could significantly enhance the results and makes the faults detection easier. This is particularly important when considering soft faults, whose detection requires a very high accuracy. The issue of well designing the window used for the PWVT, in order to optimize the detection, has also been highlighted.

References:

Figure 1. Experimental results on a coaxial cable

Figure 2. Example of a damaged cable
PROGRAMMABLE EXTENDED SEC-DED CODES FOR MEMORY ERRORS

RESEARCH TOPICS: MEMORY, YIELD, REPAIR, BISR, ERROR, CORRECTION
V. GHERMAN, S. EVAIN, F. AUZANNEAU, Y. BONHOMME

Redundant memory columns are an essential ingredient of memory design for yield and reliability. We propose a way to increase the capacity of masking memory columns with isolated defective storage cells using spare memory columns. Single-bit soft-errors affecting any bit position can be corrected simultaneously with single-bit hard errors induced by any subset of memory columns.

Manufacturing and wear-out induced defects are identified as major threats for the yield and the reliability of memories produced with advanced scaled-CMOS technologies. In parallel, soft-error rates at chip and system levels remain essentially unchanged or they increase, as is the case with the SRAM memories.

Memory protection against soft errors is usually ensured with the help of single error correction and double error detection (SEC-DED) codes. In such cases, redundant memory columns are necessary to store the check-bits of the SEC-DED codes. Additional redundant memory columns, called spare columns, are required to replace completely malfunctioning regular columns affected by manufacturing or wear-out induced defects.

In memory units with a large number of banks, the majority of banks will not have completely defective columns and the available spare columns can be used to mask out malfunctioning storage cells. Unfortunately, conventional column replacement has limited repair efficiency for this kind of defects.

We propose [1, 2] a memory protection scheme to ensure the correction of both hard and soft errors based on extended SEC-DED (E-SEC-DED) codes and bit-swapping.

The E-SEC-DED is based on the extension of a systematic SEC-DED code with a number of check-bits equal to the number of spare columns available in a memory bank.

This extension enables the correction of all double-bit errors that affect at least one bit position from a fixed sub-set of bit positions in the extended code words. Any double-bit error in which these bit positions are not involved remains detectable.

The proposed E-SEC-DED codes have a hierarchical structure and can be easily reduced to the original SEC-DED code or to E-SEC-DEDs with a lower number of supplementary check-bits. This allows their application to memory banks with an arbitrary number of completely defective columns.

The bit positions of the E-SEC-DED code words which are better protected against the double-bit errors can be mapped to the memory columns with defective storage cells based on bit-swapping, as illustrated in Figure 1.

The bit-swapper can be dynamically reconfigured based on status information that designates the memory columns with defective storage cells. This facilitates the integration into built-in self-repair (BISR) schemes.

In this way, the number of columns where the defective storage cells can be masked is significantly increased with respect to solutions based on conventional SEC-DED codes and column replacement. Even in the case when only one spare column is available, two distinct columns with defective storage cells can be masked out instead of a single one as is the case with conventional columns replacement.

It is also possible to apply this repair approach to memories that do not require soft error protection.

![Figure 1: The bit-swapper maps bit positions of the E-SEC-DED code words to memory columns.](image)

References:
GENERALIZED PARITY-CHECK MATRICES FOR SEC-DED CODES WITH FIXED PARITY

RESEARCH TOPICS: SEC-DED CODE; PARITY-CHECK MATRIX
V. GHERMAN, S. EVAIN, N. SEYMOUR, Y. BONHOMME

Extended Hamming and Hsiao parity-check matrices can be used to define systematic linear block Single Error Correction-Double Error Detection (SEC-DED) codes. We show that these parity-check matrices are particular instantiations of a generalized parity-check matrix that can be used to define SEC-DED codes with fixed parity and efficient hardware implementations.

Single Error Correction-Double Error Detection (SEC-DED) codes provide an effective way to increase the reliability of semiconductor memory subsystems. Accesses to SEC-DED protected data involve operations such as data encoding or error checking/correction. The last operation is the most critical since its implementation requires higher area and performance overheads.

One factor that influences these costs is the density of the parity-check matrix, also called H-matrix, which in the case of binary codes is defined as the percentage of 1-elements. Another hardware optimization enabling the fixed parity of the SEC-DED code words which allows efficient double error detection.

Nowadays, only extended Hamming and Hsiao H-matrices are available to implement SEC-DED codes with fixed parity. In an extended Hamming H-matrix, the fixed code word parity is encoded with the help of an all-one row (Fig.1), while in a Hsiao H-matrix, this is ensured by the restriction to have only columns with an odd number of 1-elements (Fig.2).

The Hsiao H-matrices provide faster hardware implementations due to a lower density and to a more uniform distribution of the 1-elements over the matrix rows.

We propose a way to further reduce the H-matrix density of SEC-DED codes with fixed parity. This method relies on a generalization of the restriction used in the definition of Hsiao H-matrices. We prove that the fixed code word parity can be ensured if a sub-set of the H-matrix lines can be found which intersects each matrix column in an odd number of 1-elements. As a consequence, Hsiao and extended Hamming H-matrices become particular cases of the generalized H-matrix and sparser H-matrices can be found for a wide range of code word sizes.

Moreover, with the generalized H-matrices a lower number of syndrome bits can be used to compute the overall code word parity as compared to Hsiao H-matrices.

For example, H-matrix in Fig. 3 obtained with our approach offer faster hardware implementations to extended Hamming (Fig.1) and Hsiao (Fig.2) due to a lower density and to a more uniform distribution of the 1-elements over the matrix rows.

Synthesis results proved the potential of the generalized H-matrices to provide more efficient hardware implementations.

Fig. 1: 5×13 Hamming H-matrix. Only the last row is used to enable fixed code word parity.

Fig. 2: 5×13 Hsiao H-matrix. All rows are used to enable fixed code word parity.

Fig. 3: 5×13 H-matrix with 3 rows used to enable fixed code word parity.

References:
CHRONOSCOPE: A STATIC ANALYSIS TOOLS FOR C MULTITASK REALTIME APPLICATIONS

RESEARCH TOPICS: STATIC ANALYSIS, MULTITASK REAL-TIME APPLICATION, C LANGUAGE

SELMA AZAIEZ, BELGACEM BEN HEDIA, THIERRY GOUBIER, VINCENT DAVID

The safety of multitask and real-time applications relies on the respect of several properties (e.g. absence of deadlock, atomicity, respect of temporal constraints, etc.). Verifying such properties from the source code requires a complex analysis platform that is able to identify code patterns semantic and to apply the appropriate verification process.

CHRONOSCOPE is an action initiated by IRSN (Institut de Radioprotection et de Sûreté Nucléaire) and CEA/DACLE/LaSTRE. Its goal is to reason about design rules that have to be respected within source code and ensure the absence of errors. For instance, race conditions which are common errors in parallel programming, lead to unintended non-determinism and erroneous results. In practice, race conditions and deadlocks are avoided by applying a design rule which consists on protecting access to shared memory with locks and imposing a partial order on lock acquisitions. To date, existing static analysis tools are developed to check errors in sequential programs (e.g. ASTREE, PolySpace, CAVEAT, etc.) or are dedicated to a single specific property such as absence of deadlock.

The project started on establishing a list of design rules that ensure the safety of multitask realtime applications by respecting properties such atomicity, absence of deadlock, respect of temporal constraints, etc. Properties verifications were classified within 5 levels of analysis (cf. Fig.1.). In each level, models are extracted from the source code and several rules are verified by different analyzer tools.

Analyser tools are activated depending on identified code patterns (e.g. how tasks are created, what communication and synchronization patterns are used: producers/consumers or readers/writers, etc.). Hence, the analysis platform has to be modular to allow such flexibility. Moreover, as analyzed applications are implemented in C language, it has to be based on a strong C parser. Frama-C has been adopted as a basis for our analysis platform. It actually provides all needed features for Level 0 analyses.

Using different tools and different techniques for properties analysis complicate the validation process and a high expertise is required for each type of property. In [1], we propose a pattern-based approach to harmonize the validation process. We introduce the property analysis pattern which provides the analysis process according to the code pattern identified within the source code and the property to verify. A dedicated formalism was proposed to describe it.

This approach provides more generality than existing ones. It can be applied for different systems using different languages. Users can plug-in different language parsers and provide the corresponding API semantics. This approach also allows knowledge capitalization by explicitly defining the verification and transformation processes.

Finally, this year was also dedicated to study atomicity verification process which is stronger than simply checking the absence of race conditions. Indeed, either checking that access to shared memory is protected; atomicity imposes that order of read and write actions ensures the coherency of the shared data.

References:

Figure 1. CHRONOSCOPE levels of analysis
FROM MODEL-BASED TO REAL-TIME EXECUTION OF SAFETY-CRITICAL APPLICATIONS

RESEARCH TOPICS: REAL-TIME, MODEL-BASED, CODE GENERATION

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PARTNERSHIP: ESTEREL TECHNOLOGIES

Developing safety critical real-time systems and ensuring properties such as deterministic behaviour is a challenging task. Automatic transformations from synchronous modelling languages to RTOS are required for the development of real-time applications without compromising the safety. We present an automatic transformation from SCADE to the OASIS safety-oriented real-time execution platform.

Various domains, such as the automotive or avionic industries, develop increasingly complex real-time systems. Model-based approaches have been proposed to specify requirements of such systems and design them. Such design environments allow modelling and simulation of applications as well as generation of qualifiable/certified code. Generated code can then be compiled and run on various Real-Time Operating Systems (RTOS). Classical RTOS are based on an event-triggered approach for the execution of applications and do not provide sufficient predictability and analyzability: the deterministic behaviour of an application cannot be ensured prior to its execution.

The goal of the OASIS approach [1] is to build safety-critical real-time systems where the system behaviour is independent from the asynchrony that is allowed during the execution of an application. Therefore and by construction, OASIS is a complete answer to demonstrate the system timeliness: all timing constraints of all activities are clearly expressed in the design phase and can be formally proven to satisfy (or not!) the capacities of the hardware support. SCADE is a synchronous language derived from Lustre and implemented in the Esterel Technologies SCADE Suite model-based development environment dedicated to critical embedded software.

To the best of our knowledge, few connections exist between synchronous modelling languages, which allow one to develop applications with certified functional behaviour, and time-triggered execution platforms, which guarantee temporal determinism of systems.

The main difficulty in the transformation is computing the logical clocks that define the temporal behaviour of the agents in such a way as to preserve the functional semantics of the model and optimize the usage of computing resources [2]. One of the main differences between SCADE and OASIS computation models concerns the propagation of data during one computation cycle. In SCADE, data is propagated from inputs to outputs at each computation cycle. In OASIS, all agents read their inputs simultaneously and then simultaneously publish the results of their computation. In order to preserve the computation semantics throughout the transformation, each agent is assigned a specific slot of the computation cycle. Thus, the intermediate values are computed and published by the corresponding agents before the agents that require these values for their computations start their respective cycles. This is illustrated by the figure below with the green lines identifying the original cycles of the SCADE model (level control in water tank) and the dashed arrows - the data flow.

Figure 1. OASIS coordination for a SCADE model.

References:
Assuming that tasks have been allocated on CPUs, the difficulty in distributed real-time systems is to ensure an optimal scheduling of network accesses. We claim that the network scheduling must be generated automatically by an off-line tool chain. We present how we adapted Time-Constrained Automata (TCA) to model communication requirements, in the context of a multi-scale time-triggered execution model.

Distributed architectures are becoming a common target for real-time embedded safety-critical systems, notably in order to enhance their availability. The design and implementation of such systems must be carefully performed. However, the difficulty is to conceive critical functions according to a framework that ensures an optimized scheduling of network accesses, with no help from the application designer. In this work, we focus on the schedulability analysis and scheduling of bus accesses using a Time Division Multiple Access (TDMA) approach for time-triggered real-time systems. TDMA divides the global time into a sequence of time slots, each of them is assigned to an unique CPU so that no network collision can occur. We assume that tasks have been allocated on CPUs of a distributed system.

The schedulability analysis of a simple TDMA protocol (periodic) has already been studied by the research community. We consider the problem of scheduling bus accesses made, not by periodic tasks, but by tasks whose timing behavior are specified using Time-Constrained Automata (TCA) model [1]. Using such a task model, the behavior of tasks are modeled by automata and constrained by time intervals. This is a more expressive task model than the periodic task model.

Our first contribution is to show how we adapted the TCA model to express timing-constraints on data exchanges for a multiscale time-triggered execution model [2]. Applied to a network, the semantic of the four kinds of nodes of the TCA model are the following:

- An Afterd node constrains the exchange of a data item to start after the date d.
- A Befored node constrains a data item to be available for consumers’ tasks before the date d.
- A Syncd node is a combination of an Afterd and a Befored nodes.
- A No node imposes no temporal constraints on data exchanges.

We further optimize the computation by taking into account possible differences between producers, consumers and any temporal behavior of the considered communication mechanisms. Our second contribution is then to transform requirements on data exchanges expressed using TCA into a linear programming problem. We then generate the TDMA scheduling of bus accesses that fits the description of data exchanges requirements in TCA. We show that the proposed approach can be fully integrated in an off-line tool chain. Figure 1 shows the verification of the on-line fulfillment of the off-line generated network schedule of a sample application (speed regulation of a vehicle).

Figure 2. Generated and observed TDMA schedule.

References:
PharOS is a complete set of tools to design, implement and execute hard real-time real-time systems on embedded platforms, such as control and command systems found in automotive embedded systems. We present here the features of PharOS that allows it to address mixed-criticality real-time applications, i.e. applications with safety critical tasks running concurrently with non-critical tasks.

Over the last decades, the number of electronic equipments embedded in complex systems such as automotive vehicles or airplanes has increased in drastic proportions. At first, system architects used to embed one computing unit per functional system, which resulted in large distributed and heterogeneous real-time systems. The current number of equipments makes this approach no more sustainable, mainly due to its high costs.

As a result the trend is to integrate several (possibly unrelated) applications on fewer computing units, resulting in what is called a mixed-criticality system.

This integration raises however a number of issues, such as:

- efficiently and securely sharing resources (and especially CPU time) between these applications;
- providing the same degree of isolation than achieve when using separate computing units;
- combining different real-time paradigms and APIs;
- handling multicore computing units, that are becoming the usual solution of the chip designers to increase performances.

PharOS is the system that we built to address these problems. PharOS is a complete set of tools to design, implement and execute real-time systems on automotive embedded platforms, comprising a compiler and offline analysis and code generation tools, with a safety-oriented kernel.

The keystone of this approach is a dynamic time-triggered methodology that supports full temporal isolation without wasting CPU time. This relies on a rich model of tasks that accurately describes the task constraints, and admits an optimal dynamic scheduling algorithm. Moreover, it allows exact feasibility analysis, which avoids wasting CPU time by oversized the time resources for the tasks. The task model is automatically extracted from the application code written in PsiC, a superset of C with statements for inter-task communications and timing annotations, that enforces isolation between the tasks.

Furthermore, PharOS guarantees the determinism of the application despite the parallel execution. This provides a behavioral isolation between the tasks, which is a unique feature of PharOS.

In addition, memory isolation is handled through automatic off-line generation of fine-grained memory protection tables used at runtime.

These isolation mechanisms are building blocks for the support of mixed-criticality applications. Several further extensions expand the support for mixed-criticality within the system. These extensions include fault recovery, support for the cohabitation of event-triggered with time-triggered tasks, and para-virtualization of other operating systems.

Automatic translation from PsiC into the PharOS task model

References:
[1] Matthieu Lemerre, Emmanuel Ohayon, Damien Chabrol, Mathieu Jan and Marie-Bénédicte Jacques,
 Execution time knowledge is a requirement in embedded software, specifically for scheduling validations and for real-time constrains verifications. Execution time analysis aims at identifying all possible execution path of a given program and predicting the actual execution time through system architecture and execution process modeling. In this work, we present a new proposal for low level modeling of branch predictors.

Execution Time knowledge is a requirement for scheduling theories, including multi-processor scheduling optimization, and for verification of real-time constrains. That means tools for execution time analysis have a growing role to play in embedded software development tool-chains. Of course, one naive approach is to make a sampling of empirical execution times. Nonetheless, in some corner cases, this approach is insufficient for accurate scheduling analysis, and is inconsistent with hard real-time timing analysis requirement. Indeed, in the later case, guarantees and proofs must be provided on the execution time boundaries and such guarantee cannot be shown on execution time sampling.

Execution time analysis is an important field of research, with still on-going challenges to face: the ever changing technological landscape of processor architecture, introducing new features on a regular basis; the non-deterministic behaviors of several processor feature like cache memories, pipeline stalls, and so on; and finally the limits of decidability of programs in the general case. Therefore only a subclass of program are formally analyzable, and on of the goal of execution time analysis is to expend the field of automatic analysis as far as possible, and being able to include as accurate an execution model as possible (e.g. taking into account fully preemptible scheduling policies).

Two main fields of execution time analysis can be distinguished: the high level analysis which wants to analyze all the possible execution paths of a given program, and the low level analysis which use these results with a mathematical model of the system that execute the program in order to evaluate the possible execution time as accurately as possible.

Our works lie into this low level analysis, as some earlier works dealt with cache memory modeling for low level analysis [1,2]. We used the same kind of formalism (based on linear algebra and a Markov model) to model branch prediction behaviors. A first extended paper was published in WCET Workshop at ECRST 2011 (the main workshop of the domain) for the “simple” saturating counter based branch predictor [3]. The main principle is to extend the automaton of the branch predictor (fig. 1) onto an abstract state automaton which takes into account that under static analysis some branch predictions have unknown outcomes (fig. 2).

The associated operators were defined and a first evaluation of branch prediction related timing was done on several standard benchmark programs.

A work in progress paper was published in RTSCA conference and CPSNA workshop with a first step to take complex history based branch predictors into account [4].

References:

Figure 3 Simple branch predictor principle (based on a 2 bit saturating counter)

Figure 4 Associated abstract space (model)
SPECIALIZED OS FOR HIGHLY DEPENDABLE HARD REAL-TIME SYSTEMS

RESEARCH TOPICS: PARALLEL EXECUTION MODEL, OS, NUCLEAR SAFETY COMPLIANCE
S. LOUISE, M. LEMERRE, C. AUSSAGUÈS, V. DAVID

The OASIS model provides a quantum leap in ease of design and programming over old state of the art methods for nuclear power instrumentation and Control (I&C) systems. The requirements that are enforced by very strict standards and rules offer very few latitude for a generic OS. In this work we show how we designed and programed a generic OS for the execution support of the C language that conform to the strict standard ISO-60880 for nuclear safety, but still get good performance within these constrains.

Instrumentation and Control programmed systems for nuclear power plant follow very strict standards (in conformance with the associated risks of such facilities). These standards, being very conservative, make some serious limits on the use of a standard OS with these systems.

The OASIS kernel is then an achievement, not because as an OS and execution support for OASIS applications it has some extraordinary feature or implements a breakthrough in OS design, but because it mix a good step up from usual I&C nuclear power system design by allowing real parallel tasks, and a conservative enough implementation, with a sane design for safety.

The OASIS kernel [2] is a generic (i.e multi-applications) OS that implement a specialized support of the language associated with the OASIS model [1]: the C language. It provides a very strict and strong memory protection scheme; it contains provably no dead code; and makes some continuous auto-test of the application regarding its logical and time related behavior.

OASIS has two main layers (see figure 1):

- the micro-kernel which acts as the time manager, schedules the real-time tasks and act as a watch-dog for any timing overrun,
- the agent kernel manages communication between tasks, and perform auto-tests on the logical behavior of each real-time task under its supervision.

Since only the micro-kernel is non-preemptible, the overall system can reach good performance inspite of its safe design (and inspite of the strict memory protection scheme), enabling to switch between task in less than 2 µs in the worst case while doing 4 MMU context switch meanwhile, on a relatively old Pentium M processor.

The kernel was used in the industrial product ODS, made by Areva-NP for the new generations of nuclear power plants, and the ODS allows for a generic real-time display with a full featured HMI (mouse, keyboard, touchscreen, modern graphic interface) for emergency shutdown monitoring [3].

Figure 5 – The layered architecture of an OASIS application: the OASIS kernel has 2 parts (µ-kernel and agent-kernel) defining a strict memory protection scheme that depends on the associated task context. Transition between layers are done through carefully managed service calls.

References:
[1] S Louise, V David, J Delcoigne, C Aussaguel, OASIS project: deterministic real-time for safety critical embedded systems, 10th ACM SIGOPS European Workshop (rank B), Saint-Emilion, France, September 2002
TASK MIGRATION MECHANISMS FOR HARD REAL-TIME DISTRIBUTED SYSTEMS

In the context of distributed non real-time systems, several mechanisms have been proposed to migrate tasks in order to reduce their freeze time. In this work, we focus on distributed hard real-time systems. We present four techniques: Total Copy, Prefetch Precopy, Prefetch Postcopy, Mixed Copy, taking advantage of the static description of the temporal behavior of hard real-time tasks.

Task migration is a mechanism that has been well studied in the past decades in distributed non real-time systems. The main goal of the various proposed techniques is to reduce the so called freeze time of a task, i.e. the time interval during which a task cannot be executed due to on-going migrations. Allowing a freeze time in a real-time system could make the system less predictable and could lead to miss some deadlines. Nowadays, critical real-time systems such as automotive and avionic control system applications are often distributed. The reliability of these systems is important: even if a hardware failure occurs such as a node crash and therefore the loss of all the tasks executed on this node, critical tasks must still be executed to guarantee availability. One of the most prevalent strategies to achieve, at best, the graceful degradation of distributed hard real-time system is to handle with a set of replicas of critical tasks, using dynamic replication capability when failures occur. The design of guaranteed migration mechanisms for hard real-time system, with predictability properties, is therefore needed.

We show how we can build adapted migration mechanisms to the context of distributed hard real-time systems [1][2]. Such systems assume the static description of both their temporal and logical behavior, i.e. the real-time constraints associated to each task and the possible execution paths of tasks are known. We present four migration techniques that show this claim: Total Copy, Prefetch Copy, Prefetch Postcopy and Mixed Copy. The Figure illustrates the smallest, current and largest interval of transfers of the Mixed Copy strategy. Mixed Copy (see Figure 1) consists in copying the memory required by the next job after migration deadline first, then transfer all remaining memory whether the task has been resumed in the destination node or not.

In addition, this static description of possible execution paths allows the identification of memory areas that are required (in read, write or execute access) by each job of a given hard real-time task. We use this relationship to efficiently organize data transfers on the network according to different strategies (Prefetch Pre and Postcopy policies) and temporal constraints associated to jobs. We formalize the various temporal constraints that describe the feasibility conditions of migrating a task whatever the migration deadline is. Specific additional tasks are used to implement in each node the migration policy of tasks. These tasks are integrated to the existing task set to verify CPU and network schedulability.

References:
FLEXIBLE AND PERFORMING KERNELS DYNAMICALLY GENERATED WITH DEGOAL

RESEARCH TOPICS: DYNAMIC COMPILATION, PROCESSING, EMBEDDED SOFTWARE, HPC
H.P. CHARLES, D. COUROUSSÉ, Y. LHUILLIER

SPONSORSHIP:
PARTNERSHIP:

deGoal is a tool designed to build fast and portable binary code generators, in order to improve the performance of CPU-bound applications. It currently supports the STxP70 core of the P2012 platform, ARM processors used in the embedded domain, and Nvidia GPUs (PTX) used for High Performance Computing.

Modern compilers embed a lot of optimization knowledge to make the most of the target architecture. Such compilers are however unable to exploit runtime information, in particular the data to process, because code generation is done before the application has started its execution.

deGoal is a tool designed to tackle this issue, i.e. the generation of machine code that depends on the data to process. It is different from JIT compilers (Java or LLVM), because it is not based on an intermediate representation (no bytecode), has a low memory footprint, puts a strong focus on hardware portability and is faster than any code generator. Using deGoal the developer is able to embed tiny specialized code generators, called “completettes”, in an application. Such a completette will be able, at runtime, to generate the code of a processing kernel. The generated kernel is optimized depending on the data to process, the target processor and its instruction set.

deGoal currently supports the STxP70 core of the P2012 platform, ARM processors used in the embedded domain, and Nvidia GPUs (PTX) used for High Performance Computing (HPC).

On the P2012 platform, we demonstrated the effectiveness of deGoal on matrix processing and on the implementation of a memory allocator. Figure 1 presents the speedup obtained on matrix multiplication. It compares a static version compiled using the platform compiler with full optimization and an implementation using deGoal. Our implementation provides a performance increase of 111% using VLIW instructions, and 56% without VLIW support for square matrices of 56 elements. The binary code generated by deGoal is not sensitive to compiler’s options, and provides good performance whatever the size of the input matrices. The memory allocator we implemented is an optimized version of dlmalloc. Using deGoal we managed to bring extra flexibility to the initial static implementation without degrading performance. We also exploited runtime information to adapt the behavior of the allocator to the memory properties of the application. The performance of the allocator could then be improved by an max./average speedup of 56%/35%. This work is funded by the SMECY project.

On Nvidia GPU accelerators, thanks to deGoal our completette is able to specialize the code on the fly. Our actual experimentations use data size information to produce more efficient code by inserting stride and fixed addresses and also by removing unnecessary tests. This work is funded by the European ITEA2 H4H project.

![Figure 1. Speedup results of the matrix multiplication on the STxP70-v4 core.](image)

References:
VERY FAST INTERROGATION SYSTEM FOR SPECTRALLY MULTIPLEXED FIBER BRAGG GRATING-BASED SENSORS

RESEARCH TOPICS: LASER, OPTICAL FIBER SENSORS
MOURAD BEN ABDALLAH, GUILLAUME LAFFONT, NICOLAS ROUSSEL AND PIERRE FERDINAND

This study deals with the development of a very fast interrogation system for Fiber Bragg Grating-based sensors to fulfill end-user requirements, i.e. a system able to measure very small wavelength shifts, while scanning a wide spectral window (several tens of nanometers) to address a large number of sensors. In such a context, this paper presents the development and the characterization of a tunable source for the high-speed interrogation of spectrally multiplexed FBGs [1]. The source developed makes possible to sweep a range > 80 nm, with an output power of 1.8 mW, at a nominal frequency from 20 kHz up to 100 kHz. This tunable source was successfully used to analyze a line of several FBGs, initially at rest, and then subjected to several levels of deformations.

To date, tunable sources techniques have several drawbacks. Some of them cannot scan a wide spectral range and are limited to nearly 10 nm. Effective sweep rates, in other techniques (like thermal variation VCSELs, several tens of hertz), do not exceed 20 kHz. In other cases, employed techniques work only within the XS-Band (at 1300 nm as a center wavelength). Otherwise, there are many applications where high-speed (several tens of kHz), wide spectral range (several tens of nanometers), C+L-Band optical frequency swept lasers are desired. In this paper, we propose the development of such a source.

Figure 1 shows that the spectral range takes the values 85, 70, 70, 60 and 40 nm respectively at the frequencies 20, 40, 60, 80, and 100 kHz. This drop in the spectral range scanned by the source vs. the rate is linked to cutoff frequencies of FFP-TF and its control electronics. As shown in Figure 2 (a), we detect peaks that represent the reflection time-domain spectra of the six Bragg gratings inscribed along the fiber. This experiment was, initially, conducted in the complete absence of mechanical stress. In a second step, we applied three levels of successive deformations by suspending various masses (61 g, 153 g and 353 g) at the end of the sensor. Figure 2 (b) illustrates the spectral response, unfiltered, of one of the six FBGs after these several induced deformations.

References:
Cancer treatment by Radiation Therapy involves a combination of irradiation times and beam orientations to allow the medical physicist to deliver the prescribed dose to the target volume while preserving surrounding healthy tissues and Organs at Risk (OARs). Treatment Planning Systems (TPS) are used to plan the treatment using morphological patient data, obtained by medical imaging methods.

In Brachytherapy (BT), sources are placed within or next to small-scale tumors, invasively or through body cavities (intracavitary). High-dose-rate (HDR) BT uses a single high-activity iridium ($^{192}$Ir) source, unreeled (computer-controlled) from a remote afterloader, injected into the patient through hollow tubes and eventually withdrawn. High depth-dose gradients are generated (inverse square law, e.g. 10 to 20 % mm$^{-1}$).

Severe accidents in RT have been associated with the incorrect use of TPS or false dose measurement during its commissioning. In vivo Dosimetry (IVD) is therefore an additional safeguard against RT accidents (legal requirement in France since 2011). The deviation between planned and delivered doses must remain below $\pm$ 5 %. However, the high dose gradient configurations make conventional external dosimetry methods (e.g. 2-D EPID, point dosimeter) challenging for IMRT and BT, leading to intracavitary (IC) measurements, close to OARs. Chains of catheter-mounted dosimeters (tiny MOS-FETs, RPLs or TLDs) were previously demonstrated but they do not provide on-line dose monitoring and thus lead to time-consuming maintenance and calibration. Moreover, sensor identification is unmanageable.

In external Beam RT, high dose gradients are also encountered in Intensity-Modulated RT (IMRT) that uses multileaf collimators to generate sharp transversal dose gradients.

The compliance of the FODC with medical specifications were successfully tested (X-ray localization, radiation resistance, etc.). The FODCs are re-usable after sterilization (plasma process). The implementation of FODC for intracavitary IVD would lead to simpler and less costly IVD (in terms of maintenance cost and consumable).

Metrological validations were performed at CEA-LIST LNHB (Laboratoire National Henri Becquerel, French National Metrology Laboratory for Ionizing radiation) with a $^{192}$Ir source and a Saturne 43 LINAC. The FODC dose response is energy-independent at Megavoltage energies (LINAC). A small energy dependence is found for iridium sources (the dose response increases with source-to-detector distance, –1.8 % cm$^{-1}$). Self-compensation is demonstrated by calibrating the FODC at a reference mean source-to-detector distance (typ. 2.5 cm).

Finally, the compliance of FODC prototypes was checked during preclinical validations at Centre Léon Bérard (CLB) with respect to medical specifications and constraints (imaging, probe insertion, validation within anthropometric phantoms) in a context of HDR BT of prostate. This study calls for further developments on echographic crystal localization, real-time source localization (in HDR BT), prototyping development and CE-marking in the perspective of industrial transfer.

References:
We report here on the 2007 discovery, in perfect archaeological context, of part of the engraved and ocre-stained undersurface of the collapsed rockshelter ceiling from Abri Castanet, Dordogne, France. The decorated surface of the 1.5 metric ton roof-collapse block was in direct contact with the exposed archaeological living surface onto which it fell. Since there was no sedimentation between the engraved surface and the archaeological layer upon which it collapsed, it is clear that the Early Aurignacian occupants of the shelter were the authors of the ceiling imagery. This discovery contributes an important new dimension to our understanding of the earliest graphic representation in SW France almost all of which was discovered before modern methods of archaeological excavation and analysis. Comparison of the dates for the Castanet ceiling and those directly obtained from the Chauvet paintings reveals that the “vulvar” representations from SW France are as old or older than the very different wall images from Chauvet.

In 2007, in an attempt to understand how the Northern (Peyrony) sector fit into a pattern of lateral sedimentary variation observed in the Southern sector, we returned there to excavate a fragment of the primary archaeological layer preserved beneath a massive block estimated to weigh 1.5 metric tons. To control the archaeological context of this block in case of engravings, and in consultation with French archaeological authorities, we removed it in pieces by controlled breakage using mason’s wedges. As the operation proceeded, we observed significant traces of color and deep engravings on the block’s undersurface which sat directly on the archaeological layer. This context-oriented approach to excavation bore fruit as the imprint of the engraved image was clearly preserved on the surface of the archaeological layer (Fig. 1). Immediately beneath the block were numerous flint artifacts fractured in place, confirming the massive impact of the roof collapse and the status of the engraved surface as a portion of the ancient ceiling of the shelter. There was no intervening deposition/occupation between the underside of the block and the occupational surface, implying that very little time passed between the engraving and the collapse of the ceiling onto the exposed surface. A terminus ante quem date for the archaeological layer should therefore be a good proxy for the engraved undersurface of the collapsed ceiling.

We exercised extreme prudence in cleaning the decorated surface, being instructed by the recent discoveries of painted surfaces on Aurignacian limestone blocks from Fumane in Italy. From the moment of the removal of the first portion of the new Castanet block, we took the precaution of not cleaning the surface, awaiting x-ray fluorescence mapping of the surface to monitor for various mineral pigments. This XRF analysis performed by the CEA-LIST team allowed informed cleaning of the decorated surface. The “painted” nature of the block’s surface remains to be confirmed, and initial X-ray fluorescence testing suggests that the red coloring may well be derived by transfer from the hematite-rich layer onto which it fell.

Figure 1. The engraved vulvar representation from the decorated block.

References:
ELECTROSTATIC GRAFTING OF DIAMOND NANOPARTICLES TOWARDS 3D DIAMOND NANOSTRUCTURES

RESEARCH TOPICS: DIAMOND-BASED DEVICES
H.A. GIRARD, E. SCORSONE, S. SAADA, C. GESSET, J.C. ARNAULT, S. PERRUCHAS*, L. ROUSEAU†, V. PICHOT‡, D. SPITZER‡, P. BERGONZO (*ÉCOLE POLYTECHNIQUE, †ESIEE-ESYCOM, ‡NS3E-ISL)
SPONSORSHIP: ANR (P3N NADIA 2008-2011)
PARTNERSHIP: ÉCOLE POLYTECHNIQUE, ESIEE-ESYCOM, NS3E-ISL, ENS CACHAN

Diamond is an outstanding material due to the combination of its mechanical, electrical, thermal, and optical properties. However, this material may be difficult to process at the micro- or nanoscale when specific scientific and technological applications require high aspect ratios or 3D structured diamond films. 3D profiles are required for instance in the design of diamond based MEMS or NEMS devices, optical systems, or also biomedical devices.

Such structures are usually fabricated using top-down approaches, mostly based on etching of a thick diamond layer through a mask such as porous alumina, Au nanodots, molybdenum or other materials. While these methods lead to well defined structures even for patterns of nanometric scale, they are not optimum in terms of efficiency since the growth of a thick diamond layer is time consuming and its post-processing can be somehow cumbersome. Hence a direct bottom-up approach would appear more appropriate, as growing a diamond film over pre-structured substrates or directly in a sacrificial mould. In that case, diamond nanoparticles, acting as seeds, will be needed to initiate the diamond growth and have to be initially deposited on the substrate.

Thanks to a new method we recently developed [1,2], we are now able to achieve extremely dense deposit of diamond nanoparticles on a substrate, allowing growth of ultra-thin diamond layers with thickness below 70 nm. This method is based on electrostatic interactions between oxygen terminated NDs with a substrate coated with a polyelectrolyte. Since this technique is based on the NDs self-adhesion as achieved from dipping, there is no limitation to obtain a homogenous deposit over 3D structures, to the wetting limits of surfaces to be coated.

Figure 7 shows silicon nanotips initially covered with diamond nanoparticles and then exposed to a CVD growth. Starting from the nanoparticles, a coalesced diamond layer is rapidly achieved, following the shape of the substrate. The homogeneity and the density of the initial deposit of the diamond nanoparticles lead to a perfect coating of the silicon nanostructures.

On Figure 8, the same procedure was applied with silicon moulds. Nanometric wells were designed in a silicon wafer by e-beam lithography and successfully covered with diamond nanoparticles. Successive CVD growths were then performed to fill with diamond these nanometric wells. After chemical dissolution of the silicon mould, perfect all diamond nanostructures were obtained, matching the dimensions of the wells with a high reproducibility.

Proofs of concept achieved in this study highlight the potentiality of the method towards development of diamond-based optical, electrochemical, sensing and biomedical devices.

References:
EARLY STAGES OF SURFACE GRAPHITIZATION ON NANODIAMONDS

RESEARCH TOPICS: DIAMOND NANOPARTICLES, SURFACE CHEMISTRY
T. PETIT, J.-C. ARNAULT, H. A. GIRARD, M. SENNOUR*, P. BERGONZO
(*MINES PARIS, PARISTECH CNRS UMR 7633, FRANCE)
PARTNERSHIP: MINES PARIS CNRS UMR 7633

Nanodiamonds (NDs) are promising candidates as metal-free catalysts or as markers and drug delivery vectors for biomedical applications. Indeed, NDs combine intrinsic properties of nanomaterials, including small sizes and high surface-to-volume ratios, with unique diamond properties such as high thermal stability and the existence of photostable color centers, associated with a controllable surface reactivity. In particular, remarkable chemical and catalytic properties have recently been reported on NDs annealed under vacuum below 900°C. Enhanced reactivity was attributed to the formation of sp2 carbon on the ND surface. Nevertheless, the corresponding graphitic structures could hardly be detected around the diamond core using high resolution transmission electron microscopy (HRTEM). Although it is now well established that on-ion-like carbon is formed by graphitization of NDs after annealing under vacuum at temperatures above 1000°C, surface transformations occurring at lower temperatures still remain poorly understood. The Diamond Sensors Laboratory at CEA LIST has shown that two different graphitization regimes occur on detonation NDs depending on the annealing temperature.

Between 700°C and 900°C, surface defects are reconstructed into graphitic structures and the diamond core remains unmodified. Above 900°C, graphitization of the diamond core is initiated. This result has been shown by performing sequential annealing treatments under ultra-high vacuum and monitoring the evolution of the surface chemistry in situ by X-ray Photoelectron Spectroscopy (XPS), which is highly sensitive to different carbon hybridizations. Fitting of the XPS carbon core level (C1s) with components related to sp3 carbon, sp2 carbon and defects after each annealing treatment revealed the temperature thresholds for surface and bulk graphitization (Fig. 1).

These results show that significant differences are observed between the surface reactivity of NDs and bulk diamond, which only graphitizes above 1600°C. The selective synthesis of a thin graphitic layer on the ND surface by annealing under vacuum at relatively low temperatures (<900°C) gives rise to hybrid nanocarbons which may combine the intrinsic core properties of diamond with the surface reactivity of sp2-based nanomaterials. The specific properties of these hybrid nanoparticles are currently under investigation at CEA LIST.

Figure 1: C1s XPS spectra of NDs after sequential annealing treatments of 3 h at (a) 700, (b) 900, and (c) 1100°C. Fitting components Cl (red), CII (green), and CIII (blue), related to sp3 C-C bonds, sp2 C-C bonds, and defects, respectively, are plotted under the experimental curves. (d) Evolution of the fractional peak areas with respect to annealing time.

References:
SENSORS & SIGNAL PROCESSING
IONIZING RADIATION METROLOGY
MAGNETIC CALORIMETER FOR THE MEASUREMENT OF HARD X-RAY EMISSION INTENSITIES

RESEARCH TOPICS: X-RAY SPECTROMETRY, CRYOGENIC DETECTORS
M. RODRIGUES, M. LOIDL, C. LE-BRET
SPONSORSHIP: LNE
PARTNERSHIP: KIP HEIDELBERG

The analysis of radioactive samples by X-ray spectrometry with semiconductor detectors is often difficult because their energy resolution is usually not good enough to separate the different X-ray lines. Metallic Magnetic Calorimeters (MMCs) can be an alternative to facilitate these analysis; they can offer both high energy resolution and high intrinsic detection efficiency from 0 to 100 keV.

MMCs are thermal detectors, i.e. the energy of each absorbed photon is measured as a temperature elevation. At very low temperature, typically few tens of mK, a very large pulse height-to-noise ratio can be obtained that is an essential condition for high energy resolution. We have designed a MMC with an energy resolution of 57 eV at a photon energy of around 30 keV. The absorber is made of gold, whose high Z provides high intrinsic detection efficiency, greater than 90 % below 60 keV. The photon emission intensities of the KX of cesium emitted by a 133Ba source were measured (figure 1.a) with this detector.

We are involved in the development of MMCs for metrology applications such as the determination of hard X-ray emission intensities emitted by radionuclides. MMCs are thermal detectors, i.e. the energy of each absorbed photon is measured as a temperature elevation. At very low temperature, typically few tens of mK, a very large pulse height-to-noise ratio can be obtained that is an essential condition for high energy resolution. We have designed a MMC with an energy resolution of 57 eV at a photon energy of around 30 keV. The absorber is made of gold, whose high Z provides high intrinsic detection efficiency, greater than 90 % below 60 keV. The photon emission intensities of the KX of cesium emitted by a 133Ba source were measured (figure 1.a) with this detector.

The preliminary quantitative measurements of relative X-ray emission intensities are in relatively good agreement with other measurements and with theoretical predictions. Moreover, the present detector shows numerous qualities compared to a HPGe detector. The energy resolution is constant and equal to 57 eV up to around 40 keV with an intrinsic detection efficiency close to unity for the K X-ray of cesium around 30 keV (table 1). For these photon energies, the response function of the detector does not show tails in the peak shape and the escape peak intensities are relatively small (table 1 and figure 1.b).

For future MMCs, it is crucial to increase the count rate for decreasing the statistical uncertainties on the measured X-ray intensities. Moreover an improvement of the energy resolution by a factor 2 would lead to the separation of the Kα lines and to a safer peak fitting process. From theoretical considerations one can expect an improvement of this energy resolution by more than a factor 2 (30 eV).

<table>
<thead>
<tr>
<th>Photon Energy (keV)</th>
<th>FWHM (eV)</th>
<th>Escape peak intensity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMC</td>
<td>HPGe</td>
<td>MMC</td>
</tr>
<tr>
<td>4.286</td>
<td>59</td>
<td>200</td>
</tr>
<tr>
<td>30.625</td>
<td>57</td>
<td>280</td>
</tr>
<tr>
<td>30.973</td>
<td>57</td>
<td>280</td>
</tr>
<tr>
<td>53.160</td>
<td>69</td>
<td>350</td>
</tr>
<tr>
<td>80.998</td>
<td>72</td>
<td>421</td>
</tr>
<tr>
<td>160.61</td>
<td>145</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. The energy resolution of the present MMC is compared with the one of a HPGe detector for different photon energies of 133Ba. The experimental escape peak intensities of the MMC are compared with the escape peak intensities of a HPGe detector.

Figure 1.

a) Final energy spectrum of the 133Ba source.
b) Spectrum of the region of K X-ray lines of cesium with the fit of the Voigt functions.

References:
A NOVEL TYPE OF ABSORBER PRESENTING A CONSTANT DETECTION EFFICIENCY FOR UP TO 25 KEV X-RAY PHOTONS

RESEARCH TOPICS: X-RAY SPECTROMETRY, CRYOGENIC DETECTORS
M. RODRIGUES, M. LOIDL, C. LE-BRET
SPONSORSHIP: LNE
PARTNERSHIP: KIP HEIDELBERG

Atomic data, nuclear data, or the composition of a radioactive source can be determined by measuring the photon emission intensities deduced from the energy spectrum delivered by an energy dispersive detector [1]. One essential condition to make precise measurements is to have an accurate calibration of the full-energy peak (FEP) efficiency, but its energy dependence makes this condition difficult to fulfill. The present work covers the development of a high-energy resolution detector (few tens of eV) having the smallest possible energy dependence of its efficiency. The photon energy range of interest lies between a few hundred eV and about 30 keV: a region where the X-ray lines are numerous and concentrated in a small energy range, making the high energy resolution of cryogenic detectors very helpful to separate them.

A novel type of absorber was conceived in order to obtain an intrinsic efficiency close to unity below 25 keV; it combines the advantages of high- and medium-Z materials. This absorber is composed of two layers: the first one is made of a high-Z material in order to reach the largest photon absorption with the smallest thickness. The second layer, whose role consists in reabsorbing the secondary photons escaping from the first layer, is made of a medium-Z material directly facing the source. Using Monte Carlo simulations, it has been demonstrated that the intrinsic efficiency of such a bi-layer absorber, made of 33 µm of silver (medium-Z) and 100 µm of gold (high-Z), has practically no discontinuities and is nearly constant below 25 keV.

A metallic magnetic calorimeter equipped with such an absorber has been realized and characterized with a 241Am source. The simulated efficiency is in agreement with the experimental data. The obtained energy resolution of 39 eV at 26 keV is not limited by anomalous absorber heat capacity or bad thermalization processes in the absorber [2]. This energy resolution is 6 times better than the best of HPGe semiconductor detectors (figure 2) and found constant up to 60 keV.

Finally, this detector combines both high energy resolution and constant intrinsic efficiency close to unity. These qualities are fundamental for precise measurements of X-ray intensities. One can already measure relative intensities without any calibration of the detector efficiency.

References:
ON THE STOCHASTIC DEPENDENCE BETWEEN PHOTOMULTIPLIERS IN THE TDCR METHOD

RESEARCH TOPICS: RADIONUCLIDE METROLOGY, TDCR LIQUID SCINTILLATION METHOD, GEANT4 SIMULATION
C. BOBIN, C. THIAM, C. CHAUVENET, J. BOUCHARD
SPONSORSHIP: LNE

Developed for radionuclide standardization using liquid scintillation, the Triple-to-Double Coincidence Ratio (TDCR) method is applied using the counting of double and triple coincidences obtained with a specific system composed of three photomultiplier tubes (PMT). The detection efficiency and the activity are determined using a statistical TDCR model of light emission. The mathematical relation between the experimental TDCR value and the detection efficiency of double coincidences is then established using the product of individual probabilities to detect at least one photoelectron in a PMT.

Using the formalism of conditional probabilities, it is demonstrated that this construction of the classical TDCR model is in fact based on an implicit prerequisite of stochastic independence between PMT countings. This condition had never been explicitly mentioned among the usual assumptions specified for the application of the TDCR model. Triple and double coincidence countings can be sensitive to stochastic dependence when the counting in a PMT is influenced by the counting due to the same disintegration in another PMT. To demonstrate it, time and geometry dependence effects have been investigated for low-energy-radiation emitting radionuclides (< 20 keV).

The influence of the coincidence resolving time was observed experimentally for the standardization of 3H (E$_{\beta_{\text{max}}} = 18.6$ keV) using the scintillation cocktail Ultima Gold. As depicted in Fig.1, the activity calculation performed with the classical TDCR model does not completely compensate for the counting variations. From the measurements carried out with various resolving times, a residual difference of about 0.5% was obtained between activities calculated at 40 ns and 250 ns [1].

The proposed explanation is that when the number of scintillation photons generated per disintegration is low, coincidence counting becomes sensitive to the time distribution of photons after the disintegration. In this case, the probability of counting a coincidence depends on the arrival time in a PMT of the first photon of the coincidence. This introduces a stochastic dependence related to time between PMTs that can cause biases in the activity calculation. This effect has been confirmed by using simulations. Finally, it has been concluded that the validity of the classical TDCR model is obtained when the resolving time is sufficiently long compared with the time distribution of photon arrivals in PMTs.

In the classical TDCR model, the possibility for coincidence countings to be affected by geometrical effects due to the location of light emission inside the vial is not considered. To investigate this phenomenon, a modeling of the TDCR counter has been developed using the Geant4 code [2] that allows the simulation of the propagation of photons from their creation to the production of photoelectrons in PMTs. The results have shown the existence of geometric dependence between PMTs for low-energy emission. This effect causes an underestimation of the activity for emitters of discrete-energy radiation. This has been experimentally verified by comparison with the activity given by the 4\(\beta\rightarrow\gamma\) coincidence method for $^{51}\text{Cr}$ (maximum energies of x-ray photons and Auger electrons between 4 keV and 6 keV).

![Figure 1. Relative deviations of the $^3\text{H}$ calculated activity value according to increasing resolving time. The reference value corresponds to 40 ns resolving time.](image1)

![Figure 2. Geometry modeling of the TDCR counter with the Geant4 code including the optical cavity with the vial surrounded by the PMTs.](image2)

References:
ENERGY-DISPERSIVE DETECTOR CHARACTERIZATION WITH SOLEX: A COMPACT TUNABLE MONOCHROMATIC X-RAY SOURCE

RESEARCH TOPICS: X-RAY METROLOGY
Y. MENESGUEN, M.-C. LÉPY
SPONSORSHIP: LNE

The X-ray metrology activities of the laboratory include detector characterization as well as elemental atomic data measurements.

One of the major issues in X-ray metrology concerns the calibration of detectors. For many element analysis techniques using X-ray fluorescence (XRF), energy-dispersive detectors such as GeHP, CdTe, Si(Li) or more recent SDD type detectors are used. Accurate quantitative results depend on the detector efficiency calibration. Efficiency calibration needs an X-ray photon source of well-known fluence rate which is not so common. The intensities of X-rays emitted by radionuclides have uncertainties not better than 2% even for the widely used $^{57}$Fe radionuclide. They rely on databases of fluorescence yields $\omega_{KL}$ and $\omega_{KL}$ probabilities, and fluorescence yields are subject to uncertainties of several percent. Moreover, very few radionuclides produce predominantly X-rays and so, few energies are accessible. A better knowledge of these intensities would help but experimental techniques need well-calibrated detectors. For these reasons, having an independent technique to calibrate X-ray energy-dispersive detectors is of high interest.

The Source Of Low-Energy X-rays (SOLEX) of LNHB produces a monochromatic X-ray beam in the 0.6–28 keV energy range. It is composed of an X-ray tube as photon source together with a monochromator crystal (Table 1). Both of them are motorized so as to select the incidence angle and satisfy the Bragg law and therefore select the energy of the outgoing photons. Two beam outputs are selectable allowing us to lead the monochromatic X-ray beam on two detectors for comparisons. Dedicated signal processing, amplifying systems and multichannel analyzers are used to record the spectra. The second position is permanently equipped with a gaseous proportional counter which is used as an absolute flux measurement instrument [1]. An example of absolute efficiency calibration of an energy-dispersive detector is given in Fig. 1.

Table I. Monochromator crystals

<table>
<thead>
<tr>
<th>Crystal</th>
<th>$E_{\text{min}}$ (eV)</th>
<th>$E_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsAP (001)</td>
<td>570</td>
<td>1996</td>
</tr>
<tr>
<td>Mica (002)</td>
<td>745</td>
<td>2626</td>
</tr>
<tr>
<td>Béryl (101)</td>
<td>919</td>
<td>3163</td>
</tr>
<tr>
<td>InSb (111)</td>
<td>1964</td>
<td>6809</td>
</tr>
<tr>
<td>LiF (200)</td>
<td>3639</td>
<td>12493</td>
</tr>
<tr>
<td>Quartz (11 (2))</td>
<td>4086</td>
<td>14597</td>
</tr>
<tr>
<td>LiF (220)</td>
<td>5136</td>
<td>17978</td>
</tr>
<tr>
<td>Si (400)</td>
<td>5472</td>
<td>19307</td>
</tr>
<tr>
<td>Quartz (13 (40))</td>
<td>6222</td>
<td>20760</td>
</tr>
<tr>
<td>LiF (420)</td>
<td>8121</td>
<td>28429</td>
</tr>
</tbody>
</table>

Figure 1. Absolute efficiency of a Si(Li) spectrometer

References:
NEW REFERENCES IN TERMS OF ABSORBED DOSE TO WATER IN MV X-RAY BEAMS FOR SMALL RADIATION FIELDS

RESEARCH TOPICS: METROLOGY FOR MODERN EXTERNAL BEAM CANCER THERAPY
SPONSORSHIP: LNE, ERA-NET PLUS

For external radiotherapy, the hospital reference ionization chambers are calibrated in reference conditions in fields of 10x10 cm². Much smaller fields are used in the new treatment modalities. However, the calibration coefficient ($N_{DW}$) of the ionization chamber (IC) varies with beam size. One of the work packages of the Euramet project “External Beam Cancer Therapy” was dedicated to the realisation of references in terms of absorbed dose to water under intensity modulated radiation therapy conditions (IMRT). LIST/LNHB established references of absorbed dose to water for different beam energies, 6 MV Flattening Filter Free (FFF), 6 MV, and 12 MV, of the LNHB linear accelerator and different beam sizes (4x4 cm² and 2x2 cm²) [1].

The LNHB reference of absorbed dose to water is based on graphite calorimetry. A graphite calorimeter measures the elevation of temperature due to the irradiation of its inner part, the core. For the measurements in the 2x2 cm² field size, a new smaller graphite calorimeter had to be built [2]. Commercial ICs of small sizes had also to be tested in order to choose a well suited reference IC [3].

The ratio between absorbed dose to water and absorbed dose to graphite is calculated with Monte Carlo codes (EGSnrc and PENELOPE). The absorbed dose to water is then derived from the relation with $D_{w} = D_{core} \left( \frac{D_{w}}{D_{core}} \right)_{EGSnrc} \cdot \prod_{k}$.

The absorbed-dose-to-water ratios were calculated by Monte Carlo and correspond to the product of correction factors.

Monte Carlo calculations were experimentally validated. Dosimeters are alternatively irradiated in the graphite and water phantoms. Then, the ratio of the measured absorbed doses in the dosimeters in both phantoms is compared to the ratio of the equivalent Monte Carlo calculations (simulation of the dosimeters). Alanine dosimeters, read using an Electronic Spin Resonance spectrometer, were used for this purpose as the alanine pellets are of small sizes (Ø 0.5 cm).

The standard uncertainties (k=1) on the reference IC $N_{DW}$ lie between 0.33 to 0.46%.

For an Exradin A1SL ionization chamber, the ratios between $N_{DW}$ in a small beam and $N_{DW}$ in the 10x10 cm² beam are shown in figure 1 as a function of the beam energy and the beam size. Between 10x10 cm² and 2x2 cm², the effect is less than 0.5%.

At the end of the project, PTB (Germany) and LNHB compared their newly developed absorbed-dose-to-water references based respectively on water calorimetry and on graphite calorimetry [4]. They were in agreement within 1.5 standard deviations from 10x10 cm² fields to 2x2 cm² and for beams of 6 to 10 MV (Fig. 2).

References:
LOW-ENERGY X-RAYS FOR CONTACT THERAPY - PAPILLON 50

RESEARCH TOPICS: DOSIMETRY FOR LOW-ENERGY X-RAYS USED IN CONTACT THERAPY

J.M. BORDY, M. DENOZIERE, J. PLAGNARD, N. LECERF, J. GOURIOU, E. LEROY, V. LOURENCO

SPONSORSHIP: ANR

PARTNERSHIP: CENTRE ANTOINE LACASSAGNE, UNIVERSITÉ NICE SOPHIA ANTIPOLIS, ARIANE MEDICAL SYSTEM, DOSISOFT.

A treatment unit named “Papillon 50” is used in the department of radiotherapy of the Centre Antoine-Lacassagne, Nice, France. This unit emits a continuous bremsstrahlung X-ray spectrum lying up to 50 keV; it is currently used associated with applicators of different diameters and shapes to treat rectal cancers. The same unit can be used for other superficial localizations up to 1 cm depth such as tumor bed after local surgical excision (breast) or skin cancers. Due to the use of low-energy photons, the contact therapy modality enables delivering high doses to the tumor protecting healthy tissues around it. The goal of the ANR project “Papillon 50”, launched in 2009, was to provide an accurate evaluation of the doses delivered to the tumor.

Reference doses, for a given radiation quality, are provided in terms of air kerma. They are used to calibrate dosimeters such as ionization chambers. Then, these dosimeters are used to calibrate the radiation field emitted by the treatment unit. Finally, the absorbed dose to the tumor is calculated through depth dose curves. Such a procedure insures the traceability of the absorbed dose to the tumor to the primary standards. LNHB has worked on the first step.

For dosimeter calibration purposes, the radiation quality must be as close as possible to the one emitted by the treatment unit. It was measured using a CdTe spectrometer with an additional collimator to account for a very high radiation flux (Fig. 1).

The measured spectrum is different from the spectrum emitted by the treatment unit because of photon scattering in the spectrometer and the steep variation of the detector sensitivity (Cd and Te K-shell absorption edges). As there is no unfolding software to derive the emitted spectrum for a continuous bremsstrahlung spectrum, two Monte Carlo models of the measurement set up were used: one including the spectrometer, one without the spectrometer. The first model allows comparing the calculated and measured spectra in order to validate the model. Once this validation is achieved, as can be seen in Fig. 1, the second model allows calculating the X-ray spectrum, unperturbed by the spectrometer. The Monte-Carlo codes used for this study were PENELOE and MCNP5.

Three radiation qualities, already used for international comparisons with BIPM, were chosen to calibrate the ionization chambers. As can be seen on figure 2, the CCR50(b) spectrum is similar to the experimental one. The CCR30 and CCR50(a) spectra being under and above CCR50(b), they allow checking the variation of the calibration coefficient with radiation quality. This variation should not be too large. The largest deviation in terms of calibration coefficient between these 3 radiation qualities was less than 3.2% for a PTW 23342 ionization chamber. Compared to 1.5% (k=1) of uncertainty on the calibration coefficient, this deviation is found acceptable.

References:
NEW LNHB PRIMARY STANDARDS FOR THE CALIBRATION OF $^{125}$I BRACHYTHERAPY SEEDS

RESEARCH TOPICS: DOSE METROLOGY
I. AUBINEAU-LANIECE, J. PLAGNARD, D. CUTARELLA, J. GOURIOU, B. CHAUVENET
SPONSORSHIP: LNE, ERA-NET PLUS

CEA/LIST/LNHB is developing standards in terms of reference air kerma and absorbed dose to water dedicated to the calibration of $^{125}$I brachytherapy seeds that are used for the treatment of ophthalmic and prostatic cancers.

The manufacturing process of the complex and miniaturised brachytherapy seeds leads to geometrical asymmetries within each seed and to a lack of reproducibility from one seed to another. In that context, prior to the standards developments, a full characterisation of the $^{125}$I IBt Bebig I25.S16 brachytherapy source was performed [1]. The seed dimensional variations were characterised using X-ray images (Table 1). The photonic emission anisotropy was measured using a Si-PIN detector, and a sensitivity study was performed based on Monte Carlo calculations of the absorbed dose to water distribution due to seed dimensional variations.

The primary standard is based on a circular-shaped free-air ionization chamber (Fig. 1) and Monte Carlo calculated conversion factors. This innovative design is aimed at accounting for the brachytherapy seeds emission anisotropy in the transverse plane. The overall diameter of the chamber is about 1 m. The components dimensions and geometries enable the calibration of sources that emit photons of energies up to about 150 keV ($^{125}$I emits photon with energy less than 35 keV).

According to the dosimetric quantity to determine, reference air kerma or absorbed dose to water, the iodine seed is respectively either held in a low attenuating Kapton tube or inserted at the center of a 1 cm radius equivalent water sphere (Fig. 2).

The transfer from the experimental configuration to the reference one (according to the dosimetric quantity to assess) is ensured by the appropriate conversion factors calculated using Monte Carlo simulations.

Such standards allow to assess the reference air kerma and the absorbed dose with an uncertainty of typically 1.5% and 1.6% (k=1).

This work was carried out in the frame of the project “Brachytherapy”, part of the ERA-Net plus action iMERA+ involving the European national institutes of metrology and their association EURAMET. Comparisons with the standards developed by partner laboratories (PTB, ENEA) are ongoing.

References:
ASSESSMENT OF SMALL VOLUME IONIZATION CHAMBERS AS REFERENCE DOSIMETERS IN HIGH-ENERGY PHOTON BEAMS

RESEARCH TOPICS: DOSE METROLOGY
M. LE ROY, L. DE CARLAN, F. DELAUNAY, M. DONOIS, P. FOURNIER, A. OSTROWSKY, A. VOUILLAUME, J.M. BORDY
SPONSORSHIP: LNE, ERA-NET PLUS

LIST/LNHB is in charge of the French national absorbed-dose-to-water standards for radiation therapy. While current standards and dosimetry protocols are based on a radiation field of 10x10 cm², new radiation therapy modalities use much smaller fields (down to 4 mm in diameter) to better target tumours.

In order to reduce the gap between standards and clinical practices, LNHB developed primary standards in MV photon radiation beams for fields down to 2x2 cm².

Once primary standards are established, an ionization chamber is calibrated in terms of absorbed-dose-to-water. This chamber then becomes the LNHB working standard that enables the calibration of ionization chambers used in hospitals.

Typical cylindrical ionization chambers used in 10x10 cm² fields (0.6 cm³ sensitive volume) are too large to be used in 2x2 cm² fields. Therefore, a new type of ionization chamber with suitable size had to be selected among the commercially available small-volume ionization chambers[1].

Eight different types of small-volume cylindrical ionization chambers, coming from three manufacturers (PTW, IBA and Exradin), were tested. Their sensitive volume goes from 0.057 to 0.007 cm³. For each type, 2 to 4 chambers were investigated.

Chambers were irradiated in a continuous 60Co photon beam. Two main characteristics were studied:
- the stability under continuous irradiation,
- the variation of the ionization current as a function of applied polarization voltage.

1. STABILITY UNDER CONTINUOUS IRRADIATION
To be suitable as a LNHB working standard, the variation of the measured current should not be greater than ± 0.1% over a 16 hours irradiation time.

All PTW and the Exradin A1SL chambers showed a satisfying stability under irradiation. For other types, at least one chamber showed a current variation of more than ± 0.1%.

2. VARIATION OF THE IONIZATION CURRENT AS A FUNCTION OF APPLIED POLARIZATION VOLTAGE
To be suitable as a LNHB working standard, the chamber saturation curve must have a behaviour corresponding to the ionization-chamber regime, for which the absolute value of the current increases with applied voltage, for both polarities [Fig.1].

The IBA CC01, IBA CC04 and Exradin A1SL chambers showed a proper response as a function of applied voltage for both polarities; PTW chambers showed the expected response only for positive voltages [Fig.2]; Exradin A14SL and A16 had an unsatisfying response for both polarities.

CONCLUSION
Among the small-volume chambers tested, all the Exradin A1SL, one IBA CC04 and one IBA CC01 were suitable to be used as working standards at LNHB. As a result, an Exradin A1SL chamber was chosen as the working standard for 2x2 cm² irradiation fields.

This work was carried out as part of the European metrology research project “External Beam Cancer Therapy”, in the frame of the ERA-NET Plus action “IMERA+” involving the European national metrology institutes and their association EURAMET.

References:
SMALL SECTION GRAPHITE CALORIMETER (GR-10) AT LNE-LNHB FOR MEASUREMENTS IN SMALL BEAMS FOR IMRT

RESEARCH TOPICS: DOSIMETRY METROLOGY

J. DAURES, A. OSTROWSKY AND B. RAPP

SPONSORSHIP: LNE

CEA/LIST/LNHB is the French metrology laboratory for ionizing radiation particularly in charge of the dosimetric standards. Graphite calorimeters are among the best primary instruments to realize the unit of absorbed dose. Within the Euramet JRP7 project External Beam Cancer Therapy, a work package was dedicated to the primary standards for IMRT (Intensity Modulated Radiation Therapy). New forms of therapy with ionizing radiation like Intensity Modulated Radiation Therapy, Tomotherapy and related techniques have led to substantial improvements of the conformity of tumour and dose distribution. At the same time the dosimetry for these new techniques lacks traceability. A wide range of new traceable methods of measurement will be developed and put at the disposal of the medical physicists in the clinics.

This new radiotherapy modality uses small field sizes which do not ensure the lateral secondary electron equilibrium.

The variation of the response of the ionization chamber of the user with the size of the beam, and consequently the calibration coefficient has to be evaluated. This variation could be due to the change of the electron spectrum. The response of the graphite calorimeter is independent of the electron spectrum for it measures directly the deposited energy avoiding the knowledge of W/e (mean energy expended in air per ion pair formed per unit charge) and the average interaction coefficients on the photon and electron spectra. Then the graphite calorimeter is used within this study as primary standard.

The existing GR-09 graphite calorimeter has been successfully used for the beam sizes of 10x10 and 4x4 cm² whereas it was not small enough to perform measurements in the 2x2 cm² beam size. Therefore, during the project a small section graphite calorimeter, GR-10, has been developed. The conception and the tests of this calorimeter were presented at the final conference of the European project [1] and published in the BIPM metrology journal [2].

The new calorimeter is presented figure 1. The scheme of the central part (dimensions in mm) is given on the top part with the corresponding radiography below. On the left the photography of the core (sensitive element) with the 3 Kapton tubes for support and the thermistors wires (4 pairs).

As a final test, measurements were performed with both calorimeters in a cobalt-60 beam and 12 MV high energy photon beam at LNHB facilities. The beam size was 10x10 cm² were both calorimeters can perform measurements without edges problems. The results are summarized in table 1.

The results of the measurements with the GR-10 graphite calorimeter in the 2x2 cm² in the frame of the JRP7 project have been reported during the Conference on Advanced Metrology for Cancer Therapy CAMCT 2011 [1] and will be the subject of another publication.

Table I. Comparison of GR09 and GR10 graphite calorimeters

<table>
<thead>
<tr>
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<th>GR-09</th>
<th>GR-10</th>
<th>GR-10 /GR-09</th>
</tr>
</thead>
<tbody>
<tr>
<td>60Co measurements</td>
<td>39.35</td>
<td>39.36</td>
<td>1.0083</td>
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<tr>
<td>Gy/h</td>
<td>0.05</td>
<td>0.18</td>
<td></td>
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<tr>
<td>12 MV measurements</td>
<td>1.4045</td>
<td>1.4038</td>
<td>0.9995</td>
</tr>
<tr>
<td>Gy/a.u.</td>
<td>0.08</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>γ-Co simulations</td>
<td>2.245</td>
<td>2.244</td>
<td>0.9996</td>
</tr>
<tr>
<td>Gy-cm²/a.u.</td>
<td>12</td>
<td>10</td>
<td></td>
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<tr>
<td>0.07</td>
<td></td>
<td>0.08</td>
<td></td>
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<tr>
<td>12 MV simulations</td>
<td>1.086</td>
<td>1.085</td>
<td>0.9990</td>
</tr>
<tr>
<td>Gy-cm²/a.u.</td>
<td>10</td>
<td>10</td>
<td></td>
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<tr>
<td>0.09</td>
<td></td>
<td>0.09</td>
<td></td>
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</tbody>
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a.u means arbitrary unit which are different for the measurements and the simulations

Figure 1. LNE-LNHB graphite calorimeter GR10

References:
DEVELOPMENT AND EXPERIMENTAL VALIDATION OF A TPS SOFTWARE TO DETERMINE THE DOSE OUTSIDE THE RADIATION BEAM

RESEARCH TOPICS: RADIOTHERAPY, SIMULATIONS
I. BESSIÈRES, B. POUMARÈDE, J.M. BORDY (LIST/LNHB)
SPONSORSHIP: OSEO INSPIRA

In the fight against cancers, radiotherapy remains the most powerful and widespread technique. Even if the new IMRT modality allows a more accurate definition of the target volume, low doses are still delivered to organs at risk around the tumour (see Figure 1). Epidemiological studies demonstrated the relationship between peripheral doses and second cancers or heart diseases. Many experimental studies measuring the variation of the peripheral dose with the treatment parameters have been undertaken. Up to now, very few studies have been performed on out-of-field Monte Carlo (MC) simulations. To our knowledge, MCNPX is the only one MC code that has been used to simulate the peripheral dose in radiotherapy. Nowadays, there is thus no specific and accurate tool predicting the peripheral dose.

The aim of our work is to develop a MC tool to compute the dose at the target volume and at the organs at risk in order to enable a decrease of the peripheral dose by adapting the treatment’s parameters. This tool will be implemented in a TPS (Treatment Planning System).

The first step consists in validating the out-of-field MC calculations, using a comparison with measurements in a specific large water tank. The PENELOPE MC (Monte Carlo) code has been parallelized to save computation time by running the calculations on a cluster of 84 processors.

To validate the simulations results, OSL (Optically Stimulated Luminescence) dosimeters made of Al₂O₃:Ca and reference ionization chamber (NE2571) were used. Irradiation has been done at LNHB (French Primary Standard Laboratory for ionising radiations) on a GE Saturne 43 accelerator at the 6, 12 and 20 MV qualities.

Four main factors are applied to the raw reading of the OSL measurements: particular sensitivity for each OSL, the measured calibration factor, air calibration factor Dwater/Kair correcting the fact that the calibration has been done in air whereas the measurements have been performed in water and finally the energy dependence correction factor. Indeed, we measured a high over-estimation of the dose (by a factor 3 or 4) for photons with low energy (< 100 keV). Consequently, we developed an energy dependence correction protocol. It combines the results of the experimental over-response curve with PENELOPE spectra calculations at measurement points.

Figure 2 shows out-of-field dose profiles at reference depth (10 cm) for MC calculations, ionization chamber and OSL measurements. The doses are normalized to the maximum of dose. Considering that the ionization chamber dose is the reference value, one can observe a good agreement with the OSL and the MC results.

The next step is the clinical validation with the OSL dosimeters within an anthropomorphic phantom and with an IMRT step-and-shoot treatment plan. At the same time we are working on the acceleration of the calculations. The implementation of reduction variance techniques such as DXTRAN in the MC tool should be helpful to increase calculation efficiency out of the beam.

References:
[2] Bessières I., « Développement et validation expérimentale d’un logiciel de planification de traitement pour la détermination de la dose corps entier en radiothérapie » Rencontres Jeunes Chercheurs 2010
Development and Commissioning of Monte Carlo Models of 6 and 18 MV Photon Beams Using PENELOPE and GATE Codes

Research Topics: Radiotherapy, Simulations

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(*Centre François Baclesse Caen, Centre Léon Bérard – Creatis, Lyon)

Sponsorship: OSEO INSPIRA
Partnership: CLCC F. Baclesse Caen, Creatis Lyon, Siemens

Monte Carlo (MC) simulations currently allow accurate calculation of the dose delivered to patients in radiotherapy treatments, provided that the medical linear accelerator (linac) delivering the irradiation beam can be modelled accurately. The commissioning step consists in verifying that the MC linac model well reproduces the actual beam physical characteristics, and is hence of the utmost importance.

This work aims at developing and commissioning a MC model for the 6 and 18 MV photon beams of an ARTISTE linac (cf Figure 1), the most recent linac commercialized by Siemens Medical Solutions to perform innovative intensity-modulated radiotherapy treatments (IMRT). The MC modelling of the beams is the first step towards the use of MC simulations for more complex radiotherapy applications.

Two MC codes were used to develop the models: PENELOPE, which is considered as a reference code in external radiotherapy, and GATE v6.0, a MC code initially dedicated to nuclear medicine applications but which recently included new modules enabling simulations for radiotherapy applications. Both codes are optimized for radiotherapy purposes and include commonly used variance reduction techniques. The goal of this work is also to assess the GATE capabilities for radiotherapy by comparing its performances with PENELOPE.

Experimental data required by the commissioning were acquired, i.e. percentage depth doses (PDD) and lateral dose profiles measured in a water tank (large MP3, PTW) with a PTW Semiflex 0.125 cm³ ionization chamber, at dmax, 5 and 10 cm, and for field apertures from 5x5 to 30x30 cm² at a source-to-surface distance of 100 cm. PDDs and lateral profiles were then simulated using both MC codes. The linac geometry was described in the simulation based on the manufacturer specifications. The main parameters defining the incident electron beam (mean energy, radial intensity distribution) were determined following the methodology suggested by Pena et al (Med. Phys. 2007), using PDDs and lateral profiles of the 5x5, 10x10 and 30x30 cm² fields. The incident electron beam was assumed to be monoenergetic and monodirectional. Dose computations in the water phantom were performed with a 4 mm voxel size in all directions.

At depth greater than dmax, simulated PDDs with GATE and PENELOPE both agreed with measurement to better than 1% for 6 and 18 MV. At shallower depths, both MC codes underestimated the measured dose. Lateral profiles matched measured ones within 1%/1 mm at 6 MV and within 2%/2 mm at 18 MV, for both codes. For field sizes larger than 25x25 cm², larger discrepancies are observed: the influence of the initial electron energy distribution is investigated.

The good agreement obtained between measured and simulated dose distributions ensures the validity of the developed MC models for further applications. These results also demonstrate the ability of the new GATE v6.0 release to accurately model radiotherapy photon beams, with an efficiency equivalent to that of PENELOPE. This MC model of the ARTISTE will then be used for several radiotherapy applications currently under development in our team, namely the development of a MC-based quality control tool for commercial TPSs, and the development of strategies for the dosimetric verification of IMRT treatment plans using portal imagers.

References:
PHOTOACTIVATION THERAPY WITH HIGH-Z NANOPARTICLES:
MODELLING AT A MICROMETER SCALE AND EXPERIMENTAL COMPARISON

RESEARCH TOPICS: Radiotherapy, Simulations
R. Delorme, M. Agelou
SPONSORSHIP: ANR RAPHAELO
PARTNERSHIP: ESRF, CEA DSM/INAC

An innovative approach using X-ray interactions with heavy elements seems to open a promising way of treatment for resistant cancers, such as high-grade gliomas. Such a technique is developed at the medical beam line of ESRF using monochromatic X-rays in the 50-100 keV range for the treatment of brain tumors. The use of gold nanoparticles (GNP) to treat mice bearing subcutaneous tumors led to encouraging results. However, the physical processes and biological impact of the photon activation of nanoparticles are not well understood. The experimental results cannot be explained from macroscopic dose calculations.

The aim of our work is to evaluate, at the cellular level, the dose enhancement in presence of nanoparticles and the properties of the secondary electron production using the Monte Carlo transport code PENELOPE. Those secondary electrons are expected to be the cause of the radiosensitization of the cells.

At first, upstream studies were done around the behavior of GNP under irradiation. The mean range, yields and spectra of electrons produced from the interactions of X-rays with a GNP were calculated for 8 to 100 nm diameter GNP when irradiated with monochromatic photons from 30 keV to 2 MeV. The dose enhancement was calculated in water at one micrometer around the GNP (Figure 1).

An increase of electron production by a factor 5 to 100 is observed in presence of GNP, for energies from 2 MeV to 30 keV respectively. The mean energy of the produced electrons increases with the beam energy, except after the K-edge of gold because of an enhancement of interactions with deeper atomic shells. An auto-absorption of low energy electrons for GNP with larger diameters is also observed.

On another hand, dose calculations were done in a cellular geometry containing Gadolinium-water mixture in order to compare with experimentations realized on the ID17 beamline of ESRF by our INSERM partners. Clonogenic assays have been performed on F98 cells to measure the “Sensitive Enhancement Ratio” (SER) at 4 Gy, for several irradiation energies (31 to 80 keV). SER is a measurement of the biological effect obtained by dividing the cell survival rate in the control sample by this rate in presence of Gdolium for the same absorbed dose. From the comparison of the calculated dose enhancement with the measured SER, some coherent tendencies (Figure 2) can be observed but in-depth studies are still required.

In the near future, we plan to calculate the dose in a cellular geometry considering multiple nanostructures using another Monte Carlo code, Geant4, because of its flexibility and its ability to handle simulations with large numbers of objects.

References:
FLEXIBLE AND VERSATILE EDDY CURRENT PROBES

RESEARCH TOPICS: NON DESTRUCTIVE TESTING, EDDY CURRENT PROBES
SPONSORSHIP: B. MARCHAND, JM. DECITRE, O. CASULA
PARTNERSHIP: STATICE

Non Destructive Testing (NDT) brings solutions to inspect the integrity of components in various domains such as aeronautics, nuclear energy, rail or petrochemical industry. NDT consists in combining simulation, inspection and analysis in order to detect structure defects. Electromagnetic, ultrasonic or X-rays methods are used according to the type of defects (flaws, notches…), of materials and component geometry.

Design of EC flexible array probes aims at increasing the number of sensors, enhancing the sensitivity and speeding up the inspection, in order to bring reliable and adaptable solutions for industrials needs. The simulation platform CIVA dedicated to NDT is a powerful tool that helps designing and optimizing EC probes. It also allows signal processing and analysis from computed or experimental data. Recent modules have been added so that it is now possible to simulate multi-layers arrays based on circular or rectangular coils. These sensors can be defined as emitter, receiver or both, depending on their wiring. After been clustered, they are activated at various frequencies, within specific sequences. Figure 1a gives a pattern example of an EC array design. Coils are put into two matrices (five rows, three columns) which are set on two layers. Coils on the first layer are defined as emitter when those on the second layer are receivers. Five sequences are used to activate all elements (composed with one emitter and one receiver) of the array. Coupling between elements is taken into account. The sensitivity of the probe is evaluated using a through notch, 5mm long, 0.15 mm width, located into an Inconel mock-up plate which thickness is 1mm. This defect is perpendicular to the scan direction. A screenshot of the calculated response of the defect at 1 MHz is given in Figure 1b.

In 2011, a new EC probe has been developed at CEA LIST to bring an adapted solution to the largest number of applications [1,2]. Then, the spatial resolution, the number and size of the sensors is optimized regarding the application.

This is possible since the embedded electronics is compatible with different numbers of sensors. Furthermore, the shape of the mounting can be changed depending on the geometry of the inspected surface (plate, curvatures with various diameters…)

Figure 2a is a photo of the new EC probe and Figure 2b is a photo of a 96 elements flexible film mounted on a flat configuration. The array is a matrix of 4 lines x 24 columns which spatial resolution is 350µm and its scan width is 34mm. Thanks to the flexibility of the film, the sensors keep in good contact with the inspected surface during the scan which greatly reduces lift-off noise and increases significantly SNR. The probe can be manual or mechanical used.

The performances of the 96-elements EC probe has been evaluated at CEA LIST using an aluminum plate in which three surface notches (L=1mm, W=0.1mm, H=0.2mm/0.4mm/0.8mm) have been electro-eroded (typical aeronautic application). Figure 3 is the experimental CSCAN, perpendicular to the flaws orientation.

The three defects are detected with a good SNR and the amplitude of their signature depends on their depth, as expected by the simulation. Furthermore, thanks to the high spatial resolution of the probe the length of the notches can be evaluated.

References:
CHARACTERIZATION OF CORROSION PRODUCTS IN REINFORCED CONCRETE BY X-RAY μCT

RESEARCH TOPICS: X-RAY TOMOGRAPHY, IMAGE PROCESSING, MATERIAL SCIENCES
A. VABRE, V.L. HOSTIS
PARTNERSHIP: DEN/LECBA

Reinforced concrete is a composite material composed of concrete and steel, which combines resistance qualities in compression as well as tension. Those properties are affected by the formation of corrosion products attached to the steel. This results in a volume expansion of the steel that induces cracks inside the structure.

A non-destructive measurement method to quantify the volume of corrosion products is X-ray tomography. This technique allows obtaining material maps of a sample from external measurements.

X-ray tomography acquisitions are carried out in the lab on aged samples of reinforced concrete that contains corroded steel, as shown on figure 1.

Based on tomographic reconstructions, a first image analysis consists in thresholding grey levels to separate the different materials, as shown on figure 2.

This simple technique presents the disadvantage to be manually adjusted to identify thresholds and then materials. This step is approximate and is a problem to be quantitative.

In order to improve robustness, we studied a method of automatic segmentation based on fuzzy logic. Fuzzy models have the ability to process ambiguous data and are proposed to improve the process of choosing optimal thresholds for segmentation. These works have been developed by Lin and Lee.

The method based on fuzzy logic is compared to the thresholding one and the obtained segmentation results are very similar, see figure 3.

The entire volume of the sample has been processed, the different types of materials are estimated and the calculated expansion is presented on figure 4.

It is observed a moderate expansion of the order of 5 to 15% at the interface between steel and concrete. We note that the expansion is the greatest at the center of the specimen.

To conclude, the method of X-ray tomography, coupled to two segmentation methods were used to characterize the expansion of the studied reinforced concrete. Implementation of an automated method to ensure a quantitative estimate of this parameter was also tested.

References:
A. Vabre, V. L’Hostis, Caractérisation de produits de corrosion dans le béton armé par une méthode de micro-tomographie X, 9ème Colloque Rayons X et Matière, RX 2011, Tours, France, 2011.
CT RECONSTRUCTION FROM A SMALL NUMBER OF PROJECTIONS

RESEARCH TOPICS: X-RAY TOMOGRAPHY, RECONSTRUCTION ALGORITHMS
H. WANG, M. COSTIN, S. LEGOUPIIL

The CIVA CT module includes both the simulation of x-ray projection data and the reconstruction of these projections into a volume. The sample, the X-ray source, the detector, the trajectory and all the simulation parameters are all defined in a CT scene as illustrated in figure 1.

The first reconstruction algorithm implemented in the module was the classical FDK (Feldkamp-Davis-Kress) algorithm. In parallel innovative CT reconstruction algorithms are developed which are progressively included in the CIVA CT module. The work reported here concerns the reconstruction of projection data obtained through simulations. An important aspect in CT is the high radiation dose, directly proportional with the number of acquired projections. In medical applications this is a critical issue and therefore there is a tendency to reduce it. In the case of NDT/NDE the impact is lower, but nevertheless a high dose could eventually lead to a damage of the sample. Moreover, in the two cases the lifetime of the CT systems could be improved with shorter acquisitions. In this context, we develop reconstruction algorithms which use a lower number of projection images as input and provide accurate results.

In these cases the mathematical problem of inversion is ill-posed and generally the problem is transformed to a minimization solved by an iterative algorithm.

We present here two new methods which have been recently implemented [1]:
1. PixTV. This algorithm uses a pixel-driven projector and a ray-driven back-projector and includes a regularization step with a TV (total variation) norm.

2. SparseTV. This method uses an irregular grid to describe the imaged object and uses adapted forward- and back-projection operators. An adapted TV regularization is applied.

Figure 2 presents a comparison between the new methods and the classical method FDK. The complete data set consists of 512 projections with a flat panel detector of 512 x 512 pixels with a pitch of 200µm. We present the reconstructions from 32 equi-distributed projections, extracted from the full data set.

While the FDK algorithm shows important artifacts, the two new algorithms give excellent results, very close to the ideal image represented on the profile plots by the black line (ref).

Figure 1. CIVA CT scene.
Figure 2. Reconstructions and profile plots (along the dashed line) with three algorithms: (a) FDK, (b) PixTV, and (c) Sparse TV.

References:
X-RAY MULTI-ENERGY COMPUTED TOMOGRAPHY (MECT) RECONSTRUCTION BASED ON REFERENCE MATERIAL DECOMPOSITION

RESEARCH TOPICS: TOMOGRAPHY, X-RAY, BAYESIAN ESTIMATION
CAIFANG CAI, SAMUEL LE GOUPI
PARTNERSHIP: SUPELEC-L2S

In traditional X-ray Computed Tomography (CT), a single energy is used for the data acquisition. One can only distinguish materials from their X-ray attenuation coefficients reconstructed from the measurement. Multi-Energy Computed Tomography (MECT) makes it possible to get more internal information about the object besides the attenuation coefficients. The basis material decomposition model indicates that from measurements at multiple energies, one can get fraction images of several reference materials. With a base of well-chosen reference materials, these fraction images can represent similar results compared with segmentation results but with no loss of information.

In this frame, we propose a Bayesian reconstruction approach [1]. This approach allows to get high quality fraction images from measurements at multiple energies in spite of the presence of noise and incomplete measurements. The principle of the proposed Bayesian approach is based on a Gaussian observation model. It solves the reconstruction problem as a non-linear inverse problem. By using the Maximum A Posteriori (MAP) estimation method, it transforms the reconstruction problem into an optimization problem which is solved iteratively by an optimization algorithm.

We applied the proposed approach on the experimental data obtained with a part of vertebral column embedded in resin, as shown in Fig.1.

The resin has similar properties upon X-ray beams than soft-tissue of human bodies. By using water (close to soft-tissue) and hydroxyapatite (HA), which is the major component in bone, as the reference materials, the proposed approach can get two separate fraction images. A section of the reconstruction results are shown in Fig. 2.

We can see, first, the fraction images of water and HA reconstructed by the proposed approach give respectively the resin background and the vertebrae internal structures. In traditional CT, they could only be obtained by applying further segmentation methods on the reconstruction result. Second, the coefficients of the fraction images qualitatively represent the attenuation ratios of the material contained in the object in respect to water and HA. For example, for the spinal bone located in center, its water fraction is around 0.8 and its HA fraction is around 0.45. This means that the spinal bone presents the same attenuation property upon X-ray beams compared with the material that prepared by mixing 0.80 volume of water and 0.45 volume of HA in a unit of volume.

References:

Fig.1: part of vertebral column in resin.

Fig.2: water (left) and HA (right) fractions (right)
TOWARDS A 3D STATISTICAL FLAW DETECTION METHOD IN CASTINGS USING FEW RADIOGRAPHIC PROJECTIONS

RESEARCH TOPICS: FLAW DETECTION IN CASTINGS, X-RAY RADIOGRAPHY
I. BEN TEKAYA, S. SEVESTRE, F. BUYENS
PARTNERSHIP: INSA-LYON CREATIS

Flaw detection in light alloy castings is crucial for automotive industry. X-ray radiography is used to detect inner casting flaws such as porosities and inclusions. Computed Tomography (CT) could allow efficient 3D localization of defects. Nevertheless, one major drawback of tomography is the large number of projections needed (>100), which increases the time of inspection.

To overcome this limitation we have developed a new method requiring a small number of radiographic projections (< 10). It uses the numerical model of the inspected piece, usually available in casting applications, to simulate flawless reference projections. These projections are then subtracted to the projections to be processed and statistical detection is applied. In a first step a geometric calibration step has to be applied to correct the misalignment induced by measurement errors.

We propose a calibration method that needs no dedicated calibration phantom. An iterative algorithm involving the minimization of a cost function is applied. Amongst the cost functions which have been tested, the most satisfying results are obtained using the Sum of Squared Distances (SSD) and Pattern Intensity (PI) functions. The minimization is obtained using FSQP algorithm.

The proposed calibration approach has been validated for the fan-beam geometry presented in Fig.1. Noisy projections have been simulated with known values of the geometry (8 parameters), and the calibration method has been applied to find these values starting from random approximations. The results of 50 tests are given in the Fig.2, where the percentage of successfully recovered parameters (i.e. with final absolute error < 1mm or 1°) is given for each 2mm sub-range (10 tests per sub-range).

Overall, SSD shows better performances than PI in the presence of noise on the projections. After subtraction of the reference projections a statistical approach is applied on each image and a probability map of flaw presence is estimated. The application of a threshold to the probability map results in a detection map as shown in Fig.3.

The 2D probability maps are then statistically merged in a volumetric probability map of flaw presence. Similarly, a threshold could be applied to obtain a flaw detection volume.

The main advantage of this method is that the value of the chosen threshold for detection (in 2D or in 3D) controls implicitly the rate of false detections. Further evaluations of the method on real radiographies of the connecting rod are ongoing.

Fig.1 Parameterization of a 2D fan beam computed tomography geometry: measurements under the ideal geometry assumption (green) and parameterization (blue).

Fig.2 Histogram of successfully calibrated parameters using SSD (left) and PI (right) cost functions.

Fig.3 Simulated radiography of an aluminum connecting rod containing 6 flaws (left), and the detection map obtained at 0.05 threshold of the statistical map (right).

Patent deposit 2012: BD13833, « Procédé de reconstruction volumique adaptable en tomographie par rayons X ».
ADAPTIVE MESH IMAGE REPRESENTATION FOR X-RAY TOMOGRAPHIC RECONSTRUCTION

RESEARCH TOPICS: TOMOGRAPHY RECONSTRUCTION, ADAPTIVE MESH, LEVEL-SET
M. A. QUINTO, F. BUYENS
PARTNERSHIP: GIPSA-LAB INP-GRENoble

Tomography reconstruction from projection data is an inverse problem widely used in the medical imaging and NDT fields. With sufficiently large number of projections over the required angle, analytical algorithms allow fast and accurate reconstructions. However in the case of limited number of views and/or limited angle, the data available for reconstruction are not complete, the problem becomes more ill-conditioned and the results show significant artifacts. Then, alternative approaches based on a discrete model of the problem are available, and consist in using an iterative algorithm to compute an estimate of the unknown object. All these methods are usually based on a volume representation into a grid of voxels and provide maps of densities. Even if these methods remain simple due to the linearity of the projection operator, they are both time and memory consuming.

In addition, post-processing tools are commonly applied on the reconstructed object to segment the region(s) of interest and extract quantitative measurements. Many methods of segmentation with different interpretations of the contours and various minimized energy functional are available.

Recently, novel approaches have been proposed in the field of SPECT that simultaneously perform reconstruction and segmentation. The solution we suggest for X-ray tomography reconstruction combines a new representation of the image with simultaneous reconstruction and segmentation algorithms. The method 1/ reduces the number of unknowns and thus decreases the computation time, 2/ makes the mesh faithful to the object and thus reduces the memory consuming, and 3/ makes available density and segmented material maps.

The representation is based on a mesh composed by triangles, and the density values are affected to their faces. Then, the process alternates three main steps: intensity values updates using an iterative algorithm (reconstruction), Euler-Lagrange’s curve motion formulated by level set method (segmentation), and mesh adaptation to the segmented contours.

Figure 1 shows an example of reconstruction of a numerical object composed by one material. It is a 2D orthogonal slice of a numerical knee model (1a) from which 36 projections have been performed using CIVA RT. FBP reconstruction (1b) lets appear artefacts due to the lack of data, while image 1d is more homogeneous. Image 1d shows how the mesh is coarse to represent the background and the inner region of the knee, and how it is thin all around the contour of the knee. The mesh is composed by 515 triangles to be compared to an image of 256x256 pixels (65536 pixels) or more.

Figure 2 shows an example of reconstruction of a numerical object composed by several materials. It is a typical Shepp-Logan phantom (2a) which projections have also been performed using CIVA RT. The object is here reconstructed and represented using 9545 triangles at the end of the process.

Patent deposit 2012, BD13742, Procédé de reconstruction volumique adaptative en tomodigraphie par rayons X.
GMR BASED EDDY CURRENT PROBES FOR MAGNETIC MATERIALS TESTING

RESEARCH TOPICS: NON DESTRUCTIVE TESTING, EDDY CURRENT PROBES, MAGNETIC SENSORS
N.SERGEEVA-CHOLLET, J.-M. DECITRE, O. CASULA

Non Destructive Testing (NDT) gathers methods aiming at providing information about health of the component or structure without impairing its future usefulness. Among the existing methods, Eddy Current testing (ECT) is a powerful tool of flaws detection in metal parts.

Magnetoresistive sensors are attractive for ECT because of their large bandwidth. At low frequencies they are more sensitive than conventional windings coils of the fixed size. Thus, these sensors are promising for low frequency applications, i.e. sub-surface flaw detection (because of skin depth effect) and magnetic materials inspection (because of magnetic permeability) [1].

Recent developments of CIVA permit to simulate the response of the probe with mono- or multi-elements magnetoresistive receivers to the defect [2]. Magnetic sensors are defined by their detection axis and sensitivity. Developed model has been validated by comparison with experimental results. Based on simulation optimization a probe with Giant Magneto Resistive (GMR) sensor as receiver has been developed at CEA LIST for low frequency applications (Fig.1).

For inspection of magnetic materials with such probe, it is needed to take into account that magnetoresistive sensors are sensitive to the residual magnetic field which may occur in magnetic part. This effect could perturb the response to the defect in the mock up. To overcome this problem, experimental studies of ferromagnetic plate with 2 holes (Fig.2a) have been done. A circular permanent magnet has been put to the surface of the mock-up and then removed. Experimental CSCAN is carried at the frequency of 1kHz is shown in Fig.2b. As it is well seen, both the holes and residual magnetic field created by the magnet are detected.

To reduce a parasitic signal of residual field a special electronic control loop has been developed [3]. Its aim is to monitor the polarization of the GMR sensor. Experimental CSCAN obtained using this control loop is shown in Fig.2c. Thanks to the electronic loop the signature of residual magnetic field is almost disappeared and the holes are better detected, the SNR is enhanced. Thus, electronic circuit is an efficient tool to reduce parasitic signal, inspection of magnetic materials with GMR based probes becomes possible.

New multi-elements EC probes based on GMR are under development in the frames of the ANR P2N project CANOE and European project FP7 IMAGIC. Some of these probes will contain appropriate electronic circuit for magnetic materials inspection.

References:
DATA SET REDUCTION FOR ULTRASONIC TFM IMAGING

RESEARCH TOPICS: ULTRASONIC IMAGING APPLIED TO NDT
S. BANNOUF, S. ROBERT, O. CASULA
PARTNERSHIP: INSTITUT LANGEVIN

The Total Focusing Method (TFM) imaging technique is a synthetic focusing algorithm that post-processes the matrix K(t) obtained usually after a Full Matrix Capture (FMC). For each point of a Region Of Interest (ROI), the post-processing consists in coherently summing all elementary signals of K(t) in order to focus a posteriori in every point of the ROI. The TFM provides high resolution images and advanced characterization of extended flaws [1]. The performances of such algorithm embedded in NDT-instrument are limited due to the large number of sequences of firing (N for a N-element array) and the large number of signals (N×N) to process and decrease the frame rate and, consequently, the inspection speed. This problem can be overcome to some extent if only a few elements are activated which is equivalent to using a sparse array in transmit or, in other terms, acquiring a Sparse Matrix Capture (SMC).

A Point Spread Function (PSF) corresponds to the response of an imaging system to a point-like target. Image contrast and lateral resolution depend on the PSF characteristics. The main lobe width of the PSF determines the lateral resolution while image contrast depends on side lobe level. Thus, optimization of the PSF has been used as a useful strategy for analysis and optimization of a sparse array [2].

The optimization of the sparse array consists in minimizing the number of sequences by determining both the accurate number and best locations of active elements. In the developed algorithm, these parameters are determined using three criteria based on the PSF: maximum side lobe peak below an acceptable value noted A, maximum main lobe width at -20 dB of the PSF below a threshold B and C are the different thresholds of acceptance based on characteristic of a full array radiation pattern.

The algorithm was applied to optimize the number and locations of active transmit elements on a 2-MHz array of 58 elements of 0.8 mm pitch [3]. Only longitudinal waves are considered and the following results are obtained by using the longitudinal velocity in ferritic steel. Depending on the aperture function (weights) applied in reception, the algorithm provides different results. Thus, when no apodization is used, the optimized sparse array is constituted of 13 active elements. When a trapezoidal windowing is applied, only 6 sequences are necessary to meet the desired criteria.

The number of active elements is lowered when applying apodization functions in reception. Indeed, they provide the advantage of lowering side lobes but on the other side they slightly widen the main lobe width.

Experimental data have been collected on a ferritic steel sample with several Side-Drilled Holes (SDH) of 2mm diameter and located between 30 and 60mm depth (Figure 2).

The image provided by the SMC-algorithms (Fig 3-b) with a number of sequences reduced by 4 shows low losses of image quality compared to full array imaging(Fig 3-a).

References:
REAL TIME NON DESTRUCTIVE TESTING OF AERONAUTICAL COMPOSITE STRUCTURES WITH A SELF-ADAPTIVE ULTRASONIC TECHNIQUE

RESEARCH TOPICS: ULTRASONIC PHASED-ARRAYS - ADAPTIVE INSPECTION METHOD
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PARTNERSHIP: M2M

In aeronautical industry, composite structures under testing often have complex and variable geometries. In this case, an optimal use of ultrasonic transducer arrays requires specific algorithms in electronic systems in order to achieve rapid and reliable inspections. To fulfill such requirements, a new real time and adaptive technique is presented. The SAUL method (acronym for ‘Surface Adaptive ULtrasounds’) is based on an iterative algorithm that does not require a prior knowledge of the geometrical and acoustical properties of the component undergoing inspection. All different parts of a given component (with flat, concave, convex parts…) can be inspected using the same array probe, such as a conventional linear array with a flat shape.

The gradual adaptation of the incident wave in a SAUL processing is illustrated in Fig. 1 with simulation performed with the CIVA software. The elbow represents the geometry of a typical composite corner radius and each image shows the simulated incident wave at a given iteration. With 4 successive shots, the SAUL technique gradually fits the incident wave to the complex surface.

The SAUL algorithm is implemented in the multichannel MultiX systems, manufactured by M2M Company, and the hardware design enables real time inspections at high speed: using a phased array of 128 elements and 4 shots in each cycle of iterations, the processing can be enabled with a cycle rate of 1 kHz.

Recently, the Canadian company, Mecnov, has integrated a MultiX system with the SAUL function in their industrial NDT systems. Figure 2 shows the industrial set-up composed with a complex component in a tank, a matrix phased array, and a 5-axis cartesian robot which is fully automated.

The component under testing has an H-shape and the goal is to inspect all the parts, including the flat surfaces and the convex edges of the component.

The 5-axis robot allows to orientate the probe in front of the vertical, convex and horizontal surfaces. After processing, the mapping of the component with the SAUL technique gives the Cscan image in Fig. 3, where defects are detected under the flat surfaces and the convex ones.

References:

Figure 1. Simulated incident fields for each iteration with the SAUL processing.

Figure 2. Industrial NDT set-up including a SAUL multichannel system.

Figure 3. 3D mapping of a complex composite structure using the SAUL method.
MODELLING EDDY CURRENT TESTING OF FERROMAGNETIC MEDIUM

RESEARCH TOPICS: NON DESTRUCTIVE TESTING, EDDY CURRENT PROBES, MAGNETIC SENSORS

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PARTNERSHIP: L2S, LGEP, CASSINO UNIV.

Eddy current testing (ECT) is a standard nondestructive testing technique used extensively in industry for various applications like detection of flaws or materials characterization. ECT of ferromagnetic materials is characterized by the confinement of induced currents in a region close to the piece surface, which diminishes drastically the probe sensitivity to buried flaws. In the framework of one of the authors PhD Thesis, semi-analytical models dedicated to the case of planar, stratified and ferromagnetic materials, have been developed [1]. They bring new functionalities to models developed at CEA-LIST for the optimization of probes and performance evaluation of ECT procedures.

The developments presented herein address the case of a flaw located inside a planar and ferromagnetic medium. Simulation results are obtained through the application of the Volume Integral Method (VIM). While only one integral equation, involving either the electric or the magnetic field, is needed to fully describe the non-ferromagnetic case, in the ferromagnetic case two coupled integral equations have to be solved. Therefore, when considering the ECT of a single flaw, a system of two Fredholm equations of the second kind, per layer containing the flaw, are derived from Maxwell equations. Electric and magnetic fields in the kth-layer (Figure 1) are solutions of two coupled equations involving four dyadic Green operators (only one in the case of non ferromagnetic materials). The numerical resolution of the system is carried out using the classical Galerkin variant of the Method of Moments. Finally, the response of an inductive receiving coil is calculated by application of the Lorentz reciprocity theorem. The resolution has been generalized to the ECT simulation of N flaws located in a planar stratified medium.

The results obtained [2] with the developed model have been benchmarked in the context of the collaborative project CIVAMONT2012 with two other different approaches:
- An integral formulation solved in terms of a finite-element approximation of the electric vector potential and the magnetization developed at Cassino University (DAEIMI);
- A finite-element solver using complementary magnetic and electrical formulations, developed at the LGEP (Supelec).

A cross-comparison of the results obtained by these three algorithms and the experimental and numerical ones found in [3] is performed. The configuration is the following: a plate of 10 mm-thickness (conductivity $\sigma = 3.47$ MS/m, relative permeability $\mu_r = 85$) is affected by a flaw of size 40x0.43x1.8 mm$^3$. The variation of the impedance of one coil (outer and inner diameter = 21.4 mm and 13.76 mm, height = 5 mm, turn number = 140, lift-off = 1.9 mm, frequencies go from 0.1 kHz to 10 kHz) scanning the surface part is used to detect the flaw.

In Figure 2 are represented the real part (a) and the imaginary part (b) of the so-called reduced (or normalized) variation of impedance.

The main conclusion is that the three models are in a good agreement thus cross-validating the different numerical approaches. The agreement with experiment is reasonable taking into account the uncertainties on the material characteristics: it is good at lowest frequencies while discrepancies appear at higher frequency (mainly on the imaginary part). These discrepancies can be explained by the fact that, at high frequency, it is not easy to correctly describe the attenuation parameters. Experimental validations are currently in progress on several different configurations to confirm these conclusions.

References:
Eddy-current (EC) inspection of riveted structures is a problem of immense importance for the aerospace industry. The development and propagation of fatigue cracks in the vicinity of fasteners, owing to mechanical stress concentration, may have detrimental effects on the structural integrity of the aircraft. Hence, a great amount of effort has been invested from the NDE community during the past years in developing models, which permit to obtain quantitative results of EC probe interaction with the fastener structure, with or without the presence of cracks.

Integral equation based models, like the volume integral method (VIM) or the boundary element method (BEM), prove to be very well adapted tools to such problems, which from a mathematical point of view can be seen as perturbation problems. The application of the aforementioned techniques requires, however, the former knowledge of the induced electric field in the work-piece in the absence of the crack as well as the expression (or value) of the appropriate Green’s function, which accounts for the specific geometry of the latter. State of the art simulation tools consider the integral equation formulation in planar stratified media, for which the Green’s function expressions are known, thus they treat the fastener hole as a virtual flaw. Consequently, a relatively large 3D mesh is required for the numerical solution of the resulting integral equation leading to long calculation times.

This work constitutes the first step towards a fast dedicated integral equation model for the calculation of EC probe interaction with cracks in the vicinity of fasteners, where the impact of the fastener hole will be included in the corresponding Green’s function, thus leading to a significant reduction of the computational burden of the integral equation model.

The eddy-current problem of a borehole in a half-space is treated using a semi-analytical approach referred to in the literature as the truncated region eigenfunction expansion (TREE) approach. The considered configuration is depicted in Fig. 1. Owing to the particular characteristics of the specific geometry, the straightforward application of the TREE approach presents significant difficulties. Therefore, a modified truncation approach has been adopted that treats the problem in two steps, each one based on the superposition principle. The model permits a fast calculation of the eddy-current field inside the half-space as well as the coil impedance. Fig. 2 shows a comparison of the model results for the coil impedance variation owing to the presence of the half-space (real and imaginary part) with those obtained by a commercial finite element solver (COMSOL 3.5a).

At a next step, the herein developed solution will be extended in order, firstly, to be able to treat multi-layered media, and, at a second step, it will be used for the construction of the dedicated Green’s function. The final objective is to deliver a fully operational simulation model, which will be integrated in a future version of the CIVA simulation platform.

This work has been the product of close collaboration between the CEA LIST and the University of Western Macedonia (Greece) in the framework of the CIVAMONT 2012 project.

References:
NUMERICAL MODELLING OF EDDY-CURRENT TESTING INSPECTION TAKING INTO ACCOUNT THE EFFECT OF THE MEASURING CIRCUIT

RESEARCH TOPICS: NONDESTRUCTIVE TESTING EDDY-CURRENT TESTING SIMULATIONS
A. SKARLATOS, C. REBOUD, J.-M. DECITRE, S. MAHAUT

The electromagnetic modelling of eddy-current testing (ECT) deals with the solution of Maxwell equations, where the driving currents are assumed to be fixed and a-priori known, and the receiving coils are considered open-circuited. However, in the more realistic case of voltage source excitation, the dependence of the coils impedance upon the immediate environment of the inspection probe results in variable feed currents, with the respective impact on the measured signals. In addition, the deviation of the probe coil behaviour from the ideal inductor, together with the cable response and the rest of the measuring circuitry, yield significant modifications to the frequency response of the system and the emergence of resonances. The latter are a direct consequence of the presence of spurious capacitances at various locations of the circuitry. The closer to the resonance the measuring frequency is set, the stronger the impact of the circuit response on the acquired signals is.

The aim of the present contribution is to incorporate the features of the measuring circuit in the theoretical model, in order to reproduce experimental data. According to the herein adopted approach, the eddy-current problem is first solved via the volume integral method (VIM) while using the common simplification assumptions, namely ideal inductors and current sources. The VIM approach is well adapted for the treatment of ECT problems. In the next step the results from the electromagnetic analysis are provided to the circuit model while the corresponding circuit problem with lumped elements is solved in order to evaluate the measured voltages. Fig. 1 shows the equivalent circuits for the cable and the probe coil considered by the circuit model. The connection between the eddy-current and the circuit problem is established via the self and the mutual impedances of all the coils of the measuring probe.

To demonstrate the effect of the circuit to the acquired signals, the simulation results obtained with the coupled electromagnetic/circuit model were compared with the ones of the idealised electro-magnetic model as well as with measurements. A qualitative comparison of the two results and the experimental data for the case of a rectangular notch inspection using a two-coil probe in driver-pickup connection is shown in Fig. 2. The impact of the circuit to the flaw signature is clearly recognisable by the breaking of signal symmetry. Fig. 3 shows a quantitative comparison of the three signals on the complex plane at two frequencies: 300 kHz and 700 kHz. The circuit effect is manifested by the opening of the signal lobe (and hence the breaking of symmetry). Note that a very good agreement between simulation results and experimental data is obtained even at 700 kHz, which is a close to probe resonance frequency.

The developed model has been integrated in CIVA platform and it will be available in the forthcoming version CIVA 11.

Figure 1. Equivalent circuits for the (a) cable and (b) probe coil. $R_{cab}$, $L_{cab}$, $C_{cab}$ denote the DC resistance, inductance and capacitance of the cable, $R_{pdc}$, $C_{p}$ are the parasitic elements of the coil, and $L_{con}$, $C_{con}$ model the parasitic effects of the coil leads.

Figure 2. Real part of the signal signature for a notch inspection at 300 kHz:
(a) Simulation without circuit,
(b) Simulation with circuit,
(c) measurements.

Figure 3. Simulation vs. measurements in complex plane at 300 kHz (left) and 700 kHz (right). The account for the circuit parameters in the simulation results in the observed side-enlargement of the signal lobes. $\Delta V$ is the variation of the output voltage due to the notch in respect to that of the unflawed specimen $V_0$.

References:
Non Destructive Testing (NDT) by Eddy Current (EC) method is widely employed in several industrial sectors for cracks detection. Numerical simulation tools are largely used in order to design sensors, understand the signals collected during the measurements process and as a support in expertise. This work has been accomplished inside Département Imagerie Simulation pour le Contôle (DISC) in collaboration with L2S-Supélec. It is also a part of the CIVAMONT 2012 project, with the active participation of MEANDER laboratory members from University of Western Macedonia (Greece) and Technological Educational Institute of Western Macedonia (Greece).

The main goal of our work has been to develop a semi-analytical modeling approach devoted to Eddy Current Testing (ECT) of multiple narrow cracks in planar multilayered structures. From the numerical point of view, simulation of multiple narrow cracks problems is a difficult task for classical methods, like for example, the Volume Integral Method (VIM) or the Finite Element Method (FEM). The main issues reside in narrow cracks geometrical characteristics themselves. Indeed, a narrow crack presents a small opening as well as complex profile and shape, as well as the possibility to have electrical contacts inside the crack body (See Figure 1). All these features increase enormously, with classical methods, the difficulty to simulate, in rapid and/or precise way, problems involving narrow cracks.

We have tackled the narrow crack issue by developing a Boundary Element Method (BEM) dedicated to ECT signal modeling, by starting from an approach presented in literature. Then, we have extended its capability to more realistic and challenging cases, such as the ECT of multilayered structures affected by complex narrow cracks. The principle of this method is to introduce additional assumptions leading to the description of the crack perturbation as effect of a dipoles distribution oriented toward the crack opening. Numerically speaking, such a description makes it possible to largely reduce, compared to the VIM, the number of unknowns that one needs to properly solve the problem.

A particular attention has been devoted to the analytical formulation in order to achieve generality, accuracy and efficiency. A precise derivation of the spectral-domain Dyadic Green Function (DFG) associated to the electromagnetic problem is a difficult task for classical methods, like for example, the Volume Integral Method (VIM) or the Finite Element Method (FEM). The main issues reside in narrow cracks geometrical characteristics themselves. Indeed, a narrow crack presents a small opening as well as complex profile and shape, as well as the possibility to have electrical contacts inside the crack body (See Figure 1). All these features increase enormously, with classical methods, the difficulty to simulate, in rapid and/or precise way, problems involving narrow cracks.

Numbers related to the experimental data (see Figure 2). Further perspective of this work could concern a BEM and VIM useful in problems where narrow cracks appear in conjunction with volumetric flaw.

This work has been entirely implemented inside the NDT simulation platform CIVA developed in CEA LIST. The validated capability of the BEM model will be released in the coming version of CIVA 11.

References:
X-RAY DIFFRACTION MODELING FOR THE X-RAY NON-DESTRUCTIVE CONTROL (PICASSO PROJECT)

RESEARCH TOPICS: X-RAY NONDESTRUCTIVE TESTING SIMULATION, X-RAY DIFFRACTION
CAROLE FORCE
SPONSORSHIP: FP7
PARTNERSHIP: PICASSO PROJECT

This work is developed in the framework of the PICASSO project. The goal of this European project, in partnership with aeronautical industries, is to improve the efficiency of nondestructive testing for maintenance of aeronautical structures by using simulation. One task of the project is to add X-ray diffraction model to the simulation of X-ray radiographies. X-ray diffraction appears on the radiography, under given conditions, in the form of white and dark lines. The taking into account of the diffraction in the simulation will enable to the operator before the control to simulate the object’s configurations for which the diffraction lines are minimized and to make easier the detection of defects.

The experimental set-up, chosen to observe the diffraction and to model it, is an extended transmission Laue set-up: the x-ray beam emitted by X-ray micro-focus generator is polychromatic, the crystal is fixed and the detector is a fixed flat panel located behind the crystal. But contrary to Laue set-up, the beam is divergent. So instead of observing some diffraction spots on the X-ray radiography, we observe white and dark lines corresponding to diffracted and transmitted incident rays (Kossel lines). This set-up is similar to the set-up devoted to turbine blades inspection at Safran group (Snecma).

First, we have modelled the position of the diffraction lines on the detector by modelling the reflexion of the incident rays on the reticular planes of the crystal according to the Bragg law. We have acquired experimental images (cf. Figure 20) with a simple-shaped mono-crystal of nickel, with cubic faced-centred structure, at various crystal-detector distances. The positions of the experimental lines have been compared to the simulated ones with a good agreement (cf. Figure 21). A good agreement between simulation and experiment has also been obtained for two different mono-crysalts, Si and C, with diamond structure and under different experimental conditions (voltage, source-crystal and crystal-detector distances), cf. Figure 22 and Figure 23.

Second, we are modelling the intensity of the diffraction lines in the framework of the kinematical theory. The following work will be to obtain results with intensity modelling.


References:

Figure 20: experimental X-ray radiography of a nickel monocrystal with cubic faced-centered structure.

Figure 21: simulated position of the diffraction and incident lines compared to experimental lines for nickel monocrystal.

Figure 22: on the left, experimental X-ray radiography of a silicon monocrystal with diamond structure; on the right, simulated position of the diffraction and incident lines.

Figure 23: on the left, experimental X-ray radiography of a carbon monocrystal with diamond structure; on the right, simulated position of the diffraction and incident lines.
A TRANSFER FUNCTION APPROACH TO THE DETERMINATION OF PROBABILITY OF DETECTION CURVES

RESEARCH TOPICS: NON DESTRUCTIVE TESTING, PROBABILITY OF DETECTION (POD)
F. JENSON AND N. DOMINGUEZ
SPONSORSHIP: ANR, FP7

POD curves estimations are based on statistical studies of empirical data which are obtained thru costly and time consuming experimental campaigns. Currently, cost reduction of POD trials is a major issue. A proposed solution is to replace some of the experimental data required to determine the POD with model based results. Following this idea, the concept of Model Assisted POD (MAPOD) has been introduced first in the US in 2004 through the constitution of the MAPOD working group, then in France and Europe with the SISTAE (ANR grant) and PICASSO (FP7 grant) projects. One approach to Model Assisted POD is based on a transfer function which uses empirical data and models to transfer POD measured for one specific application to another related application. The objective of this work is to show how numerical simulations could help to determine such transfer functions [1]. A practical implementation of the approach for a high frequency eddy current inspection for fatigue cracks is also proposed. Empirical data are available for the titanium alloy plates (see Figure 1). A model based transfer function is used to assess a POD curve for the inspection of aluminum components with the same technique.

A relationship between the simulated signals in the Titanium and Aluminum plates is established and then applied to the empirical signal for Titanium with fatigue cracks to get a transferred POD curve for the Aluminum component with fatigue cracks. Inspections were simulated using the software CIVA.

The usual way of computing a POD curve (the Berens approach) is based on the assumption that the signal response is linearly related to the crack length. Here, this hypothesis fails and it seems appropriate to fit piecewise linear regressions instead, and determine POD curves using this new relationship (see figure 2). The transfer function will be constructed from the regression parameters describing the relationships between the crack size and the simulated inspection responses in aluminum and titanium, and between the crack size and the experimental inspection results that are available for the titanium component. The regression parameters describing the relationship between the crack size and the experimental inspection results for aluminum plates are then obtained by application of the transfer function (these experimental results being not available, no regression analysis can be performed).

Finally, the POD curve for the detection of fatigue cracks in Aluminum is computed (see figure 3). This step requires an extension of the usual approach (the Berens approach) in order to include piecewise linear relationships in the statistical method used to determine POD curves.

References:
ACCELERATION OF ULTRASONIC RECONSTRUCTION ALGORITHM ON MASSIVELY PARALLEL HARDWARE ARCHITECTURES

RESEARCH TOPICS: ULTRASONIC RECONSTRUCTION, PARALLELIZATION, GENERAL PURPOSE PROCESSORS, GRAPHIC PROCESSING UNITS
A. PÉDRON, G. ROUGERON
PARTNERSHIP: IEF - UNIVERSITÉ PARIS-SUD

Ultrasonic imaging and reconstruction tools are proposed in Civa Software Platform, in the purpose of localizing echoes, identifying and sizing the detected defects. Because of the complexity of data processed, computation time is now a limitation for the optimal use of available information. A computationally heavy algorithm, True Cumulated View, has been implemented and parallelized on both general purpose processors (GPP) and graphic processing units (GPU).

The True Cumulated View algorithm (TCV) offers a complete visualization of the data through top, side and front views of the specimen (Figure 1). View algorithm. In the Bottom part: views assembled on a 3D model.

The inputs of the algorithm are:
- N Signals: amplitude in function of time.
- N ray-paths: geometrical polylines for which at each vertex is associated a time of flight.

Description of the algorithm:
- First step: Projection of the signal to the ray-path. Each value (amplitude, time) of the signal, can be localized on the ray-path and converted to (amplitude, (x,y,z)) value.
- Second step: for each value (amplitude, (x,y,z)), dilation of the amplitude value to a rectangular area around the point (x,y,z). Projection of the rectangular area to the final grid. For each pixel, selection of the max value between projected values and current pixel image value.

Software Optimization consisted in replacing on-the-fly dilation by a post-processed dilation performed after the processing of all ray-paths and using kernel separability to reduce compute complexity.

The GPP implementation is straight-forward and, if using a p-core GPP, ray-paths are distributed among p threads (Figure 2.) In addition, each of the previous threads runs the TCV algorithm and generates its own image. Then the images are merged by extracting the maximum value in each pixel (reduction). This step is parallelized and, being regular, is also vectorized. Finally, the dilation step is also parallelized but not vectorized.

GPU implementation strategy is slightly different. Assuming that GPU need to launch a very large number of threads (thousands of them), multiple image reconstruction cannot be used. Instead, one unique output image is used. Since different threads can potentially access the same address at the same time, dilation has to be done synchronously to be thread-safe by using atomic-max operations.

Compared to the initial GPP implementation, optimized GPP implementation runs up to 116 faster and GPU implementation up to 631. Software optimizations combined to GPU parallelization allows the user to get a very fast reconstruction in human interactive time which is a major step into NDE ultrasound reconstruction.

Figure 1. In the Top part: views computed by True Cumulated.
Figure 2. GPP implementation.
Figure 3. GPU implementation.

References:
BENCHMARK SIMULATIONS FOR THE SCATTERING OF GUIDED WAVES IN A STIFFENED ISOTROPIC PLATE

RESEARCH TOPICS: BENCHMARK, GUIDED WAVES, UT SIMULATIONS, HYBRID MODEL, EMAT
D. SEGUR, K. JEZZINE, V.BARONIAN, L. TAUPIN, A. LHEMERY

A problem of guided wave propagation and scattering has been submitted to QNDE 2011 benchmark session [1]. It is concerned with the scattering of guided waves emitted and received by two EMAT transducers positioned on either side of a stiffener over a plate made of Aluminium alloy.

The problem in hands requires the computation of cases of oblique incidence onto the stiffener. It is solved using a hybrid method recently developed at CEA [2]. The method used for computing the benchmark case was originally developed to deal with multi-layered anisotropic plates and stiffeners; it can of course deal with the elastically simpler case of an isotropic homogeneous stiffened plate.

The testing configuration for the proposed benchmark is herein described. Two identical pancake coil Electro Magnetic Acoustic Transducers (EMAT) are located on either side of a stiffener that is adhesively bonded over an aluminum plate. The plate is 1 x 1.25 m and the stringer is bonded parallel to the shorter sides at 0.5 m from one end. The experimental setup used in this benchmark study and the characteristic lengths for the cross-section of the stiffener bonded on the plate is described in Fig.1. The Young modulus, Poisson ratio and density, are E=70 GPa, v=1/3, \(\rho=2.7\) kg/m\(^3\) for aluminum and E=2.64 GPa, v=1/3, \(\rho=1.2\) kg/m\(^3\) for adhesive joint respectively.

Pancake coil EMATs are made from two opposite spiral coils burned on either side of a thin PCB film that is placed in a quasi-uniform static magnetic field created by several permanent magnets. The principle of EMATs is first briefly recalled. An AC current passing through the coil induces eddy currents in metal that interact with the static magnetic field creating Lorentz force in the in-plane direction. The excitation used is a Hanning-windowed 3-cycles tone burst with 200 kHz center frequency.

To model this benchmark configuration, one can split the problem into three different parts. The first one is concerned with the knowledge of the modes that can propagate in the plate. A Semi Analytical Finite Element (SAFE) method is used to calculate the modal decomposition for a free aluminum plate, i.e. without a stiffener. In a second step, one should calculate the amplitude of the modes effectively generated by the EMAT transducer (and the amplitude in reception as well). The last step deals with a description of the scattering phenomenon of obliquely incident guided waves modes over the stiffener and is performed through a finite element formulation, recently developed at CEA [2,3], that defines a transparent boundary conditions operator reducing the numerical cost of such a method.

Synthesis of A-scan signals in Fig.2 is then calculated for different incidence angles and comparisons made with experimental received signals. We recall that comparison between signals are only valid just before the free edge reflection echo of the S0 mode, i.e. before 105 \(\mu\)s. Good agreement is observed even if noticeable discrepancies appear for 40° and 50°. Actually, we explain this observation as a limitation of the far field assumption that considers incident plane waves. Summation of all the contributions lying in the light transducer cone should be addressed. However, diffraction effects seem to be not so pronounced for a large range of incidence angles, typically for small angles, and the assumption made could be considered as valid. In NDT applications, ones are interested in amplitude measuring of the transmitted guided waves through the stiffener that is well predicted in the simulated results. Further work will concern more realistic structures such as composite aircraft panels.

![Figure 1. Experimental setup (a) and cross section (b) of the stiffener bonded over the plate.](image1)

![Figure 2. Forward direct simulation (dotted lines) obtained with the hybrid model compared to experimental signals at given incidence (solid lines).](image2)

References:
In-service inspection of sodium fast reactors (SFR) requires the development of non-destructive techniques adapted to the harsh conditions of the environment (opaque and hot) and the complexity of the examination (large and littered reactor block). Ultrasonic techniques are seen as suitable candidates for the inspection of SFRs and two approaches are being followed: inside inspection where transducers are directly immersed in sodium coolant and inspection from outside with transducers positioned along the wall of the main vessel. Inspections from the outside may be carried out using two propagation modes: bulk waves or guided waves. Both methods have been investigated using simulation codes.

**INSPECTION WITH BULK WAVES.**
Ultrasonic probes positioned outside the reactor along the main vessel wall can be used to perform telemetry measurement without requiring severe sodium conditioning. However, inspection from outside requires to go through one or several metal plates (main vessel wall, baffle) leading to losses of energy. It is important to quantitatively determine these losses to estimate the possibility to measure the position of the various internals. Ultrasonic simulation tools have been developed, implemented in CIVA and compared to experiments in water, as the one illustrated in Figure 1.

Fig. 1 shows the results obtained for a pitch and catch configuration. The distance between the emitter and the receiver is adjusted to obtain an intersection of the emission and reception focal paths along the surface of plate 2. Experimental (top) and simulated (bottom) results show multiple echoes for earlier times of flight, coming from modes converted inside the main vessel wall. The amplitude of the front surface echo off plate 2 is also reported. We see that CIVA quantitatively predicts the mode conversions obtained in the first plate representative of the main vessel wall as well as the front surface echo of the plate 2. Thanks to simulation it is therefore possible to design NDT methods for telemetry from the outside.

**INSPECTION WITH GUIDED WAVES.**
We expect to inspect structures welded to the main vessel wall such as the core support using guided waves. The goal is to generate guided waves at the location of the weld and then propagate them along the different plates to detect defects (Fig. 2). To assess such cases, developments have been carried out, based on FEM techniques restricted to complex junctions or guides, coupled to modal decompositions on canonical guides, as illustrated on Figure 2. These developments allow to perform parametric studies such as the distance L(ab) between the two domains. A transducer of 95 kHz (10% bandwidth), generates five propagative modes (A0, A1, S0, S1, S2). Calculations are presented in the absence of a defect (a), and for two different defects (b) and (c). In absence of a crack we can see two main reflexions coming off the junction. When the crack is close to the junction (b), we see that the amplitude of the two echoes increases. When the defect is farther from the junction (c), multiple arrivals are detected; the first one is similar to the one observed in absence of the crack. Looking at such complex signals, we see how important modeling is to help interpreting the signals that will be captured in the field.

**References:**
MODELING OF ULTRASONIC STRUCTURAL NOISE IN A COMPLEX MEDIUM

RESEARCH TOPICS: ULTRASONIC NOISE, ATTENUATION, BORN APPROXIMATION
L.DUCOUSSO-GANJEHI, V.DORVAL, F.JENSON
PARTNERSHIP: SNECMA

In ultrasonic inspections of aircraft engine components, the detectability of critical defects can be limited by grain noise. This is the case for subtle defects, such as hard-α inclusion in titanium alloys, where the difference between the acoustic impedances of the defect and host material is small. A quantitative description of grain noise and attenuation in such alloys is essential to estimate accurately flaw detection reliability. A model for the propagation of ultrasonic waves in a polycrystalline material as a function of the morphologic and elastic properties has been implemented in the non-destructive testing software, CIVA.

The titanium alloy is composed of two phases, β and α (Fig. 1, left). During the solidification of the metal, the β phase appears first and forms macrograins. A macrograin is defined as a zone in which the β phase has a given crystallographic orientation. The orientation of a macrograin is assumed to be random. The α phase appears later in groups of needle-shaped crystals called crystallites. A group of crystallites having the same crystallographic orientation is called a colony.

In order to develop the model, we assume that the crystallites are too small to induce scattering. Therefore, macrograins and colonies are the only heterogeneities taken into account in the computation of scattering. The modelled two-scale structure is represented in the Figure 1 (right). The description of the microstructure can be summarized as follow: each macrograin contains a first phase of random orientation. It is separated in several colonies which contain the second phase of a given orientation. The orientation of the second phase of a colony is dependent on the orientation of the first phase of the macrograin.

The effect of the microstructure of the polycrystalline specimen on the ultrasonic propagation is defined by the backscattering coefficient \( \eta \). The backscattering coefficient depends on the morphological and elastic properties of the specimen, the wavelength and the type of the transmitted wave. The analytical model is based on the Born approximation (weak scattering) and the multiple scattering is neglected.

To use the backscattering coefficient to simulate structural noise, we generate in CIVA a random distribution of scatterers. We choose a number \( N \) of scatterers per unit volume high enough to obtain fully developed speckle. The \( \eta \) of that distribution of scatterer is related to the mean of the square of their scattering amplitudes \( A \) and to the ratio of the velocity of the scattered and incident waves

\[
\eta = N\langle |A|^2 \rangle \frac{\psi_{\text{scat}}}{\psi_{\text{inc}}}
\]

The distribution of the scattering amplitudes \( A \) is set in order to verify the above equation for the theoretical \( \eta \) of the simulated microstructure. That way, we ensure that the distribution of scatterers produces the same structural noise as the theoretical microstructure. \( \eta \) can also be used to obtain attenuation coefficients, by relating the energy lost due to attenuation to the energy scattered in every direction. These coefficients are used in the simulation in the computation of both structural noise and defect echoes. In the case of longitudinal waves, we obtain the following relation between the attenuation coefficient \( \alpha_L \) and the integrals over every direction of the scattered energy:

\[
2\alpha_L = \int_{0}^{\pi/2} \eta_{L}(\theta,\varphi,0) d\theta d\varphi + \int_{0}^{\pi/2} \eta_{\varphi}(\theta,0) d\theta d\phi + \int_{0}^{\pi/2} \eta_{\theta}(0,\varphi,0) d\theta d\phi
\]

where the three coefficients \( \eta_{L}, \eta_{\varphi}, \eta_{\theta} \) are the scattering coefficients from L waves to each possible wave. Similar equations can be obtained for transverse waves.

The general principles of the noise scattering method are outlined in Figure 2.

One example of the backscattered noise measurement (left) and simulated (right) is illustrated in Figure 2. The spatial representation shows the gated-peak-to-peak backscattered grain noise seen through a cubic specimen (70 mm in depth). The comparison is very good in texture (Fig. 3, upper part) and amplitude (Fig. 3, lower part).

Figure 1. Model of the two-phases microstructure
Figure 2. Non-oriented dynamic field
Anisotropic dynamic field
Microstructure description
Random set of point-like scatterers
Scattering coefficients a
Optical model
Computed noise
Figure 3. Measurement (left) and simulation (right) of the backscattered noise in a titanium alloy specimen (upper part). The mean noise level as a function of time simulated (blue) and measured (black) (lower part).

References:
ACOUSTIC SCATTERING MODELS
FOR ULTRASONIC TELEMETRY IMAGING

RESEARCH TOPICS: ULTRASONIC SCATTERING MODELS
B. LU, M. DARMON
PARTNERSHIP: LAUM (UNIVERSITÉ DU MAINE), SOUND MATHEMATICS LTD

This modeling study is part of a research program devoted to the development of simulation tools for monitoring inspection techniques applied to sodium-cooled fast nuclear reactors (SFWR). The characteristics exhibited by sodium, such as its opacity, have led the designers to devise specific monitoring and inspection techniques. Consequently ultrasonic techniques are seen as suitable candidates. Two approaches are being followed: the core monitoring where transducers are directly immersed in sodium near the reactor’s core and the outside inspection with transducers located along the wall of the main vessel (outside sodium medium).

The work reported here is the result of the first author’s PhD thesis [1], defended in 2011. A PhD thesis has been carried out with the aim of modeling one of the core monitoring techniques, the sodium ultrasonic telemetry which allows checking the position of the various objects contained inside the main vessel and the possible detection of defects inside these objects. The distance between the transducer and the immersed targets can be determined by measuring the time of flight of backscattered acoustic waves generated by an immersed transducer. While in-service the flow of sodium creates turbulence that leads to temperature inhomogeneities, which convert into ultrasonic velocity inhomogeneities. These velocity variations could impact directly upon the target location tolerance by introducing times of flight variations. Different scattering phenomena are also produced while the interaction between the acoustic beam radiated by the probe and the immersed targets: specular reflection, tip diffraction from boundaries and edges of the different parts. In order to optimize the probes parameters, a simulation tool is necessary to assist the design of each element of the ultrasonic telemetry.

Two wave propagation models, a deterministic and a stochastic one, have been developed in a previous work [2] to calculate the ultrasonic field radiated in an inhomogeneous medium. Deterministic calculations have shown that the fluid inhomogeneous characteristic doesn’t impact much the amplitude of the acoustic propagation field but leads to beam deviations which are well reproduced by the stochastic model.

In this paper, we are interested in the modeling of the field scattered from the immersed targets. To model the interaction between the acoustic wave and the immersed structures, classical scattering models have been firstly evaluated for rigid structures, including the geometrical theory of diffraction (GTD) and the Kirchhoff Approximation (KA).

These two approaches appear to be complementary. Combining them so as to retain only their advantages, we have developed the so-called refined KA based on the physical theory of diffraction (PTD). The refined KA provides an improvement of the prediction in the near field of a rigid scatterer [1].

To deal with the scattering from a finite impedance target more representative of a reactor structure, the initial (non refined) KA model has then been extended. The obtained model, the so-called “general” KA model, has been compared to a reference model (UTD) and provides a satisfactory fast solution for the application to telemetry, as shown in Fig. 2 for the prediction of the scattering from an elastic half-plane.

Finally, a complete simulation tool for telemetry is built by coupling this general KA diffraction model with a stochastic model [1] for wave propagation in inhomogeneous media as sodium.

Figure 1. Scattering directivity patterns predicted by the exact UTD solution for both a rigid and an elastic immersed wedge (in green) for two incident angles (a) 60° (b) 30°.

Figure 2. Scattering directivity patterns for an immersed elastic half-plane (represented by a green line) predicted by the General Kirchhoff approximation and by the exact UTD solution for two incident angles (a) 60° (b) 30°.

References:
WEDGE SCATTERING OF A CRITICALLY INCIDENT BEAM

RESEARCH TOPICS: ULTRASONIC SCATTERING MODELS
M. DARMON, P. CALMON
PARTNERSHIP: SOUND MATHEMATICS LTD

The simulation of ultrasonic NDT (Non-Destructive Testing) in CIVA is based on a semi-analytical approach consisting in calculating the beam transmitted in the part and then modeling its interaction with flaws. The work presented here aims at improving the existing models [1] used to account for the scattering of waves from surface-breaking flaws for near critical incidence. It has been carried out in collaboration with Sound Mathematics Ltd in the context of the CIVA-MONT project.

Interaction of an ultrasonic beam with an embedded or surface-breaking crack is a well-known problem in NDT. In the high-frequency regime, when the beam insonifies the whole crack two classical approximations are used depending on the situation: The Kirchhoff Approximation based on Geometrical Optics and the GTD (Geometrical Theory of Diffraction). The latter relies on solution of canonical problems of the scattering by a half-plane or a planar wedge.

This study addresses the more challenging problem of the scattering of a surface breaking crack when the incident wave is a “creeping wave” generated by the ultrasonic beam (in the case of transverse wave) near critical incidence. When the incidence is near the critical angle the Kirchhoff approximation fails. We show that efficient simulation can be obtained in that case implementing a simple modification of GTD. We model the transducer beam as a Gaussian beam, because it is a satisfying approximation which is amenable to an analytical treatment. We therefore assume a transversal Gaussian beam to be incident at a near critical angle on the part wall, at a certain distance from the crack corner.

We show in [2] that the elastic field propagating along the wall surface corresponds to a triplet of non-geometrical waves, one longitudinal (L) lateral component propagating along the surface, one T head wave radiated in the bulk, and one somewhat unusual L component, the so-called Goodier-Bishop (GB) wave whose amplitude grows proportionally to the distance to its specular reflection direction. This wave triplet interacts then with the crack corner and we show in [2] how the resulting diffracted field can be simulated using GTD.

These conclusions have been validated by studying the results obtained using finite element (FE) computations provided by the CIVA-Athena hybrid code. This code uses the semi-analytical approach for the propagation of the beam while a 2D FE calculation box can be defined around the defect area to deal with intricate phenomena such as those we address here.

The results are illustrated Figure 1. The snapshots show the beam hitting the wall and its interaction with the crack. The shadow boundaries and the corresponding directions of propagation for the resulting scattered T waves are indicated. Most of the scattered waves are identified in Figure 2: T0 is due to the reflection of the GB component of the incident triplet, T1 and T2 are doubly reflected T waves; H1 and H2 are head waves of the reflected and transmitted triplets. A fast code for simulating the full scattered field in this configuration is in progress.

Figure 1. CIVA-Athena simulations of the incidence of a transversal beam at the supercritical angle of 55°. Thick black line: the backwall crack. The wedge angle is 100°. Consecutive snapshots of the incident (a) and scattered field (b, c and d).

Figure 2. a) A schematic representation of the scattered waves. Solid arc and dashed arc: the fronts of bulk diffracted L and T (both diffracted and reflected) waves, respectively; dotted and dash-dot lines: critical rays and fronts of the head waves H1 and H2; gray areas: zones of propagation of critical wave triplets. b, c and d) Paths of reflected T waves.

References:
CHARACTERIZATION AND MODELING OF ULTRASONIC STRUCTURAL NOISE BASED ON THE MULTIPLE SCATTERING APPROXIMATION

RESEARCH TOPICS: ULTRASONIC SPECKLE, MULTIPLE SCATTERING
T.BEDETTI, F.JENSON, V.DORVAL
PARTNERSHIP: INSTITUT LANGEVIN

Structural noise can be a limiting factor during the ultrasonic inspection of certain metals. This phenomenon is related to the interaction between ultrasonic waves and the microstructure of the metal. Modeling it helps designing suitable inspection procedures. Structural noise can be separated in single and multiple scattering. The work presented here deals with the modeling of multiple scattering and is complementary to other works that deal with the modeling of single scattering [1].

Our modeling approach is based on the diffusion approximation, which implies that multiple scattering is largely dominant. It leads to an equation for ultrasonic energy propagation analogue to the equation for heat equation. In this equation, the propagation rate is entirely determined by the diffusion constant D.

The value of D can be obtained experimentally using the coherent backscattering effect. This effect causes the appearance of an interference pattern known as the coherent backscattering cone. The decrease with time of the width of this cone is related to D. In previous work, we performed a measurement with a linear phased array by emitting with one element and receiving with all elements. It allowed observing the cone and evaluating D but there were significant uncertainties. We improved that method by using beamforming, a post-processing method that uses all the data that can be measured with the array [2]. As shown in figure 1, it significantly improves the resolution of the cone. It therefore allows obtaining more precise values of D.

A method to simulate structural noise based on D has been developed [3]. In this method, the propagations of ultrasonic waves from the probe to the sample and from the sample to the probe are obtained using the ultrasonic field computation tool of the Civa platform. The propagation in the sample is computed using the diffusion approximation based on the value of D that was determined experimentally. Structural noise is obtained by combining these results.

In order to validate this method, comparisons between measured and computed structural noise have been performed. In the example of figure 2, multiple scattering is expected to be dominant due to the ratio between the ultrasonic wavelength and the grain size in the sample. It is therefore a favorable case to validate the simulation method.

The slopes of the noise as a function of time are very similar in the measurement and simulation. It proves that the method is able to correctly model structural noise in a favorable case.

The outputs of this simulation method cannot yet be calibrated, which prevents absolute comparisons of the amplitudes. Further theoretical developments should allow overcoming that problem. Another direction for future works is to combine this simulation method with a method based on the single scattering approximation, in order to be able to simulate structural noise in a wider range of configurations.

Figure 1. Visualization of the coherent backscattering cone with the former (left) and the new (right) methods.

Figure 2. Averaged envelope of the measured and computed structural noises as a function of time (not calibrated).

References:
GENERALIZATION OF THE KIRCHHOFF APPROXIMATION FOR THE SIMULATION OF ECHOES IN ULTRASONIC NDE

RESEARCH TOPICS: ULTRASONIC SCATTERING MODELS
V. DORVAL, M. DARMON, S. CHATILLON, S. MAHAUT
SPONSORSHIP: Y
PARTNERSHIP: Y

One of the modules of the Civa simulation platform is dedicated to the computation of echoes in ultrasonic non destructive testing. This module proposes several approaches to model the interaction between an ultrasonic wave and a reflector. The most used approach is based on the Kirchhoff approximation, which locally approximates surfaces as infinite planes.

The model was originally developed to model the echo arising from a crack and was based on a free-surface assumption. It can also be used to model the echo from backwalls (the part boundary), since reflections from backwalls can be considered as reflection from free surfaces. However, attempts to apply this model to more diverse reflectors gave unsatisfying results in some cases.

To address that problem, a new and more general formulation of the Kirchhoff approximation was developed [1] and implemented in Civa. It is based on a reciprocity theorem that leads to a robust mathematical formulation and is not limited to specific materials or defect. This new model is based on the following expression of $\delta\Gamma_{ba}$, the signal due to an echo:

$$\delta\Gamma_{ba} = -\frac{i\omega}{4P} \int S_{b} \cdot \sigma_{ba} \cdot \sigma_{ba} \cdot n dS$$

where $\omega$ is the angular frequency, $P$ the emitted power, $S_D$ the surface of the defect, $u$ the displacement, $\sigma$ the stress and $n$ the normal to the surface. EmD indicates the field from the emitting probe when the defect is present and $Re$ the field from the receiver when the defect is absent.

By applying the Kirchhoff approximation to this equation, a new model is obtained. It is equivalent to the previous one in the case of cracks and is more accurate for other reflectors.

In the example of figure 1, the original model was able to correctly predict the echo from the interface between plate 1 and the water but not the echo from the interface between the water and plate 2. The new model correctly predicts both echoes. Results given by the two models are compared to experiment in table 1.

<table>
<thead>
<tr>
<th></th>
<th>Experiment</th>
<th>Original model</th>
<th>New model</th>
</tr>
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<tbody>
<tr>
<td>Steel/Water</td>
<td>26 dB</td>
<td>27 dB</td>
<td>27 dB</td>
</tr>
<tr>
<td>Water/Steel</td>
<td>5 dB</td>
<td>-23 dB</td>
<td>6 dB</td>
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Table 1. Comparison between the amplitude of measured and simulated echoes

The improvement in the case of the water/steel interface is due to a term that accounts for the stress at the interface (it is the left term under the integral in the equation). This term was not taken into account by the original model, which was developed for defects with free surfaces.

In general, the new model significantly improves the prediction of echoes from interfaces where stress is significant. It is case for the water/steel example from figure 1 but also for other interfaces (soft/rigid, rigid/rigid...).

Another advantage of the new formulation is that it is valid for anisotropic material. The original model was developed for isotropic material and approximations were required to apply it to anisotropic materials. It is not the case with the new one.

In the case of volumetric defects, such as cylindrical voids for example, some errors had been observed with the original model in configurations where the emitting and receiving probes are in different directions.

The new formalism allowed correcting these errors. In the equation, the presence of the defect is only taken into account in the emitted field. In the case of a volumic defect, it is more accurate (though less intuitive) than the approach used by the original model.

Due to these ameliorations, the Kirchhoff approximation can now predict echoes for more types of reflectors in Civa.

Besides, the formalism developed for this new Kirchhoff approximation helped the development for Civa of other models based on other approximations.

References:
DESIGN OF PERFECTLY MATCHED LAYERS: APPLICATION TO ULTRASONIC NON DESTRUCTIVE TESTING

RESEARCH TOPICS: WAVE PROPAGATION SIMULATION, FINITE ELEMENTS MODELING
S. IMPERIALE, E. DEMALDENT, N. LEYMARIE
PARTNERSHIP: POEMS (CNRS ENSTA INRIA)

Finite element methods helpfully complement semi-analytical approaches in order to account for intricate propagation and scattering phenomena when simulating ultrasonic testing [1]. This motivates the search for faster and more accurate techniques, especially for restricting the computational domain around the area of interest.

The perfectly matched layers (PML) technology is often used to model unbounded homogeneous domains in wave propagation simulation. It consists in surrounding a bounded (possibly inhomogeneous) domain of interest, that may include source terms or initial data, by layers in which the wave equation is modified in order to obtain an exponential decrease of energy. It is said to be perfectly matched when no reflection occurs at the interface between the (physical) domain of interest and the (absorbing) layers.

The absorbing behavior of the equation stated in PML is described by a damping function which is introduced through a change of variables in the harmonic regime. The main difficulty lies in designing a change of variables that ensures perfectly matched property as well as stability and damping properties. The resulting problem is written back in the time domain by splitting the unknown (the solution is expressed by the sum of solutions of transport equations which involve only one spatial derivative) or by adding auxiliary variables. Each method has its own advantages and drawbacks and we focus on the splitting approach because of its ease of implementation.

However, when considering efficiency, it is better to preserve the (unsplit) wave equation in the physical domain when coupling it with the split absorbing domain to limit the number of unknowns. Moreover, most of the implementations use a damping function which is null at the interface of the physical domain and the PML to reduce numerical reflection. This damping function is chosen to grow smoothly so as to achieve a simple discretization of the underlying transmission problem. Compared to the use of a constant damping function (which simplifies the implementation but yields numerical reflection with conventional PML), this results in larger absorbing layers and thereby to additional computational costs.

We propose a more general building process that answers these problems. Our PML are constructed at a continuous level then discretized, and follow the approach first introduced by [2] for the stability analysis.

A primary reason for the novelty of our approach lies in its interpretation of the damped equations as wave equations with complex coefficients. It enables us to design perfectly matched layers through the statement of some explicit transmission conditions at the interface between the physical and the absorbing domains.

A second reason for the originality of this study is the use of a (non-overlapping) mortar element technique to write the variational form of the transmission problem. This allows for the use of a constant damping function, while the second order unsplit wave equation is preserved in the physical domain, and thereby decreases the computational costs.

Some applications are discussed and numerical results are presented in [3]. In particular, we detail the construction of PML for anisotropic acoustic waves that handles corners (in 2d and 3d) and numerical results show that a single layer of high-order elements in the PML suffices to obtain a good absorption and low reflections.

Propagation of the pressure field in the physical domain for 3d anisotropic (top) and 2d perturbed isotropic (bottom) acoustics. No reflection occurs at the boundary of the computational domain thanks to the use of suitable PML.

References:
SIMULATION TOOLS FOR ULTRASONIC GUIDED WAVE INSPECTIONS

RESEARCH TOPICS: GUIDED WAVE, ULTRASONIC NDT
K. JEZZINE, V. BARONIAN, A. LHEMERY

Guided Wave (GW) Non Destructive Testing allows the inspection of large parts without transducer scanning. However, the multimodal and dispersive nature of GWs makes it difficult to analyse and interpret the signals. This has motivated the development of simulation tools for GW NDT at CEA LIST, to conceive and optimize NDT methods or probes, and help data interpretation. They are based on semi-analytical or hybrid semi-analytical- numerical techniques and rely on a modal decomposition and post-processing of these modes to account for transducer diffraction effects and flaw scattering. Different modelling approaches are proposed depending on the regularity of the guide geometry and the nature of the defect to detect. A general formulation has been derived from the reciprocity theorem, which allows simulating the complete GW NDT response in a modal decomposition. Thus, the simulation is based on the computation of modes which propagate in the guide and their radiation and reception by transducers, as well as their scattering by flaws [1].

For regular guides (plates, pipes, or arbitrary guide section with one guiding direction) and planar flaws perpendicular to the section of the guide, these terms are calculated thanks to the SAFE (Semi Analytical Finite Elements) method well-established in the literature. For more complex NDT cases (3D flaws, geometrical singularities of the guide), a hybrid SAFE (for modes computation) - Finite Element (for computing their scattering) method has been developed [2]. Specific transparent boundary conditions have been developed which allow minimizing the size of the FE box and therefore the computation time.

An example of modal computation in a rail is presented on Figure 1. The velocities of the modes propagating over a given frequency range are displayed as well as their profiles in the guide section.

These results may be useful to choose the more suitable mode for a given application (e.g., the mode which is most sensitive to a surface breaking flaw or that which propagates over the longest distance, etc.).

A pulse-echo configuration is presented on Figure 2. A crack is detected through a junction. A piston-like transducer is mounted on the section of plate #1; the excitation is a Gaussian pulse of 10% relative bandwidth at 6dB at 95 kHz center frequency. Results shown in figure 3 compare pulse-echo waveforms in the case where plate #2 is flawless to the cases of a crack positioned just after the junction or at a distance of 400 mm from it.

The first contribution in the absence of the crack (Figure 3a) is the same as that when the crack is 400 mm away from the junction (Figure 3c). When the crack is closer (Figure 3b), this contribution is of higher amplitude.

These simulation tools have either been integrated in the CIVA software platform or are in progress of integration.

Figure 1. Group velocity dispersion curves in a rail (left). Displacement and stress profiles (right).

Figure 2. Typical GW NDT pulse-echo configuration featuring a junction and a crack.

Figure 3. Crack response corresponding to the configuration depicted on Figure 2 (a) in absence of crack, (b) crack positioned just after the junction or (c) at a distance of 400 mm from it.

References:
GUIDED WAVE SCATTERING AT OBLIQUE INCIDENCE BY A STIFFENER BONDED TO A COMPOSITE PLATE

RESEARCH TOPICS: SIMULATION OF STRUCTURAL HEALTH MONITORING OF AERONAUTIC PARTS BY GUIDED WAVES
L. TAUPIN, A. LHÉMERY, V. BARONIAN
SPONSORSHIP: EADS-IW. PARTNERSHIP: POEMS (CNRS-ENSTA-INRIA)

Structural health monitoring (SHM) is an alternative to classical methods of non-destructive testing (NDT). Sensors permanently attached to structures can be used actively for periodic examinations or passively for in-service detection of evolving defects, impacts.

Elastic guided waves (GW) at ultrasonic frequencies propagate at long range in plate structures and can detect flaws in the whole thickness. EADS-IW studies the feasibility of SHM for future aircrafts which will include many parts in composite. Simulation tools have been developed at CEA to help EADS-IW to save time in multiparametric studies for optimizing testing configurations. First, a model predicting GW in multi-layered composite plate was developed [1] in the form of a modal solution, based on the Semi-Analytic Finite Element method (SAFE). Only the thickness is meshed to get the GW solution; long range propagation is dealt analytically. Arbitrary stacking sequences are considered; they were shown to influence fundamentally long range propagation.

Present work aims at studying GW scattering by a stiffener, aeronautic plates being stiffened (Fig. 1).

To minimize the number of sensors attached to the structure and to achieve their optimal positioning, amplitudes of GW scattered by the stiffener must be predicted; they depend on the wave incidence angle onto the stiffener. Thus, the fundamental problem to be solved is the prediction of modal amplitudes of waves scattered by a stiffener for arbitrary incident GW mode making a known angle relatively to the stiffener — assumed to be of arbitrary shape and invariant in one direction (Fig. 2).

Predicting GW scattering by an arbitrary shaped composite stiffener makes it necessary to solve the problem locally by means of a generic numerical tool (here, a FE solution). It is otherwise efficient to use the SAFE model for GW propagation elsewhere.

The solution is obtained as a hybrid SAFE/FE model; it generalizes an original hybrid model developed at CEA in collaboration with POEMS which was limited to GW normally incident on the scattering feature. The original model relied onto ad hoc exact transparent conditions at the boundaries of the FE zone (scatterer) written as operators on the modal solutions describing GW in an infinite plate; these conditions are translated into a set of equations that complement the standard FE system dealing with the FE formulation applied to the 2D meshed zone. A simple post-processing allows getting transmission and reflection modal coefficients. Such exact boundary conditions cannot be derived in the arbitrary incidence case. An approximate solution has been obtained (detailed theory in [2]) which can be as accurate as the exact one but requires an additional matrix inversion over the modal solution.

The method has been implemented, validated theoretically and experimentally. An example is briefly described of a 12-layer C-epoxy plate of sequence [90, 45,0,0,+45,0]S° with a stiffener of sequence [90, 45,+45,45,0,45,0,+45,45,90]°. Fig. 3 shows various scattering coefficients for an A0 incident mode as they vary with the incident angle at a given frequency or with the frequency at a given angle. The overall behaviour is very complex.

This complexity explains why experiments with no knowledge of such behaviours cannot succeed. Simulations prior to experiments are necessary to design an optimal SHM configuration. Variations in GW behaviour with material parameters and stiffener geometry make it necessary to launch simulations each time one of these parameters is changed.

References:
SIMULATION OF ACOUSTIC EMISSION FROM CRACKS UNDER STRESS

RESEARCH TOPICS: GUIDED WAVE, ULTRASONIC NDT
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Acoustic emission (AE) is a non-destructive testing method used in various industries (aerospace, petrochemical, power generation, civil engineering, mechanical engineering, etc...) for the examination of large structures subjected to various stresses. The energy released by a defect under stress (the AE phenomenon) can propagate as guided waves in thin structures or as surface Rayleigh waves in thick ones. Sensors (possibly permanently) are positioned at various locations on the structure under examination and are assumed to be sensitive to these waves. Then, post-processing typically based on signal processing and triangulation algorithms can be used to invert these data, allowing one to estimate the position of the defect.

The results reported here have been obtained in the framework of the first author’s PhD thesis which aims at proposing efficient models in the aim of simulating AE testing. The developments carried out are based on specific models for the AE sources, for the propagation of guided or Rayleigh waves and for the behaviour of AE sensors. The coupling of a fracture mechanics based model for AE source and surface/guided wave propagation models is achieved through an integral formulation relying on the elastodynamic reciprocity principle [1]. As a first approximation, a simple piston-like model is used to predict the sensitivity of AE sensors.

We consider the configuration presented on Figure 1.

AE from the buried crack is composed of body waves as well as surface waves. Nevertheless, at some distance from the crack, the Rayleigh wave dominates due to different geometrical decay. Hence, if the observation point is located far enough from the crack, only the radiated Rayleigh wave needs to be considered.

As the crack propagates, the release of normal stresses on the crack faces produces a transient surface wave signal that can be predicted applying the so-called reciprocity theorem. This theorem connects two different elastodynamic states, state A and state B.

State A is defined as the desired solution for the surface wave generated by a crack under stress while state B is an auxiliary solution corresponding to a virtual surface wave. The amplitude of the Rayleigh surface wave is subsequently obtained after applying the reciprocity theorem in the frequency domain. It is expressed as an integral over the crack surface of the crack opening displacement that can be computed thanks to a fracture mechanics model. The displacement in the time domain is then obtained using the inverse Fourier transform. The signal at an observation point located 100mm away from the crack is represented on Figure 2.

Using a piston-like model, the delivered voltage by a circular 10mm diameter transducer located 100mm away from the transducer can be computed (Figure 3).

References:
INSPECTION OF PLANAR NON-MAGNETIC MATERIALS WITH MAGNETIC ACOUSTIC TRANSDUCERS: EXPERIMENTS AND SIMULATION TOOLS

RESEARCH TOPICS: NON DESTRUCTIVE TESTING, SIMULATION ULTRASONIC TESTING

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The characterization or detection of flaws in ultrasonic inspection requires the generation of ultrasonic waves in solid materials. Conventional piezoelectric transducers are able to generate the ultrasonic energy but transfer from the transducer to the material under test requires the use of coupling. For some specific applications, the probe cannot be immersed or cannot be in contact with the specimen due to surface roughness or high temperature. For the inspection of conducting material, an alternative consists in applying an electromagnetic coupling. Electro-Magnetic Acoustic transducers (EMATs) have the capability to generate a great number of ultrasonic waves of different types without any contact or liquid coupling. Unfortunately, the poor efficiency of the transduction effect in the transmitter/receiver probe leads to a poor signal-to-noise ratio. So, efficient simulation tools are required to perform various parametric studies in order to optimize the performances of such transducers. CEA LIST has developed, into the CIVA platform, fast simulation tools to help NDT experts in designing such transducers.

In general, an EMAT transducer consists in a set of coils driven by a pulsed current (see Figure 2), locally inducing an eddy current density $J$ in the specimen under test, and a set of magnets generating a static magnetic field $B$ in the same area. Figure 1 depicts a typical configuration, dedicated to the generation of longitudinal waves in planar structures. In this case, eddy currents are directed toward the $y$ direction and the static magnetic field is oriented toward the $x$ direction. Semi-analytical eddy current models of CIVA, addressing the harmonic regime, have been extended to the time domain by using Fourier synthesis. The Lorentz force, defined as $F = J \times B$, is then calculated and used as a source term by ultrasonic models of CIVA.

The propagation of acoustic waves is simulated inside the specimen. A great number of waves (SH, L, S, Rayleigh, Lamb) can be simulated according to the arrangement of the EMAT probe. Figure 3 depicts the configuration associated to a real transducer, which has been used to perform experimental validations. An example of the transmitted ultrasonic field is displayed in Figure 4.

The case of planar structures made of ferromagnetic materials is currently investigated by taking into account magnetostrictive effects. Guided modes generated by EMATs in planar structures are also implemented into the platform. A perspective of this work is the modeling of EMAT phased arrays.

References:
A biologically inspired approach to learning temporally correlated patterns from a dynamic vision sensor is presented, in complete break with classical frame-based algorithms. When tested with real-life data, the system is able to learn by itself and detect car trajectories on a freeway with 98% accuracy, after only 10 minutes of traffic learning.

The overwhelming majority of vision sensors and processing systems currently in use are frame-based, where each frame is generally passed through the entire processing chain. Now for many applications, especially those involving motion processing, successive frames contain vast amounts of redundant information, which still need to be processed. This can have a high cost, in terms of computational power, time and energy. For motion analysis, local changes at the pixel level and their timing are really the only information one needs, and it may represent only a small fraction of all the data transmitted by a conventional vision sensor of the same sensibility.

Spiking silicon retinas, which are directly inspired from the way biological retinas work, are a direct response to the problematic exposed above. Instead of sending frames, silicon retinas use Address-Event Representation (AER) to asynchronously transmit spikes in response to local change in temporal and/or spatial contrast. However, classic vision processing algorithms are inefficient or simply do not work with them. Image-based convolutions for example are difficult to implement, because pixels activity is asynchronous and the data stream is continuous.

To overcome these difficulties, we propose a novel approach that fully embraces the asynchronous and spiking nature of these sensors and is able to extract complex and overlapping temporally correlated features in a robust and unsupervised way [1,2]. We use a biologically inspired Spike-Timing-Dependent Plasticity (STDP) learning rule to process dynamic spike-based stimuli, recorded from an asynchronous sensor. We show how motion sequences of individual objects (Fig.1) can be learned from complex moving sequences with a feed-forward spiking neural network (Fig.2).

Such a neural network could very well be used as a pre-processing layer for an intelligent motion sensor, where the extracted features could be automatically labeled and higher-level object tracking could be performed. Because the STDP learning rule is very loosely constrained and fully local, no complex global control circuit is required. This also paves the way to very efficient hardware implementations that could use large crossbars of emerging resistive memories.

Fig.1. Top: dataset used for the learning (traffic recording). Bottom: sensitivity map of the neurons for each traffic lane.

Fig.2. Neural network topological overview for visual features learning, directly from data recorded with the AER sensor.