ADREAM

Architectures for Dynamic Resilient Embedded Autonomous and Mobile systems

The Research Program and the Experimentation Platform

Towards the Design, Deployment and Evaluation of Cyber-Physical Systems

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Section 1: Introduction

The new LAAS-CNRS project, called ADREAM, Architectures for Dynamic Resilient Embedded Autonomous and Mobile systems, is an interdisciplinary research program dedicated to the design and evaluation of complex intelligent cyber-physical systems, *thus involving system science, information science, control science, communication science and energy science*.

ADREAM research addresses the methods, mechanisms and algorithms to be developed to build large cyber-physical architectures. The aim is to understand and solve the new main technical challenges coming from the coherent and innovative integration of many domains, technologies, architectures and devices, e.g., sensors, robotics, machine-to-machine communication, networking, dependablitity, decision, optimization, embedded systems and energy systems.

In the framework of the French *Contrat de Projets État-Région 2007-2013*, and with the support of the French State, of the *Région Midi-Pyrénées*, of the EU through the FEDER progam, of the *Toulouse Métropole* Urban Community, of CNRS and LAAS-CNRS, the research program of this very ambitious, challenging and multidisciplinary project has been complemented by the definition and the construction of a new unique experimental design and evaluation platform.

The ADREAM platform is a new buiding, fully equipped with sensors, robots, networks, embedded devices, and photovoltaic electricity production equipments. The building will allow the researchers who are working on the project, and in particular the researchers who are residing in the building, to design and validate the required advanced architectures and systems, and to give a real evaluation of the new services provided to the users.

Finally, a long-term goal of this research project and of the experimentation platform is to implement, deploy and understand what are, among the various developed solutions, the ones that can effectively improve quality of life and optimize energy utilization in real buildings. More precisely, the platform will be used to propose the best support systems to all people both at their working places and homes.

As a consequence, ADREAM is both:

- a research program dedicated to the design and validation of complex dynamic resilient embedded mobile autonomous cyber-physical systems, supported by a large set of methods, tools and projects,
- an innovative experimentation building that complements the program, implements and integrates several of the research results on sensors, robots, communications, networks, and energy, and that is also able to provide to the designers a real support for implementing and evaluating the proposed components and architectures.
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This note provides a concise presentation of[1] *that gives the main features of the ADREAM research project and of its experimentation platform, i.e., the building that hosts it.*

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[1] J. Arlat, C. Artigues, Y. Deswarte, M. Devy, M. Diaz, J.-M. Dilhac, K. Drira, B. Estibals, K. Kanoun, A. Nketsa, P. Pons, F. Vernadat, *Le Programme Scientifique du projet ADREAM*, LAAS-CNRS, 2012 (In French) https://www.laas.fr/public/sites/www.laas.fr.public/files/general/ADREAM/pdf/ADREAM-ProgrammeScientifique113-01-15.pdf

The External View of the ADREAM Building

Section 2: The ADREAM Cyber-Physical Systems Research Program

As the ADREAM program will develop research on methods, devices, services and tools, and will implement many experiments for evaluating new cyber-physical systems, it will have to

- propose and design, in the addressed science and technology domains, new innovative disciplinary and inter-disciplinary solutions,
- deploy and validate these results on a large real cyber-physical system of significant complexity, but observable and controlable.

The scientific program will address a large set of topics related to the design of these new embedded cyber-physical systems. From the work undertaken in these areas by LAAS research teams, eight main topics were proposed, addressing the technologies, methodologies and design supports.

The first six topics presented in the next sections describe the research that will be conducted by the laboratory, and dedicated to the techniques, technologies, algorithms and services needed for designing these cyber-physical systems, i.e., Micro and nano sensors, Autonomic computer systems, Localization, navigation, robotics and mobility, Optimization and control, Energy Systems, and Security and privacy.

As this will lead to highly complex architectures, high-level software tools to support the design phases are indispensable. The last two sections present the two related topics themes, i.e., Co-simulation and co-validation environments and Formal development of adaptive mobile systems. The first topic is dedicated to validation by simulating a large part of the architecture, or the system as a whole, and the second one to the verification of the quality of the most critical parts of the proposed system.

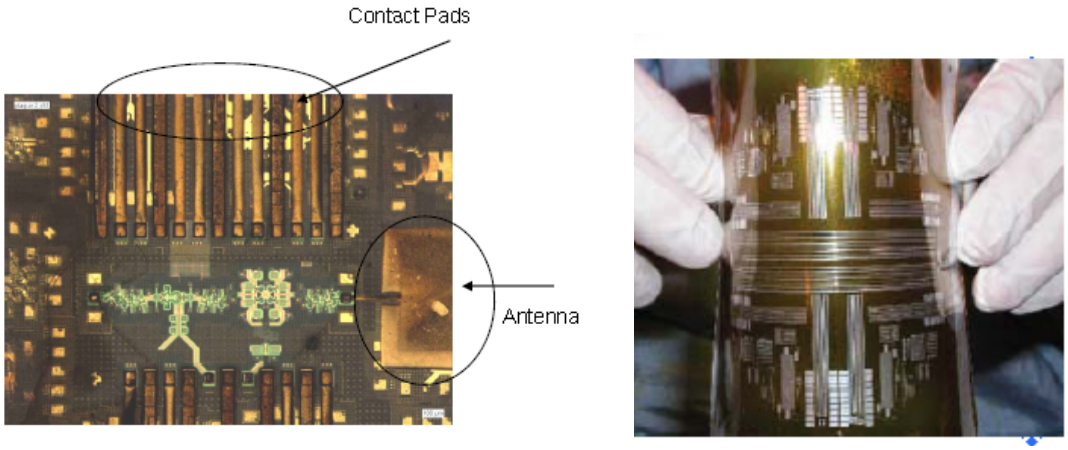
A high level presentation of this set of topics, that will be investigated by LAAS-CNRS, in still to be defined cooperations with partners, are now given. They are as follows:

- Micro and Nano Sensors

- Autonomic Computing Systems
- Localisation, Navigation, Robots and Mobility
- Optimisation and Control
- Security and Privacy
- Energy Systems
- Formal Development of Adaptive Mobile Systems
- Co-Simulation and Co-Validation Environments.

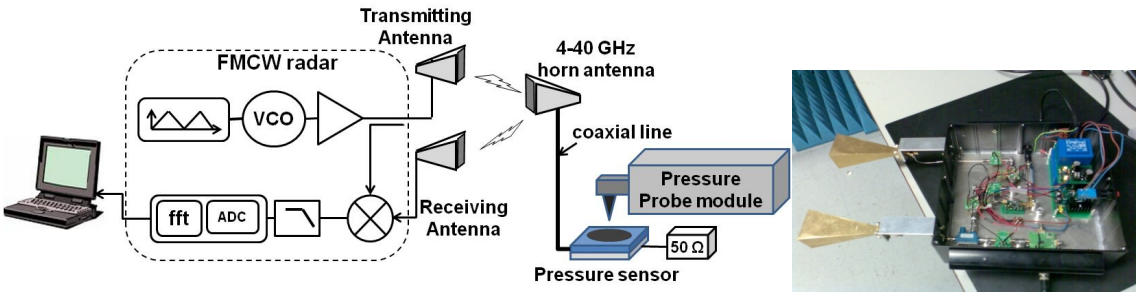
2.1 Micro et Nano Sensors

An autonomous communicating sensing system is usually defined by a detection module, the sensor, in charge of the information measurement and transfer, that includes: a transducer giving the electric signal, a small processing computer, a communication element, and a power unit.



SiGe 60GHz Transmitter and Integration

Another family of approaches leads to the development of passive sensors, which only include a transducer (e.g., electromagnetical), in which a signal is sent by a processing unit and only sent back, (not processed), by the sensor. The interest here is of course energy autonomy, with no consumption, and hardware minimisation (no electronic circuit).



Radar Interrogation and View of the 30 GHz Radar

As a consequence, the main following generic problems that will be considered in the research, are:

- New transducers that have to be designed in given domains, cost and performance features (stabilized laser sources, electrochimical detection in smal volumes, etc.),
- The multi-physical, multi-scale and predictive modeling and the virtual prototyping of very heterogeneous sensors (e.g., including mecanical, optical, electronical, etc., devices),

- The technological integration of micro et nano sensing systems, including the integration of detection materials, of transduction, of encapsulation, of generic technologies as "Silicium and Polymers", etc.,
- The sensor robust conditioning for hostile (humidity, temperature, pressure, vibrations, corrosion, etc.) environments,
- The measurements and drifts error corrections, including self-calibration and self-diagnostic, and providing dynamic reconfiguration,
- Energy generation, scavenging, storage and management, to provide, as much as possible, energy autonomy for embedded sensors.

2.2 Ubiquitous Autonomic Computing

An adequate level of autonomic computing will be necessary for new complex computing systems, as manual management will become more and more difficult to define and implement.

This topic is dedicated to the design and development of methods, software and tools to address:

- complex system monitoring, diagnostic and analysis (using on-line measurements),
- context analysis and decision selection (for adaptativeness),
- real operational adaptation (including a dynamic reconfiguration of the distributed hardware configuration, of the communication stacks and protocols, and of the applicative or service software).

The scientific objectives will mainly address guaranteeing or optimizing the non-functional properties of the systems, and more precisely, its autonomic, resilience and quality of service, including anomaly detection, even in the case of errors in the communication traffic.

The main research themes will concern:

- the resilience of ubiquitous systems,
- the adaptive quality of service and the intelligent control of autonomic communications,
- the unsupervised detection of networks traffic anomalies.

The research will include approaches for developing the components and services behaviors (hardware and software), the requested deployment rules for a fully distributed hardware infrastructure, and the selection of the most adapted communication protocols. It will also address all the control phases defining the management cycle for providing the properties of self-configuration, self-protection and self-adaptation.

2.3 Localization, Navigation, Robots and Mobility

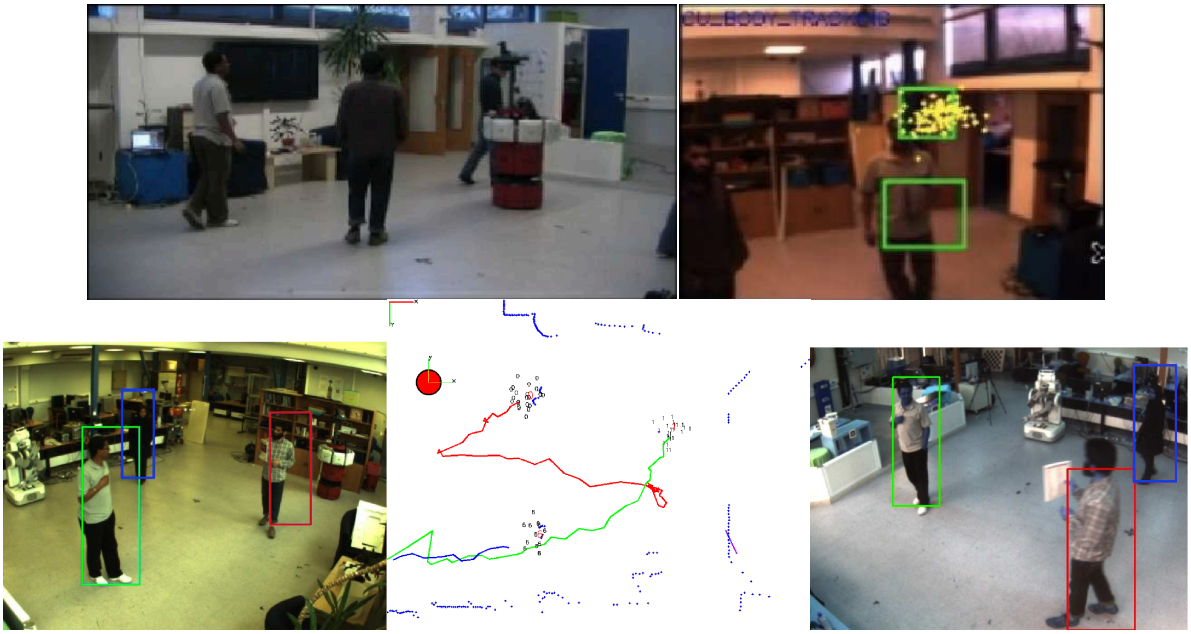
The computing autonomous system will be enriched with context knowledge coming from new sensors, and with cognitive actions from the robots, while having to support mobility. Mobility here concerns two different complementary domains: a) Ambient Intelligence, to design and deploy communicating devices, located on human beings or on mobile devices, able to estimate the context, to interpret it, and to send adequate actions; b) Robotics, with the deployment of a set of cognitive mobile robots, also able to physically interact with the users, with the environments, or with objects.

The purpose of this topic is to design and deploy fully integrated systems, which means to develop and validate at least the localisation, authentication, navigation and communication services.

This will also mean to develop and deploy a large set of interconnected cooperative embedded elements (including sensors, routers, processors, robots, etc.) including:

- localization means to evaluate the coordinates of all entities (as objects, robots, people) with respect to a given, possibly mobile, reference,
- authentication of each entity of the environment, together with a learning of their characteristics, the learning being supervised or not supervised;

- navigation, i.e., how to perform the best moves in the environment, even in very dynamic contexts.



Coordinated Human-Robot Navigation

This research will mainly be dedicated to:

- Authentification knowledge engineering and software technology,
- Sensing, understanding, monitoring and surveillance Environment,
- Diagnosis and dependability of robotics systems,
- Robust control for robots, robot-human interaction, and multi-robot coordination and cooperation.

2.4 Optimization and Control

The intelligent environments considered by ADREAM are instrumented by embedded systems providing perception, processing, mobility and communications functions, and using elements such as sensors, robots, networks and services.

Furthermore, their integration to build complex architectures in interaction with the humans implies considering many requirements, as strong real time, high criticity, and garanteed robustness, even in the case of multiples uncertainties or of partial or intermittent informations, etc.

These requirements apply for defining low-level control strategies as well as high-level decisions. As an example, the control rules in mobile agents must be of acceptable complexity, while guaranteeing a correct behavior in hard contexts.

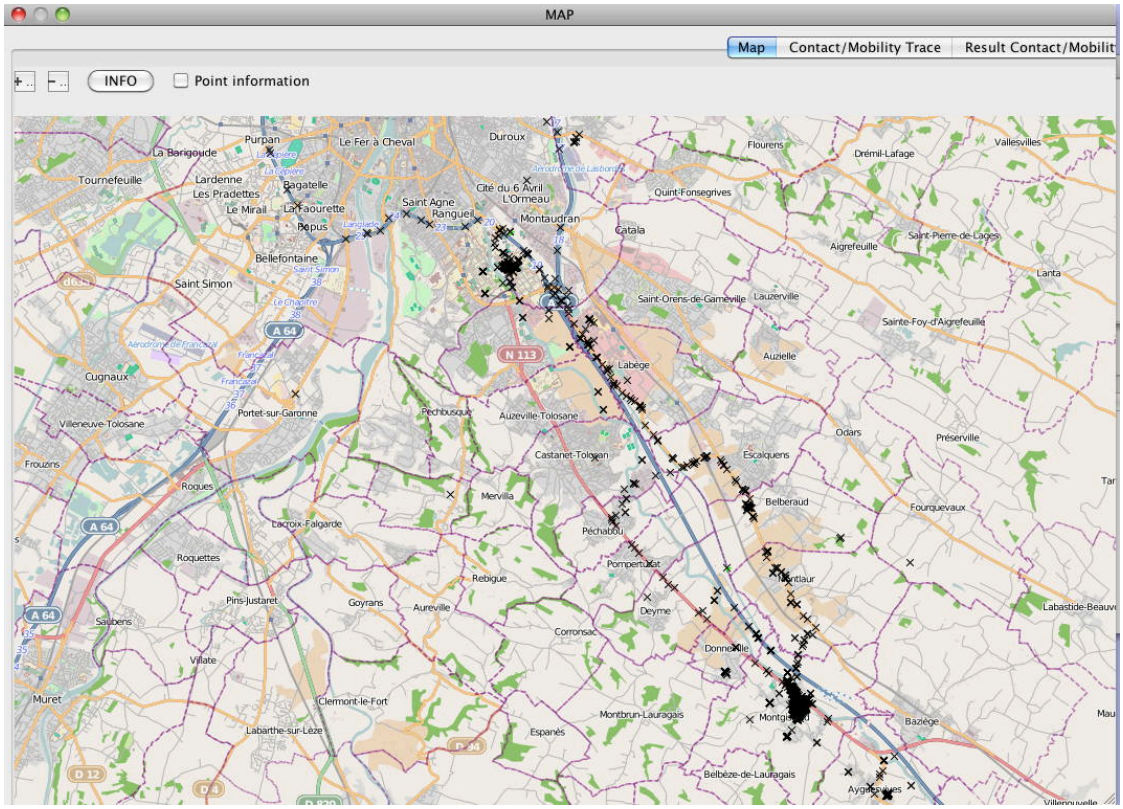
At the high levels, the potential limited capacity of the communication channels often implies to develop a task scheduling subject to hard temporal constraints. Also, the possible unexpected faults needs combinatorial optimization that guarantees a correct robustesness level for dynamical reconfiguration capacity (e. g., of the mobile elements).

As a consequence, the research objectives mainly deal with:

- the control systems, and in particular using limited information and for robotics
- the two scientific problems related to the techniques of combinatorial optimisation in embedded systems, i.e., mobility organisation and task scheduling,
- The optimisation solutions for open perception problems in robotics.

2.5 Security and Privacy

ADREAM considers a large set of interconnected objects, from simple devices to mobile autonomous embedded systems, that are increasingly impacting our everyday life, from the working places (e.g., office networks, plant networks) to the personal environments (e.g., home networks).



Example of Mobility Traces

As a consequence, security and privacy become a quite important problem, often neglected, for instance when attractive applications are put on the market without considering enough privacy, especially for applications vulnerable to attacks. These resulting possibilities can lead to industrial espionage, fraud, abusive use of personnal data (e.g., for intrusive marketing, blackmail, libelling, etc.), or even crimes.

Because of this strong interaction with the humans, security and privacy failures occur because the collected, processed, sent or stored data can be very sensitive in applications such as:

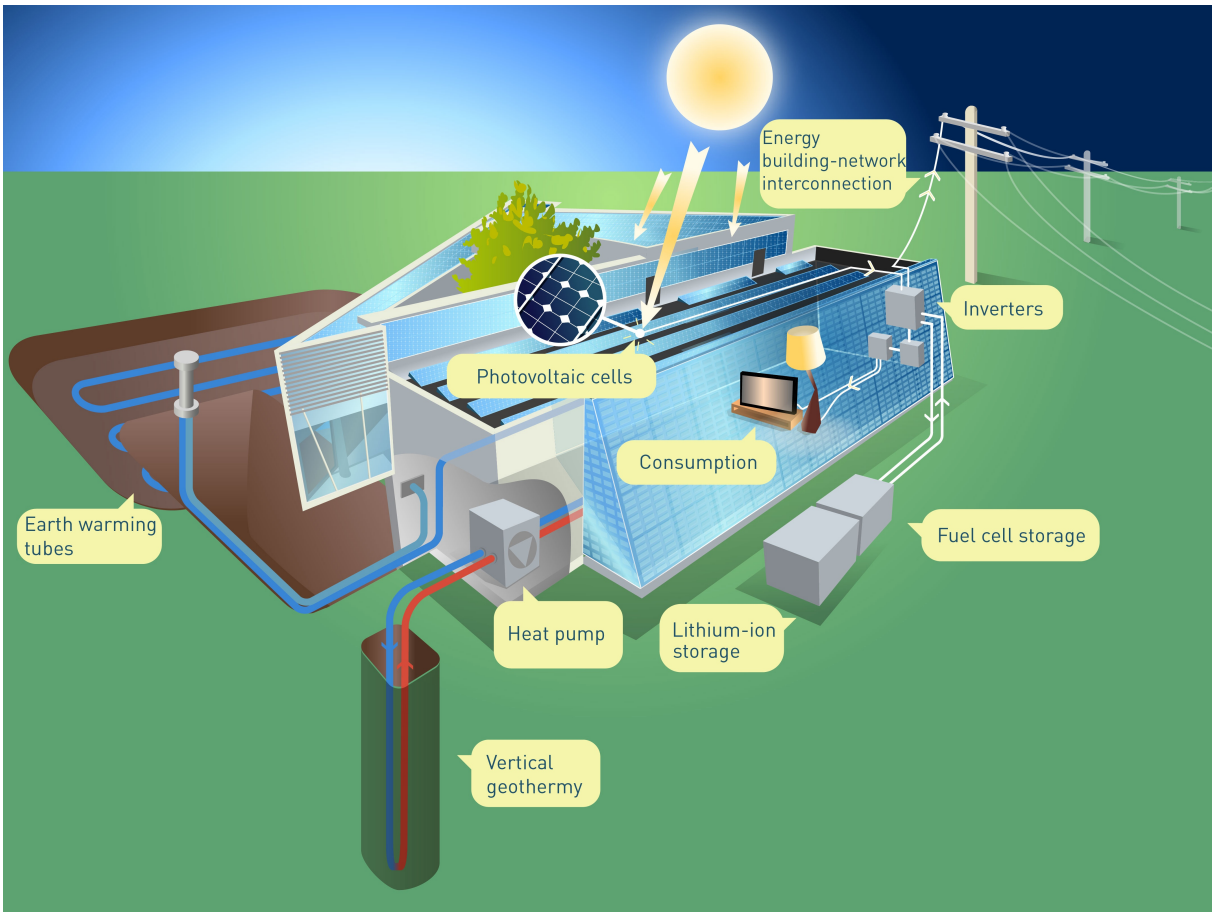
- offices, plants, enterprise networks, critical infrastructures, etc., that may handle important commercial or industrial data,
- administrations, hospitals, services, etc., that collect, store and process personal data,
- homes, for instance for intelligent electrical counters or medical devices, as well as for participations in virtual communities (family, gaming, political, etc.), with private data,
- public spaces, transports, civil security, etc. in which the mobile systems process data that can threathen privacy, in particular for localization data.

This will be investegated by developping mainly the two following objectives:

- vulnerability analysis and protection of largely deployed home equipements and appliances linked to the Internet,
- protection of personal data related to localization-based applications.

2.6 Energy systems

Energy management and optimization are now major concerns in our society, and the next energy networks will have, safely and rapidly, to accept multiple heterogeneous sources and to react adequately to the variations, even not anticipated, of the large number of users. These requirements led to the definition of *Smart Grids*, i.e., energy networks providing the classical "transport of energy" and furthermore using avanced capabilities for sensing, monitoring, communicating, controlling, etc.



The ADREAM Energy System

The scientific and technical objectives in this topic address all design and evaluation aspects of these new energy networks, by integrating the research in many domains that are subject to numerous multi-technological constraints. The skills needed span power electronics, computer science, control science, networking and dependability. Addressing these problems implies more particularly:

- The deep understanding of the different behaviors of all entities that are connected to the grids, e.g., the sources, in particular photovoltaic, the users, and their variations,
- The development of the global optimization and management of the energy system, by introducing all system entities (up to the sociological level), and using a massive deployment of intelligent autonomous sensors,
- The design and implementation of the related complex distributed networks and computer systems to handle the information flows, the global controls, while guaranteeing the requested properties of security, performance and dependability,
- The evaluation of these solutions using a real mini-grid, of significative but manageable complexity, in particular to illustrate the difficult problems related to quality of service and scalability.

The research will address both the energy management of buildings, including photovoltaic yield, power maximisation, conversion and storage, and the energy management of computing systems, including optimization of consumption and autonomy.

2.7 Formal Development of Dependable Adaptive Mobile Systems

The purpose of this topic is to define and experiment a set of verification, test, performance evaluation and dependability approaches for critical systems.

The approaches will have to take into account the mobility and adaptivity constraints and properties that are at the heart of ADREAM. They will address the main following five themes:

- formal development and model-checking,
- software testing,
- optimization for planning and scheduling,
- performance evaluation,
- dependability and resilience evaluation.

The research will be applied to selected systems, designed in dedicated research projects, and whose results are expected to contribute:

- on one hand, to the development and validation of the different phases of the design of critical systems,
- on the other hand, to the application, evaluation and consolidation of these methods used, developped or extended in the context of ADREAM.

2.8 Co-simulation and Co-validation Environments

Co-simulation and co-validation are often used during the design of complex systems. They are part of the set of studies needed to develop detailed design support tools needed to build complex inter-disciplinary multi-technology simulation platforms, in particular as in ADREAM.

An important work has to be conducted to define an open relevant co-simulation environment, Our approach will rely on the use of formal models and tools (see the previous topic):

- either for producing efficient test sequences,
- or for validating or strengthening the simulation results.

As system validation means comparing a model to the real world, handling the matching means to:

- formalise the simulation, one of the best ways that can be used to specify, express and validate complex simulation problems,
- experiment multi-disciplinairy examples, by proposing and evaluating a co-simulation environment able to handle multiple (often multi-physical) abstraction levels**.**

The research work will mainly address the design of the following themes:

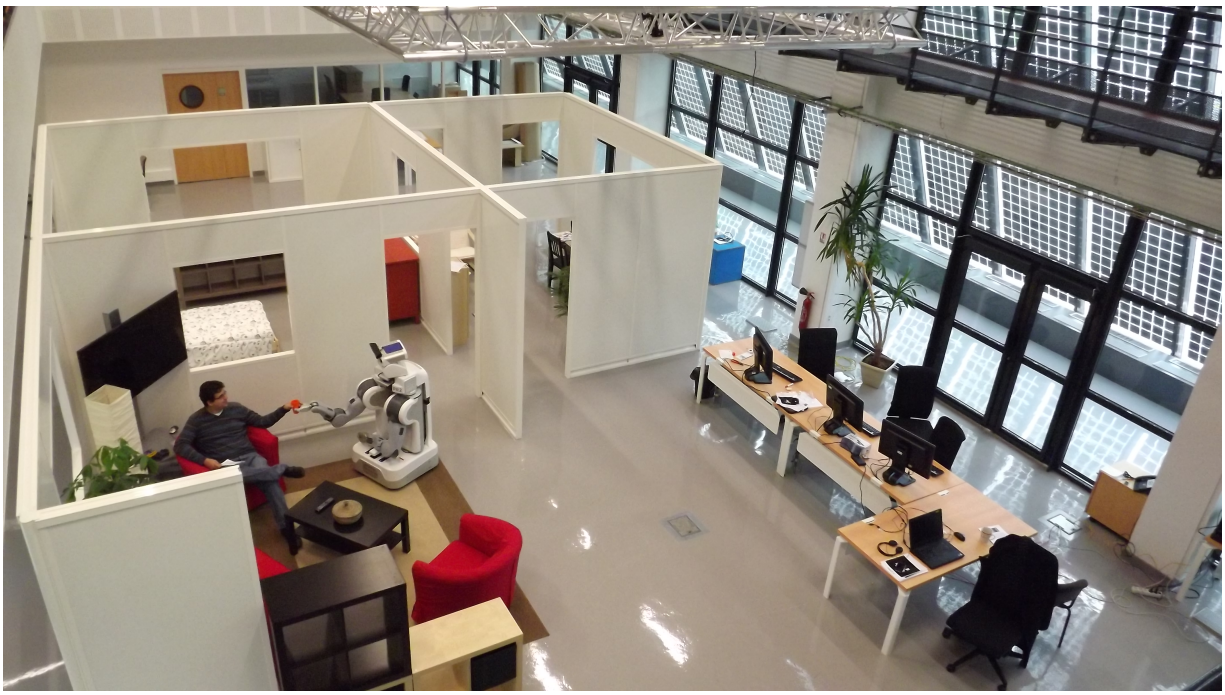
- global simulation framework, including the models,
- validation metrics and their formal representations,
- specification language and the test data generation,
- development of simulation methods and tools.

Section 3: The ADREAM Platform for the Integration of Robotics Cyber-Physical Systems and for Energy Optimization

The building is an advanced environment for the design and the validation of ubiquitous, autonomous, resilient and energy-aware systems by relying on pervasive computing and distributed intelligence.

It integrates a large set of different devices into an intelligent integrated environment with sensors, actuators, networks, robots, powered by a massive photovoltaic production of 100 KWc.

The Photovoltaic Main Window Facade



The Cyber-Physical Experimentation Room

The ADREAM platform integrates many complementary knowledge and skills originating from the electronic, energy, decision, robotics and critical computing systems research areas of the laboratory, and will be used to demonstrate, by designing and deploying a real complex system, the innovative facets of the developments, realizations and integrations of the research conducted on these domains by LAAS and its cooperating partners.

The platform addresses in particular the optimal production and consumption of electrical energy, the perception and interpretation of the environment, the cooperation of robots with humans, the design of sensor networks, the architecture of protocols and services for machine-to-machine communications, subject to given performance and dependability constraints, i.e., availability, security, and privacy.

Unique in Europe, the platform today includes in particular:

- a photovoltaic energy production system, with inverters, sensors, a system for storing energy, and lab benches connected to the photovoltaic panels of power generation,
- a decor apartment infrastructure for experimenting machine-to-machine communications, detection of people behaviors, and planning and interaction of the humans with companion robots,
- three autonomous robots, cameras and vision sensors, presence sensors, sensors for 3measuring the electricity production and consumption of the main building sub-systems, environmental sensors (weather, temperature,...), etc.

More specifically, the energy related facilities include:

- a front facade made of bi-glasses and tri-glasses photovoltaic modules,
- an experimental characterization terrace equipped with tiltable solar panels,
- a roof with a weather station and solar panels fixed and tilted at 10°,,
- a buffer gallery, located behind the front photovoltaic window, and equipped with an air circuit of adiabatic free-cooling,
- an exchanger connected to a 5 m deep Canadian well, which delivers an air at 15 degrees Celsius,
- three geothermal heat pumps, connected to 18 geothermal probes reaching 100 m depth.

Section 4: Conclusion

The goal of the ADREAM project is to produce new results in many domains related to complex mobile embedded controlled cyber-physical systems, including energy, sensors, robots, networks, decision, autonomy and adaptivity. It also spans the development of methodologies and approaches, first for implementation and actual deployment, and second, for validation and evaluation.

The project also tackles the new challenges coming from the coherent cooperation of the research results various domain, following a "System of Systems" approach, e.g., the integration of all of them altogether, in a coherent and innovative way, and in particular in the new ADREAM building and experimentation platform.

Contacts

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