IRI celebrated in 2015 its 20th anniversary. These two decades have consolidated IRI as a reference center in Spain for research in robotics and automatic control. We saw this year the culmination of this growth process with the recognition of IRI as a María de Maeztu Center of Excellence for the forthcoming four-year period (2017-2021) with a strategic research program on human-centered robotics.

The research activities that have led us to this success are of varied nature. We can highlight those presented in the following:

- The immediate future at Institut de Robòtica i Informàtica Industrial is posed with plenty of stimulating activity

Juan Andrade
Director

IRI's researchers published 86 indexed journal papers during this period, 60% of them in journals positioned in the first quartile of their respective disciplines. 9 book chapters, 1 edited book, and 100 conference papers. Of these, we celebrate 5 articles in the IIEEE Transactions on Industrial Electronics, the highest-ranked journal in the automation and control systems subject category, 2 articles in the IEEE Transactions on Pattern Analysis and Machine Intelligence, and 1 article in the International Journal on Computer Vision, the second and third-ranked journals in the computer science-artificial intelligence subject category.

Fifteen PhD students completed their studies during this period. Special recognition is given to Gonzalo Ferrer, finalist of the 2016 euRobots Georges Giralt PhD Award to the best European PhD in robotics; for his work on social robot navigation in urban dynamic environments; and to Edgar Simó, who obtained the 2016 Estève-Vivanco Prize to the Best PhD Thesis on Artificial Intelligence awarded by the Catalan Association for Artificial Intelligence. Edgar's work on the use of deep learning in computer vision for the creation of recommendation systems for the fashion industry received significant national and international media attention.

Other achievements during this period include the first prize in the CEABOT humanoid robotics contest awarded to Lao Pires and Alejandro Suárez, the best oral paper to Congcon Sun in the WIRE conference, and the participation of Prof. Carme Torras in the alwinians organizing committee of the 2015 IEEE International Conference on Robotics and Automation.

Our scientists continue to be very active in the procurement of competitive funds to support their research. This period we ran 38 projects with a total budget of 7.6M€, 70% of which comes from EU competitive calls. Most funds are linked to competitive research projects, although other relevant initiatives are also present. A long-term partnership with Cetaqua for contributions in the development of innovative solutions for the water cycle management.

The immediate future is posed with plenty of stimulating activity at IRI, and I am sure that our scientists and collaborators worldwide will find a great setting for their scientific success.
The Institut de Robòtica i Informàtica Industrial is a Joint University Research Institute of the Spanish Council for Scientific Research (CSIC) and the Technical University of Catalonia (UPC).

The Institute conducts basic and applied research in robotics and automatic control.

It was created in November 1995 and is located in the Parc Tecnològic de Barcelona, in the Faculty of Mathematics and Statistics building in the South Campus of UPC in Barcelona, Spain.

**ORGANIZATION**

**DIRECTOR**
Juan Andrade

**DEPUTY DIRECTOR**
Carlos Ocampo

**RESEARCH LINE LEADERS:**

- **MOBILE ROBOTICS**
  Alberto Sanfeliu

- **KINEMATICS AND ROBOT DESIGN**
  Josep Maria Porta

- **AUTOMATIC CONTROL**
  Maria Serra

- **PERCEPTION AND MANIPULATION**
  Carme Torres

**DEPARTMENT HEAD:**
Pablo Jiménez

**REPRESENTATIVES:**

- PhD Members: Antonio Agudo
- PhD Students: Àngel Santamaria
- Support Personnel: Evili del Río

ADDRESS:
Parc Tecnològic de Barcelona, C/ Llorens i Artigas 4-6, 08028 Barcelona, Spain
The María de Maeztu scientific excellence seal has been awarded to IRI by the Spanish State Research Agency for the period 01/07/2017–30/06/2021. Beneficiary entities are both CSIC and UPC as a joint research unit. A 4-year Strategic Research Programme will be developed in Human-Centered Robotics.

The concept of human-centered robotics is meant to include the many different situations in which robots are in close contact and interact with humans. These include, but is not limited to, social robotics with significant human-robot interaction, collaborative robotics in which humans and robots work together to achieve a common task, or assistive robotics in which robotic technologies are exploited to help the elderly or the impaired.

7 key core challenges were identified that apply to all these domains, and translate into these 7 specific scientific objectives of significant relevance and novelty.

**Project description**

- Emphatic natural human robot interaction and collaboration
- Robust localization and mapping
- Dexterous textile manipulation
- Robot learning using natural communication
- Energy supply and management
- Advanced supervision and control
- Ethical, regulatory and philosophical aspects of social robotics

**Project description**

Textile objects pervade human environments and their versatile manipulation by robots would open up a whole range of possibilities, from increasing the autonomy of elderly and disabled people, housekeeping and hospital logistics, to novel automation in the clothing internet business and upholstered product manufacturing.

Although efficient procedures exist for the robotic handling of rigid objects and the virtual rendering of deformable objects, cloth manipulation in the real world has proven elusive, because the vast number of degrees of freedom involved in non-rigid deformations leads to unbearable uncertainties in perception and action outcomes.

This proposal aims at developing a theory of cloth manipulation and carrying it all the way down to prototype implementation in our Lab. By combining powerful recent tools from computational topology and machine learning, we plan to characterize the state of textile objects and their transformations under given actions in a compact operational way (i.e., encoding task-relevant topological changes), which would permit probabilistic planning of actions (first one handed, then bimanual) that ensure reaching a desired cloth configuration despite noisy perceptions and inaccurate actions.

In our approach, the robot will learn manipulation skills from an initial human demonstration, subsequently refined through reinforcement learning, plus occasional requests for user advice. The skills will be encoded as parameterised dynamical systems, and safe interaction with humans will be guaranteed by using a predictive controller based on a model of the robot dynamics. Prototypes will be developed for 3 envisaged applications: recognizing and folding clothes, putting an elastic cover on a mattress or a car seat, and helping elderly and disabled people to dress.
IRI IN NUMBERS

In the biennium 2015-2016, our center has continued being a scientific leader in the fields of robotics and automatic control in Spain. We have seen significant strengthening in many aspects such as scientific production and fundraising.

Our research staff published 207 scientific papers in journals and conferences in the period 2015-2016, more than in the previous two years. Growth is appreciated not only in the quantity of publications, but also in quality, increasing by 29% the number of articles published in highly-ranked journals.

Regarding the procurement of competitive funds for research, we have signed 19 new projects this two-year period, nearly reaching more than 3.8 million Euros of secured research funds.

MEMBERS IN THE STAFF

- 31 Permanent Research Staff and Postdocs
- 36 PhD Students
- 11 Support and Technical Staff
- 41 Undergraduate and Master Students
- 15 Services Staff
- >21 Robots

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STAFF EVOLUTION since 2006 (stacked chart)

total: 134 persons

RESEARCH PROJECTS

- 14 European Projects
- 12 National Projects
- 10 Regional Projects
- 6 CSIC Projects
- 5 Tech. Transfer Projects

BUDGET OF THE PROJECTS

- 3814,4 Secured funds of the project initiated in period 2015/2016 (in thousand of €)
- 1619 European Projects
- 1019,7 National Projects
- 2127,9 Regional Projects
- 169 CSIC Projects

see page 16

PHD THESES DEFENDED in 2015/2016

- 15 PhDs

see page 69

SCIENTIFIC PUBLICATIONS in 2015/2016

- 207 papers

see page 60
FACILITIES

LABORATORIES

Barcelona Robot Laboratory

The Barcelona Robot Lab encompasses an outdoor pedestrian area of 10,000 sq m, provided with 21 fixed cameras, a set of heterogeneous robots, full wi-fi coverage and partial GPS coverage. It has the capability to process real-time images for robotic applications. This laboratory is used for urban pedestrian mobile robotics research in national and European projects.

Kinematics and Robot Design Laboratory

The Kinematics and Robot Design Laboratory was initially created to validate the practical interest of our parallel robot designs, but it has rapidly derived into an active lab where the prototypes designed by the researchers of the Kinematics and Robot Design Group are implemented as proofs of concept. Such prototypes include reconfigurable mechanisms, rolling robots, active surfaces, force-sensing structures, and cable-driven platforms.

Mobile Robotics Laboratory

The Mobile Robotics Laboratory is an experimental area primarily devoted to hands-on research with mobile robot devices. The lab includes two service robots for urban robotics research based on Segway platforms, a 4-wheel rough outdoor mobile robot, a fully automated electric vehicle, a six-legged LAURON-III walking robot, 3 Pioneer robots, three aerial autonomous robots (from 500gr to 5kg of payload) and a vast number of sensors and cameras. The laboratory is also equipped with an aerial trial area (4x7m) which includes a 12-IR-camera Optitrack positioning system.

Perception and Manipulation Laboratory

The lab is equipped with 2 workcells: one with 2 industrial manipulators and an XY positioner, and the other with 2 WAM arms in a reconfigurable arrangement. Additionally, researchers can find a 3 fingered hand, a Delta haptic interface, force sensors, several conventional cameras, and high-speed, high-resolution, and 3D cameras. The laboratory service offers quick experimental setups, several standardized software tools, and expertise in robot control and perception algorithms.

Fuel Cell Control Laboratory

The objective of the Fuel Cell Control Laboratory is the validation and testing of control strategies that maximize energy efficiency and extend the life of high and low temperature PEM fuel cell systems. The laboratory has five fuel cell test stations equipped with the necessary sensors and actuators to operate the systems in a safe and automated way, as well as the capability to implement a great variety of high level and low level controllers. The facilities are equipped with a monitoring system to comply with the necessary safety conditions.

Water-cycle Control Systems Laboratory

The aim of this laboratory is to test and validate modelling and control developments for dynamic systems associated to the water cycle. Hence, it provides platforms of pressure, flow and level processes, over which it is possible to implement real-time advanced control strategies.

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SERVICES

IT Services

The IRI IT service (IRITIC) is responsible for all the computer and communications infrastructure of the Institute, as well as user support. We have a small data center properly suited with rack servers and communications devices.

Administration

The Institute has the support of an administrative service in charge of all accounting related to projects and contracts as well as the management of the whole Institute’s human resources, space and equipment.

Outreach and Tech Transfer Office

The Outreach and Tech Transfer office was constituted in 2015 as part of the Tecnio certification program funded by ACCIÓ and with personnel from the Plan de Garantía Juvenil. It is in charge of managing dissemination and outreach activities, including press releases, visits, social networks; as well negotiation and management of tech transfer agreements with industry.
The Institute’s research activities are organized in four research lines: (1) Kinematics and Robot Design, (2) Mobile Robotics, (3) Perception and Manipulation, and (4) Automatic Control.

Three of them tackle various aspects of robotics research, including indoor and outdoor human-centered human-safe robotics systems, and the design and construction of novel robotic mechanisms. Efforts in the fourth line are aimed at research on modeling, supervision and control on energy systems and the water cycle.

IRI’s research activities are funded primarily by grants from the EU Research Framework Programme and by competitive funds from the Spanish Ministry of Economy, Industry and Competitiveness through various research funding programs.

Other sources that support our research include projects funded by the Government of Catalonia, by our hosting institutions (CSIC and UPC), and through technology transfer contracts.
The Kinematics and Robot Design Group carries out research on the design, construction, and motion analysis of complex mechanisms and structures. In Robotics, these devices are parallel manipulators, multi-fingered hands, reconfigurable mechanisms, or cooperating robots, to name a few, but they appear in other domains too, as mechanistic models of locomotive organisms, molecular compounds, or nano-structures.

The group seeks to extend the current knowledge on complex articulated systems, and how the motions of such systems can be planned, simulated, and controlled in an efficient and reliable way. Broadening such knowledge is essential for the development of the increasingly sophisticated devices of today’s Robotics, which must be designed to operate within prescribed workspaces, dexterously manipulating objects, and avoiding singular configurations and collisions with the environment at all times. Our efforts focus on developing theories to analyze the behavior of such systems, and on experimentation with physical constructions of the systems. The group activity organizes around four principal lines: robot design and construction, position analysis of multi-loop linkages, motion planning and singularity analysis.

During the period 2015-2016, the efforts of the group have covered a wide range of activities including the development of fundamental theoretical methods based on distance-geometry, the implementation of kinodynamic planning methods for constrained robotic systems, and the construction of original mechanisms to validate the results. The latter include a rolling robot, several parallel mechanisms, a programmable surface, an educational ball-and-plate system, and a six-degrees-of-freedom cable-driven parallel robot. The research results have been published in selective conferences, high-ranked international journals, and in two books of the Springer collection in Mechanisms and Machine Science.
RESEARCH AREAS

The group designs and constructs innovative mechatronic devices mainly based on parallel architectures.

Robot design and construction

The group develops techniques for linkage position analysis, i.e., for computing all possible configurations that a linkage can adopt, while respecting the kinematic constraints imposed by its joints. The problem finds applications to robotics, structural biology and computer-aided design. During the period, the group contributed with distance-geometry methods to simplify the motion analysis of linkages, with novel grasping methods, and with the development and distribution of the CuikSuite, a general software toolbox for the kinematic analysis of general multibody systems.

Position analysis

Singularity analysis

Robotic systems typically exhibit singularity subsets. These are loci of configurations where problematic losses of control or dexterity arise. They also reveal the boundaries of the task and joint workspaces, and all motion barriers that may be encountered in their interior. The ability to compute these loci is thus essential, not only to anticipate possible problems during robot operation, but also to provide valuable information to the robot designer.

Path planning

The group also develops methods for closed-chain motion planning. In Robotics this problem appears, for instance, in motion planning for parallel manipulators, in object manipulation with anthropomorphic hands, in constraint-based object positioning, or in surgery or humanoid robots. In all cases, a number of loop-closure constraints give rise to a configuration space of a complex structure in which standard algorithms for motion planning cannot be directly applied.
In the past few years, cable-driven parallel mechanisms have been increasingly studied since they are low-cost, light-weight robots that have all the required physical features in industry regarding the load capacity or the workspace size. Up to now, in most applications involving cable-driven robots, the platform moves the load freely in open space at high speeds and without any force feedback. However, a fully autonomous and safe cable-driven robot must be able to properly react to the contacts between the load and the environment. Thus, the objective of this project is to design and build a force-controlled cable-driven robot and to use it to simulate low gravity conditions, such as those of the underwater environment. The main scientific and technological contribution of this project will be within the frame of robots with force-position hybrid control. Despite their relevance, there are very few commercial robots with such hybrid controllers and, the one proposed herein will be the first cable-driven robot with such type of control.

Beside the simulation of low gravity conditions, such novel devices would easily find applications in many areas. The easy transportation of heavy loads is a demanding necessity in civil infrastructure services, disaster management, automated warehouses, and manufacturing companies, just to name a few. Moreover, a low-gravity simulation such as the one proposed in this project, can be used, or instance, in the rehabilitation of lower limb injuries, where the robot movements and the interaction forces with the environment should be softened.

The project addressed the design of a cable-driven robot, its physical construction, and the development of all the modeling and control tools necessary to properly simulate and command it.
The research activities of the Mobile Robotics line are aimed to endow mobile robots and ubiquitous computing devices the necessary skills to aid humans in everyday life activities. These skills range from pure perceptual activities such as tracking, recognition or situation awareness, to motion skills, such as localisation, mapping, autonomous navigation, path planning or exploration.

During the period 2015-2016 the group successfully completed the EU ARCAS project, demonstrating together with the other members of the consortia, the first-in-the-world aerial manipulation devices, and continued their work on perception and control of aerial manipulators with a new EU project, AEROARMS. Furthermore, this period also saw the conclusion of the EU CargoANTS project in which simultaneous localisation and mapping, and autonomous navigation solutions were developed and successfully demonstrated for truck trailers in port container terminals. These efforts are now continued for the case of trailer carriers in the EU project LOGIMATIC, which commenced in March 2016.

The group also continued leading the public and user driven technology innovation efforts of the EU ECHORD++ project on the Urban Robotics field, identifying cities and citizens needs and selecting the robotics technologies that meet such demands. In the social robotics topic, the group continued providing solutions for the safe motion of robots alongside humans in pedestrian areas in the national projects ColRobTransp, RobInCoop, and RobInstrukt.

During this period, the group has also contributed with solutions to the private sector in the field of human-robot collaboration for the factories of the future, on human-robot collaboration for the automotive sector, and on the validation of computer vision systems also for the automotive sector.

The immediate future presents new challenges for the group. We have secured funding through two new EU projects, one to continue our research on aerial robotics, and one more for the sharing of robotics infrastructures across Europe. Moreover, the scientific leadership of the MdM project, and the participation of the group researchers in the ERC Clothilde project provides plenty of stimulating activity for the group for the years to come.
RESEARCH AREAS

Urban service robotics

The group focuses on the design and development of service mobile robots for human assistance and human robot interaction. This includes research on novel hardware and software solutions to urban robotic services such as surveillance, exploration, cleaning, transportation, human tracking, human assistance and human guiding.

Social Robotics

The group’s work on social robotics has an emphasis in human robot interaction and collaboration, developing new techniques to predict and learn human behavior, human-robot task collaboration, and the generation of empathic robot behaviors using all types of sensors, computer vision techniques and cognitive systems technologies.

SLAM and robot exploration

We develop solutions for indoor and outdoor simultaneous localization and mapping using computer vision and three-dimensional range sensing using Bayesian estimation. The research includes the development of new filtering and smoothing algorithms that limit the load of maps using information theoretic measures; as well as the design and construction of novel sensors for outdoor mapping. This research area also studies methods for autonomous robotic exploration.

Robot localization and robot navigation

This research area tackles the creation of robust single and cooperative, indoor and outdoor robot localization solutions, using multiple sensor modalities such as GPS, computer vision and laser range finding, INS sensors and raw odometry. The area also seeks methods and algorithms for autonomous robot navigation, and robot formation, and the application of these methods on a variety of indoor and outdoor mobile robot platforms.

Object recognition

The group also performs research on object detection and object recognition in computer vision. Current research is heavily based on boosting, deep learning and other machine learning methodologies that make extensive use of multiple view geometry. We also study the development of unique feature and scene descriptors, invariant to changes in illumination, cast shadows, or deformations.

Tracking in computer vision

We study the development of robust algorithms for the detection and tracking of human activities in indoor and outdoor areas, with applications to service robotics, surveillance, and human-robot interaction. This includes the development of fixed/moving single camera tracking algorithms as well as detection and tracking methods over large camera networks.
**ECHO**D ++

European clearing house for open robotics development plus plus

The European Commission funded ECHORD++, a 5-year project (2013-2018), which aims at strengthening the cooperation between public bodies, scientific research, and industry in robotics.

IRI is leading the ECHORD++ PDTI instrument in Urban Robotics that wants to bridge the technical innovation through public demand “identifying the cities and citizens needs and selecting the tailor-made high-quality robotic technology to close the gap between demand and supply”.

The first phase - Activities for public demand knowledge - finalized with the selection of the Urban Challenge “To mechanize sewer inspections in order to reduce the labour risks, objectify sewer inspections and optimize sewer cleaning expenses” of the City of Barcelona.

In January of 2015, the call for RTD proposals was launched and IRI managed the development of the Solutions Design, Prototypes and Small Scale series of the selected proposals arriving to innovative pre-commercial robotic products at the end of 2018.

**CARGO-ANTS**

Cargo handling by automated next generation Transportation Systems for ports and terminal

Cargo-Ants aimed to create smart Automated Guided Vehicles (AGVs) and Automated Trucks (ATs) that can co-operate in shared workspaces for efficient and safe freight transportation in main ports and freight terminals. The specific objectives were:

1. Increase performance and throughput of freight transportation in main ports and freight terminals and maintain a high level of safety.
2. Develop an automated shared work yard for smart AGVs and ATs.
3. Develop and demonstrate a robust grid-independent positioning system and an environmental perception system that oversees safety of operations.
4. Develop and demonstrate planning, decision, control and safety strategies for Automated Next generation Transportation systems (ANTS), i.e. smart AGVs and ATs.

**ARCAS**

Aerial robotics cooperative assembly system

The ARCAS project proposed the development and experimental validation of the first cooperative free-flying robot system for assembly and structure construction. The project paved the way for a large number of applications including the building of platforms for evacuation of people or landing aircrafts, the inspection and maintenance of facilities and the construction of structures in inaccessible sites and in the space.

The detailed scientific and technological objectives were new methods for motion control of a free-flying robot with mounted manipulators in contact with a grasped object as well as for coordinated control of multiple cooperating flying robots with manipulators in contact with the same object; new flying robot perception methods to model, identify and recognize the scenario and be used for the guidance in the assembly operation; new methods for the cooperative assembly planning and structure construction by means of multiple flying robots with application to inspection and maintenance activities; and strategies for operator assistance in manipulation tasks involving multiple cooperating flying robots the possibility of distributing the operations on highly-parallel processing units. A final goal is to demonstrate the usefulness of the platform on complex problems of Robotics, such as grasp synthesis for an anthropomorphic hand.
CEEDS
The collective experience of empathic data systems

The Collective Experience of Empathic Data Systems (CEEDS) project addressed the creation of a novel integrated technology that supports the experiencing, analyzing and understanding of massive datasets. A key axiom of CEEDS is that discovery is the identification of patterns in complex data sets by the human brain. It is these implicit information processing capabilities that CEEDS seeks to exploit.

The implicit cues, as measured through novel sensing systems, including bio-signals and non-verbal behaviour form the core information on which the CEEDS system will process data and present them to the user(s).

Confluence is achieved firstly through immersion of the user in synthetic reality spaces, that allow to explore complex data spaces following narrative structures of varying spatio-temporal complexity, and secondly, through an unobtrusive multi-modal wearable technology that will provide an assessment of the behavioural, physiological and mental states of the user.

AEROARMS
Aerial robotics system integrating multiple arms and advanced manipulation capabilities for inspection and maintenance

AEROARMS proposes the development of the first aerial robotic system with multiple arms and advanced manipulation capabilities to be applied in industrial inspection and maintenance (I&M).

The objectives are: R&D on aerial manipulation to perform I&M; developing systems which are able to grab and dock with one or more arms and perform dexterous accurate manipulation with another arm. Also develop helicopter-based aerial manipulators.

New methods and technologies for platforms which can fly and manipulate with the coordinated motion of the arms.

Installation and maintenance of permanent NDT sensors on remote components; Deploy and maintain a mobile robotic system permanently installed on a remote structure.

To achieve the above objectives AEROARMS will develop the first aerial telemanipulation system with advanced haptic capabilities able to exert significant forces with an industrial robotic arm, as well as autonomous control, perception and planning capabilities. Special attention will be paid to the design and system development in order to receive future certification taking into account ATEX and RPAS regulations.

LOGIMATIC
Tight integration of EGNSS and on-board sensors for port vehicle automation

LOGIMATIC proposes an ad-hoc advanced location and navigation solution to enable the automation of existing port vehicles with a significantly lower cost which will allow short-medium term investments until the whole port fleet is renewed with fully autonomous vehicles in the long term. The project will develop and demonstrate an innovative location and navigation solution for the automation of the operations of straddle carriers in container terminals. Objectives:

1 - To develop an advanced automated navigation solution based on the integration of Global Navigation Satellite Systems (GNSS) and sensors onboard the SC vehicles.

2 - To implement a GIS-based control module compatible with existing Terminal Operating Systems (TOS) for optimized global (yard level) route planning and fleet management.

3 - To implement security mechanisms in order to detect and avoid spoofing and/or jamming attacks.

4 - To assess the impact of application of such automated approach at large scale through simulation.

5 - To integrate, validate and demonstrate the proposed solution in a real port yard.

Leader for IRI
Alberto Sanfeliu
Funding org
HORIZON 2020
Period
September 2010 / February 2015
IRI Budget
645 000 € (Total 6,5M €)

Leader for IRI
Juan Andrade
Funding org
HORIZON 2020
Period
February 2016 / January 2019
IRI Budget
328 750 € (Total 2 M €)

Leader for IRI
Alberto Sanfeliu
Funding org
HORIZON 2020
Period
June 2015 / May 2019
IRI Budget
563 881 € (Total 4,72M €)

**PAU+**

**Perception and action in robotics problems with large state spaces**

Contribution to the theoretical foundations of computational models of perception and action and their application to the solution of challenging robotics problems with large state spaces. The contributions include efficient online probabilistic inference algorithms on graphical models with applications to SLAM and for rigid shape estimation/extension to non-rigid object reconstruction and pose estimation using geometric and appearance cues, as well as robust pose estimation for uncalibrated vision systems.

**Investigator**
Juan Andrade

**Period**
January 2014 / June 2017

**Budget**
180,000 €

**Funding org.**
CSIC

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**Robot-Int-Coop**

**Robot-human interaction, cooperation and learning in urban environments**

The main goal of this project is to advance in the design of mobile and flying robots that can interact, learn and cooperate with people for urban tasks, adapting themselves to the environment and changing conditions. Developing new perception techniques for robots based on learning and adaptation, to incorporate visual servoing techniques for the interaction between humans-robots, to explore new interaction techniques between mobile-aerial robots with humans and to develop new cooperation techniques.

**Investigator**
Alberto Sanfeliu

**Period**
January 2014 / June 2017

**Budget**
180,000 €

**Funding org.**
CSIC

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**ColRobTransp**

**Human-robot collaboration for the transportation of goods in urban areas**

The main objective in this project is to advance in the design of new mobile robots that are capable to transport products in the last mile of urban areas, overcoming with the help of humans complex situations in navigation and product delivery. Not only navigation in urban crowded areas is complex, but also it is important how the robots overcome complex street situations, for example, streets semi-blocked due to street repairing or vehicles not well parked that do not allow to reach the delivery place.

**Investigator**
Juan Andrade

**Period**
December 2016 / December 2019

**Budget**
217,800 €

**Funding org.**
CSIC

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**Robot-Int-Coop**

**Robot-human interaction, cooperation and learning in urban environments**

**Investigator**
Alberto Sanfeliu

**Period**
April 2013 / March 2015

**Budget**
100,000 €

**Funding org.**
IRI

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**VAVAT**

**Autonomous vision for unmanned aerial vehicles**

In this project we developed guiding strategies for unmanned aerial vehicles (UAVs) for the cooperative building of structures. This required the use of computer vision techniques for the detection, identification, and tracking of the structure elements. The detection and identification tasks are necessary for the localization of objects and to determine grasping and assembly poses. Experiments were performed both in indoor and outdoor settings where illumination, wind, and other environmental factors cannot be predicted.

**Investigator**
Juan Andrade

**Period**
September 2012 / August 2015

**Budget**
100,000 €

**Funding org.**
CSIC

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**COLAROB**

**Human-robot collaboration in manipulation, navigation and explanation tasks**

The COLAROB project tackled the integration of software and hardware subsystems in the robotic platforms at IRI to provide support to the EU projects IntelAct and Cargo-ANTS. In particular, we adapted the backdrivable robotic WAM arm to the mobile outdoor platform TEO for the manipulation of deformable objects, and adapted the 3D Velodyne sensor and migrated the PoseSLAM software to the ROS programming environment for their use with IRI’s electric vehicle.

**Investigator**
Alberto Sanfeliu

**Period**
April 2013 / March 2015

**Budget**
50,000 €

**Funding org.**
IRI

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PERCEPTION AND MANIPULATION

Research of this line focuses on enhancing the perception, learning, and planning capabilities of robots to achieve higher degrees of autonomy and user-friendliness during everyday manipulation tasks for assistive, service and collaborative robotics. Some topics addressed are the geometric interpretation of perceptual information, construction of 3D models of both rigid and deformable objects, human pose and behavior recognition, robot action selection and planning, reinforcement learning, and teaching by demonstration.

Domestic, service and industrial robotics require the easy acquisition of 3D object models and user-friendly programming of manipulation tasks. Therefore, the efforts of our group are oriented toward 3D active perception combining several sensory modalities, such as color vision, depth from time-of-flight, structured light, stereo, and haptics; teaching manipulation skills to a robot under a learning by demonstration approach, as well as teaching the robot to accomplish tasks requiring planning through rule learning, and computer vision and deep learning techniques for the detection of human body configurations and recognition of user actions and intentions.
RESEARCH AREAS

Learning by demonstration

We devise methods to learn object-action relations to accomplish tasks at different levels of abstraction, where object models are generated from visual and depth information, and actions, involving manipulation skills, are learned from demonstrations provided by a human using multimodal algorithms that combine vision and haptics.

Planning for perception and manipulation

We are interested in planning algorithms for object modeling, with special interest in deformable objects. High-level task formulations are integrated with low-level geometry-based methods and simplified physical models, as well as with an on-line sensory-based treatment of uncertainty so as to come up with specific sequences of motion commands.

Perception of rigid and non-rigid objects

Our objective is to investigate computer vision algorithms for interpreting and understanding scenes from images, with applications in robotics and medical imaging. In particular, our activities are concentrated on retrieving rigid and non-rigid shape, motion and camera pose from single images and video sequences.
**RESEARCH PROJECTS**

### VISEN
**Visual sense, tagging visual data with semantic descriptions**

Today a typical Web document will contain a mix of visual and textual content. Most traditional tools for search and retrieval can successfully handle textual content, but are not prepared to handle heterogeneous documents. The new type of content demands the development of new efficient tools for search and retrieval.

The visual sense project aims at mining automatically the semantic content of visual data to enable “machine reading” of images. In recent years, we have witnessed significant advances in the automatic recognition of visual concepts (VCR). These advances allowed for the creation of systems that can automatically generate keyword-based image annotations.

The goal of this project is to move a step forward and predict semantic image representations that can be used to generate more informative sentence-based image annotations. Thus, facilitating search and browsing of large multimodal collections.

More specifically, the project targets three case studies, namely image annotation, re-ranking for image search, and automatic image illustration of articles.

### I-DRESS
**Assistive interactive robotic system for support in dressing**

The main objective of the project is to develop a system that will provide proactive assistance with dressing to disabled users or users such as high-risk health-care workers, whose physical contact with the garments must be limited to avoid contamination. The proposed robotic system consists of two highly dexterous robotic arms, sensors for multi-modal human-robot interaction and safety features.

The system will comprise three major components, each of strong impact to the field of assistive service robotics:

(a) intelligent algorithms for user and garment detection and tracking, specifically designed for close and physical human-robot interaction,

(b) cognitive functions based on the multi-modal user input, environment modelling and safety, allowing the robot to decide when and how to assist the user, and

(c) advanced user interface that facilitates intuitive and safe physical and cognitive interaction for support in dressing.

The developed interactive system will be integrated on commercial WAM robotic arms and validated through experimentation with users and human factor analysis in two assistive-dressing scenarios.

### SOCRATES
**Social cognitive robotics in the european society**

The research in social robotics has a common theme of interaction quality, which is a concept for characterization of how a specific mode of interaction is fit for a given task, situation, and user. Interaction quality often changes, for instance if an older adult gets tired and loses focus when interacting with a robot. Interaction quality also depends on the robot’s functionality and design. In general, Interaction Quality is a complex interplay between several performance measures and design parameters. In SOCRATES we address these issues from a range of perspectives.

To address the aim of successful multidisciplinary and intersectoral training, SOCRATES training is structured along two dimensions: thematic areas and disciplinary areas. The thematic perspective encapsulates functional challenges that apply to R&D.

The following five thematic areas are identified as particularly important, and hence are given special attention in the project: Emotion, Intention, Adaptivity, Design, and Acceptance. The disciplinary perspective encapsulates the necessity of inter/multi-disciplinary and intersectoral solutions.
**IntellAct**  
**Intelligent observation and execution of actions and manipulation**

IntellAct addressed the problem of understanding and exploiting the meaning (semantics) of manipulations in terms of objects, actions and their consequences for reproducing human actions with machines. It comprised three building blocks: learning, monitoring and execution.

The analysis of low-level observation data for semantic content (learning) and the synthesis of concrete behavior (execution) constituted the major scientific challenge of IntellAct. Based on the semantic interpretation and description and enhanced with low-level trajectory data for grounding, two major application areas were addressed by IntellAct: the monitoring of human manipulations for correctness and the efficient teaching of cognitive robots for manipulation.

To achieve these goals, IntellAct brings together recent methods for

1. parsing scenes into spatio-temporal graphs and so-called ‘semantic event chains’,
2. probabilistic models of objects and their manipulation,
3. probabilistic rule learning, and
4. dynamic motion primitives for trainable and flexible descriptions of robotic motor behavior.

**Leader for IRI**  
Carme Torras

**Period**  
March 2011 / May 2015

**IRI Budget**  
367,000 €  
(Total 2,96M €)

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**Robinstruct**  
**Instructing robots using natural communication skills**

Putting together tools from computer vision, machine learning, natural language processing and robotics. Specifically, to teach robots in a natural and human-like manner we will first develop parsers to represent both video and natural language data using an intermediate abstraction level.

We will then investigate learning approaches to discover mappings between the visual/textual content and the robot action space. In order to bring these assistive robots to outdoor and uncontrolled scenarios, the human-to-robot communication skills will be combined with new algorithms to reliably localize the robot in very large 3D maps and for long periods of time, even in GPS-denied areas.

For this purpose, we will integrate novel computer vision pose estimation algorithms with inertial sensors.

The two main objectives we pursue are commercially and socially relevant robotics technologies, as endorsed by our three EPOs. With the development of such technologies, the project will contribute to more flexible and general use of robots in assistive tasks, as well as more robust service robots able to navigate and interact in previously unknown and unstructured environments.
**MANIPlus**  
Robotic manipulation of deformable objects

While the manipulation of rigid objects has been widely addressed in the robotics community, the manipulation of deformable objects is an incipient research field, on which the Perception and Manipulation group has centered its activity.

In this project the algorithms developed for the perception, learning and manipulation planning of plant leaves (within the Garnics project) and clothing (within the PAU+ project) are being integrated and placed in a common framework, so as to turn them into software infrastructure of the lab available to future projects and contracts with industry.

**SAMMIR**  
Safe multi-modal interaction with robot manipulators

Human-robot collaborative tasks require close interaction through the use of natural interfaces while maintaining a high level of safety for both the human and the robot. The project will focus on human-robot interaction as the key robotics technology by advancing the robot abilities for physical, social, and cognitive interaction while taking into account safety as an essential criterion for collaborative task execution. The proposed research will be performed in collaboration between CSIC and three renowned international research centers and will allow the integration of CSIC knowledge in perception, vision-based interaction and robot control with each of the partners main expertise domains, namely natural language processing for robotics (Umeå University, Sweden), human-robot collaboration (Ben-Gurion University, Israel) and robot safety (Bristol Robotics Lab, UK). The Spanish company Pal Robotics will provide access to their newly-developed robotic platform and technical expertise to implement the project research results, which ensures relevant industrial involvement in the project.

**TextilRob**  
Robots for handling clothing

Whereas handling a rigid object changes only its pose, namely six parameters (three for position and three for orientation), the manipulation of a piece of clothing takes place in a potentially infinite-dimensional shape-state space. This huge dimensionality jump renders geometry-based perception techniques developed for rigid objects non-applicable in this context, and calls for the use of machine learning approaches as well as applying motions to the object to aid perception.

In this project, the algorithms specifically developed for RGB-D perception and manipulation of textile objects are being integrated and placed in a common framework, so as to establish a software infrastructure in the lab to facilitate the implementation tasks in research projects such as the ERA-Net project I-DRESS and the recently obtained ERC AdG project CLOTHILDE.
The main objectives of this research developed by this line are to contribute in the development of new methodologies of modeling, control and supervision of complex and large-scale dynamic systems; to improve the efficiency and performance of industrial processes, specially in the fields of water and energy; to implement these methodologies and designs in real systems; and to train research staff and students in the field of automatic control.

The group’s general scientific objective is the advancement in the field of modeling, control and supervision of complex and large scale systems, including nonlinearities and uncertainty with the aim to improve efficiency, reliability and sustainability of processes and systems.

The most relevant application fields, for which the group has acquired recognised expertise are: systems in the water cycle (water resources management, water distribution, urban drainage) and energy systems (fuel cells, hydrogen-based energy systems, energy generation for automobile systems, power management).

During the period 2015-2016 the group commenced its participation in two EU projects for “Global systems rapid assessment tools through constraint functional Languages”, and for “Efficient integrated real-time control in urban drainage and wastewater treatment plants for environmental protection”. Furthermore, it started participation in the MSC training network INCITE on the topic of renewable sources integration in energy systems, as well as two national projects, three regional projects and four technology transfer contracts with industry.
The study of large-scale systems requires new methodologies for modeling, supervision and control. The main research issues of the group within this topic include structural analysis, decentralized hierarchical and/or distributed control using Model Optimal/Predictive Control, real-time fault detection and isolation, fault-tolerant control, optimization in resource allocation and optimal management of resource flows.

Application fields: water and gas distribution networks, water abstraction and transport, power grids, hybrid autonomous generation systems based on fuel cell and petrochemical plants.

Efficiency, reliability and sustainability of processes and systems depend on different design aspects which are also addressed by the group researchers. This includes topology selection or reconfiguration, sizing of components, structural analysis, and sensor and actuator location. Application fields: water networks, electrical grids, autonomous power generation systems and robotics.

The development of control-oriented models and the design of advanced controllers for complex dynamic systems where phenomena of different nature are interrelated is another fundamental research topic of the group, where the experimental work and the real implementation is a fundamental aspect.

It includes distributed and lumped parameter control-oriented modeling, experimental characterization techniques, identification, diagnosis, design of observers, sliding mode control, robust control and predictive control. Application fields: polymeric exchange membrane fuel cells, power generation systems and ethanol reformers for hydrogen production.
**INCITE**

**Innovative controls for renewable sources integration into smart energy systems**

Nowadays, both consumers and genera- tors are active agents that are capable of coordinating the extraction and injection of power into the electrical grid depending on the energy cost, energy availability and even the behavior of electrical variables. This new reality is a great opportunity to improve energy efficiency and reduce CO2 footprints by using clean energy sources. But it is also a big challenge. The electrical network is one of the most complex systems ever made, with this new reality the additional controllability and the great number of actors may lead to undesirable results and even to network outages.

In order to take full advantage of these new electrical networks, it is necessary a coor- dinated and harmonic interaction among all actors in the network. This is the role of the control algorithms, thought to act at several levels to conduct the extraction and injection of the electrical power and impro- ve efficiency, reliability and resilience of the network. INCITE aims to this target, to propose new control algorithms with an inte- grated view of the future electrical networks, covering aspects like energy management, stability of electrical variables, monitoring and communication implementation, ener- gy storage, among others. The objective is to create an interdisciplinary (control, elec- trical and management fields), cross-secto- nal (academic and industry) and internatio- nal research environment.

**Efficient integrated real-time control in urban drainage and wastewater treatment plants for environmental protection**

The main goal is to demonstrate an inte- grated real time control (RTC) strategy of UDNs and WWTP to minimize the pollution of receiving waters, through the use of real- time quantity and quality data. Real-time control (RTC) based on model predictive control (MPC) has been shown to produce efficient management strategies for UDNs. However, up to date, RTC developments have been based on managing flows, not taking into account the polluting load (quality) of the carried water, which varies considerably throughout the rain event and the storage periods. Similarly, the effi- ciency of the processes depends on both the quantity and the quality of the treated water and untreated water may be refused for collective policy making in global sys- tems. This can be achieved through foun- dational scientific work at different levels: from the high-level, political modelling, adapting the social discipline of group mo- del building (as used in business organiza- tions), to include both quality and quantity control.

1. Extending existing MPC techniques in use by the consortium, to include both quality and quantity control.
2. Including fault tolerance mechanisms in RTC, so that the system may cope with sensor, actuator network integrity or com- munication malfunction.
3. Demonstrating the functionality of the proposed control system in two pilots to prove wide applicability.
4. Disseminating the results of integrated management of UDNN and WWTP for aware- ness of public and private administrations through project stakeholders.
5. Derive guidelines for replication and for the implementation, energy manage- ment of UDN and WWTP to minimize the pollution of receiving waters, through the use of real-time quantity and quality data. Real-time control (RTC) based on model predictive control (MPC) has been shown to produce efficient management strategies for UDNN. However, up to date, RTC developments have been based on managing flows, not taking into account the polluting load (quality) of the carried water, which varies considerably throughout the rain event and the storage periods. Similarly, the efficiency of the processes depends on both the quantity and the quality of the treated water and untreated water may be refused for collective policy making in global systems. This can be achieved through foun- dational scientific work at different levels: from the high-level, political modelling, adapting the social discipline of group mo- del building (as used in business organiza- tions), to include both quality and quantity control.

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Drinking water utilities in urban areas are facing new challenges in their real-time operation because of limited water sources, intensive energy requirements, a growing population, a costly and ageing infrastructure, increasingly stringent regulations, and increased attention towards the environmental impact of water use.

Such challenges force water managers to monitor and control not only water supply and distribution, but also consumer demand. This project proposes a novel integrated water resource management system based on advanced ICT technologies of automation and telecommunications for largely improving the efficiency of drinking water networks in terms of water use, energy consumption, water loss minimization, and water quality guarantees.

Two real-life pilot demonstrations in Barcelona, Spain, and Lemesos, Cyprus, respectively, will prove the general applicability of the proposed integrated ICT solution and its effectiveness in the management of drinking water networks, with considerable savings of electricity costs and reduced water loss while ensuring the high European standards of water quality to citizens.

Proton exchange membrane fuel cells (PEMFCs) are complex nonlinear systems. In order to improve their durability, efficiency, and to decrease the cost, time of development, design of new diagnostic tools is crucial. Powerful mathematical models of the dynamic behaviour of PEMFCs are necessary for the design and improvement of diagnostic tools. The project PUMA MIND will enhance the understanding of interactions, competitions and synergies among the mechanisms at multiple scales and lead to the development of robust dynamic macroscopic models for control-command purposes with predictive capabilities.

The novel mathematical models developed by PUMA MIND will be tested by an experimental work, in order to ensure the applicability on commercial attainable components and catalysts. The most suitable catalysts for the MEA manufacturing technology will be used for these experiments. The implementation of the developed models on the mentioned above catalysts might allow a significant impact, and might also contribute to the most promising solutions based on current EU industrial available components.

Operation conditions and control strategies to enhance the durability of automotive PEMFC will be derived on the basis of the multi-scale modeling approach proposed by PUMA MIND.
<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>ECOCIS</strong></td>
<td>Economic operation of critical infrastructure systems</td>
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<tr>
<td><strong>COSIN</strong></td>
<td>Synthetic fuels</td>
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<tr>
<td><strong>MESPEM</strong></td>
<td>Development of control systems for the improvement of the efficiency and the useful life in systems based on fuel cells PEM</td>
</tr>
<tr>
<td><strong>REFER</strong></td>
<td>Energy reduction and flexibility in rehabilitation buildings</td>
</tr>
<tr>
<td><strong>DiaPEM</strong></td>
<td>Polymer electrolyte membrane fuel cell Stack diagnosis system</td>
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**ECOCIS** is a coordinated project of IRI with the University of Seville and CETAQUA, which aims to develop automatic control solutions for critical infrastructure systems (CIS) such as water, gas or electricity supply networks. Specifically, the project develops techniques of structural analysis, fault diagnosis and economic predictive control for efficient, economic and reliable operation of CIS. The project solutions will be validated in problems proposed by the companies Aigües de Barcelona, CEPISA, Gas de France and Emaesa.

**COSIN** is a project structured in three large blocks. On the one hand, efforts will focus on the controlled production of enriched bio-gas having separated CO2 from CH4. On the other hand, more efficient systems of electrolysis and co-electrolysis will be developed. Finally, a substantial effort will be devoted to tasks that will be directed at improving the methanation systems themselves, including the half-life and efficiency of all components as well as evaluation.

**MESPEM** focused on the automatic control of systems based on Polymer Electrolyte Membrane (PEM) fuel cells. The project made innovative contributions to control oriented and distributed modelling, dynamic observation, diagnosis and nonlinear control of PEM fuel cells. Also addressed the control of open cathode and high temperature PEM fuel cells as well as the control of low temperature PEM fuel cells in hybrid power generation systems and the supervisory control strategies necessary.

**REFER** aims to improve the available energy alternatives for buildings, providing them with flexibility with several options to face the generation of renewable energy and energy efficiency. In order to offer alternatives beyond solar panels and relatively well-known battery packs, the project aims to increase the competitiveness of new relevant technological solutions in buildings, such as fuel cells, photovoltaics, electrolysis and the reuse of batteries of electric vehicles.

**DiaPEM** is a LLAVOR project dedicated to the proof of concept of an inexpensive PEMFC diagnosis system for future implementation on a small electronic module. The output of this diagnosis system will be the numerical estimation of important internal stack variables i.e. Tafel slope, mass transport over-voltage and membrane resistance that determine the internal fuel cell state in terms of water distribution and explain its voltage losses. Therefore a novel and cost effective PEMFC-diagnosis hardware module design will be created based on a validated methodology.
### REGIONAL RESEARCH GROUP RECOGNITION

<table>
<thead>
<tr>
<th>SGR-ROBIRI</th>
<th>Consolidated research group on Robotics</th>
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<tr>
<td><strong>Principal Investigator:</strong> Carme Torras</td>
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<td><strong>Period:</strong> January 2014 - December 2016</td>
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<td><strong>Type:</strong> Regional Funds</td>
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<td><strong>Budget:</strong> €500,000</td>
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The IRI Robotics group has a long tradition as it has been running continuously since 1997. The group concentrates its efforts on robot perception and manipulation for assistive, service and collaborative robotics. One objective of the group is to improve the understanding of perceptual data to build 3D models of both rigid and deformable objects, as well as determining human pose.

Following the approach of cognitive robotics, the group works on planning and action selection, reinforcement learning, and learning from demonstration. In the coming years, an important research focus will be the perception and manipulation of textiles, as well as teaching robots to help people to dress, under the recently awarded ERC Advanced Grant for the project CLOTHILDE.

<table>
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<tr>
<th>SGR-KRD</th>
<th>Consolidated research group on Kinematics and Robot Design</th>
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<tr>
<td><strong>Principal Investigator:</strong> Vincenç Puig</td>
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The Consolidated Research Group on Kinematics and Robot Design studies the behavior of articulated mechanisms focusing on the planning, simulation, and efficient and safe control of the motions of such systems. All these aspects are essential in the development of the increasingly complex robots demanded by industry and research nowadays.

These robots have to be designed such that they operate in pre-defined workspaces, need to dexterously manipulated objects, and must avoid singular configurations and collisions with the environment at any moment.

### SGR-VIS

Consolidated research group in Vision and Intelligent Systems

The Vision and Intelligent Systems Group (VIS) carries out basic and applied research with the aim of understanding and designing intelligent systems that are capable of interacting with the real world in an autonomous and wide-reaching manner. Such intelligent systems must perceive, reason, plan, act and learn from previous experiences. The group works on the following topics: Computer Vision techniques, for example in color image segmentation and labeling, semantic segmentation, object learning and recognition, object tracking, person tracking, face tracking and biometrics; Robotics techniques, for example in mobile (ground and aerial) robot navigation, simultaneous localization and mapping and building visual servoing, 3D object tracking, sensor fusion, human-robot interaction and human-robot collaboration; and in Pattern Recognition and Machine Learning techniques, for example in supervised and unsupervised classifiers, graph matching, on-line boosting and CNNs for computer vision and robotics applications.

### SGR-SAC

Consolidated research group on Advanced Control Systems

The "Advanced Control Systems" (SAC) research group is the most important and largest in the automatic control groups at the Universitat Politècnica de Catalunya (UPC). SAC research group has been involved in an intense research activity, in basic and applied fields in the last ten years, namely: optimal/predictive control of large scale systems (in particular, sewer and irrigation networks), fault diagnosis and fault tolerant control of gas turbines, PEM fuel cells, aerogenerators, UAVs and robots.

SAC research group has several experimental labs. One lab is devoted the research of modelling, control, fault diagnosis and tolerant control of PEM fuel cells and the other is devoted to the research in fault diagnosis. The SAC group has also organized several important international conferences in the field of automatic control.
UPCOMING H2020 RESEARCH PROJECTS

INN-Balance
Innovative cost improvements for balance of plant components of automotive PEMFC systems

The aim of INN-BALANCE is to develop a novel and integrated development platform for developing advanced Balance of Plant components in current fuel cell based vehicles, in order to improve their efficiency and reliability, reducing costs and presenting a stable supply.

Technical objectives are to develop highly efficient and reliable fuel cell BoP components; to reduce costs of current market products in fuel cell systems; to achieve high technology readiness levels in all the tackled developments; and to improve and tailor development tools for design, modeling and testing innovative components in fuel cell based vehicles.

INN-BALANCE will be focused on four main general topics; first of all on new components developments; secondly, on the vehicle integration and validation of the components in a TRL7 platform placed at a well-known car manufacturing platform; thirdly, providing innovative and cost optimized manufacturing processes especially developed for automotive BoP components; finally, on the results dissemination and exploitation, new technology broad casting and public awareness of new, low-cost and reliable clean energy solutions in Europe bringing at the same time highly qualified new job opportunities.

IMAGINE
Robots understanding their actions by imagining their effects

IMAGINE seeks to enable robots to understand the structure of their environment and how it is affected by their actions. "Understanding" here means the ability of the robot (a) to determine the applicability of an action along with parameters to achieve the desired effect, and (b) to discern to what extent an action succeeded, and to infer possible causes of failure and generate recovery actions.

The core functional element is a generative model based on an association engine and a physics simulator. "Understanding" is given by the robot’s ability to predict the effects of its actions, before and during their execution. This allows the robot to choose actions and parameters based on their simulated performance, and to monitor their progress by comparing observed to simulated behavior. For robotic disassembly, IMAGINE will develop a multi-functional gripper capable of multiple types of manipulation without tool changes.

IMAGINE raises the ability level of robotic systems in core areas of the work program, including adaptability, manipulation, perception, decisional autonomy, and cognitive ability. Since only one-third of EU e-waste is currently recovered, IMAGINE addresses an area of high economical and ecological impact.
Throughout the year IRI holds a series of invited seminars and lectures, featuring invited speakers and our own researchers presenting the results of their work prior to attending international conferences or in preparation of their PhD defense.

29 January 2015
Hilario Tomás (IRI, Robotics) Whole body control using Robust & Online hierarchical quadratic optimization.

2 February 2015
Adrià Colomé (IRI, Robotics) Learning of Robotic Tasks: Policy Search with Movement Preemptions.

2 March 2015
Gerard Pons-Moll (IRI, Motion Capture and Animation)

5 March 2015
Arturo Bibas (IA) Active Pose SLAM with RRT*

23 April 2015
Adrià Colomé (IRI) A First-In-Model-Based Framework for Reinforcement Learning of Robotic Tasks in Non-Rigid Environments

27 April 2015
Jan Fuchs (ETHZ) Neuron Reconstruction from Arborescent Electron Microscopy Volumes

8 May 2015
Gerhard Neumann (TU Darmstadt) Learning Modular Control Policies in Robotics

14 May 2015
Michael Villamizar (IRI) Modeling Robot's World with Minimal Effort

14 May 2015
Michael Villamizar (IRI) Efficient Molecular Pose Estimation for Complex 3D Models

27 May 2015
Pedroco Thomas (IRI) Approaching dual Guarantees from Matrix Algebra

6 June 2015
Ricard Téllez (IRI) The Construct: robotics simulators in the cloud

6 July 2015
Vincent Lepetit (TU Graz) Hands Deep in Deep Learning for Hand Pose Estimation

10 July 2015
Antoni Rosanas-Mozos (University of Lincoln) Machine Learning Technologies to Support Robotic Assistants

12 July 2015
Antoni Tarradellas (IRI) Large Scale Visual Scene Recognition

15 October 2015
David Martínez (IRI) State Estimation Execution in Model-Based Reinforcement Learning

3 November 2015
Ángel Santamaría (IRI) High-Frequency MAV State Estimation Using Low-Cost Inertial and Optical Flow Measurement Units

16 November 2015
Victor Varela (IRI) Real Time People Detection, Combing Appearance and Depth Image Spaces using Boosted Random Funs

20 October 2015
Edgar Simo (Universidad de Zaragoza) Fusing Global and Local Image Priors for Automatic Image Colorization

3 November 2015
Antonio Huasín (IRI) Geometric Path Planning without Pathways for Navigating Pancakes Parametrically

30 June 2016
Adrià Colomé (IRI) Using bad data for Reinforcement Learning with Policy Search algorithms to obtain better convergence to solutions

30 June 2016
Antonio Agudo (IRI) Reinventing a dynamic world

16 June 2016
Edmundo Quera (IRI) Data association and validation for probabilistic localization and mapping

10 March 2016
Joan Solà (IRI) WOLF: a versatile framework for localization and mapping

9 June 2016
David Martínez (IRI) Learning Relational Dynamics of Stochastic Domains for Planning

2 June 2016
Oscar Martínez Mozos (IRI) Navigation Technologies to Support Robotic Assistants

16 July 2016
Victor Varela (IRI) Learning Relational Dynamics of Stochastic Domains for Planning

2 December 2016
Edmundo Quera (IRI) Data association and validation for probabilistic localization and mapping

2 June 2016
Germain Ros (CVC) Semantic Segmentation for Driving Scenarios: On virtual worlds and embedded platforms

2 January 2016
Javier Civera (Universitat de Zaragoza) Mid and high-level features for dense monocular SLAM

10 March 2016
Joaquín Sol VII, A versatile framework for localization and mapping

2 July 2016
Adrià Colomé (IRI) Using bad data for Reinforcement Learning with Policy Search algorithms to obtain better convergence to solutions

15 April 2016
Aleix Martínez (Ohio State University) Policy Approximation in the Search of optimal solutions in machine learning, computer vision and beyond

5 May 2016
Andreu Cormonías (IRI) Observability Analysis and Optimal Sensor Placement in Stereo Radar Odometry

24 May 2016
Patrick Grosch (IRI) Geometric Path Planning without Pathways for Navigating Pancakes Parametrically

2 June 2016
Aleix Martínez (Ohio State University) Reinventing a dynamic world

30 June 2016
Antonio Huasín (IRI) Geometric Path Planning without Pathways for Navigating Pancakes Parametrically

30 June 2016
Antonio Agudo (IRI) Reinventing a dynamic world

20 October 2015
Edgar Simo (Universidad de Zaragoza) Fusing Global and Local Image Priors for Automatic Image Colorization

1 December 2016
Brais Cancela (Universidade da Coruña) Stress evolution and geometric modeling, as well as some modeling approach to model human behavior in crowded scenes.
IRI’s scientific production is published in the top journals of our fields of interest. This allows for an adequate dissemination of our findings to the scientific community.

Moreover, our researchers present also their work in the top conferences in our fields, thus promoting the exchange of ideas with our peers at other research institutions and related companies.

The evolution of IRI’s scientific production in bibliometric terms has grown steadily for over a decade, and continued to do so during this period.

IRI members participate in the Editorial Board of the following journals:

- IEEE Transactions on Robotics
- ASME Journal of Mechanisms and Robotics
- International Journal of Mechanics and Control
- Pattern Recognition Letters
- International Journal of Pattern Recognition and Artificial Intelligence
- Computer Vision and Image Understanding
- Electronic Letters on Computer Vision and Image Analysis

* The quartiles Q1 to Q4 indicate the quality of a journal with regards to its impact in a field, measured by the number of citations received. Source: ISI Journal Citation Report.
PUBLICATIONS

JOURNAL ARTICLES

2015


D. Escalante and R. Alquinta-Martínez. Study of the eletrochemical degradation of a proton exchange mem-
brane fuel cell: Evaluation of the membrane water content, Contact Conference on Artificial Intelligence, 2016.
EDUCATION

We are committed to excellence in higher scientific education, through the mentoring of undergraduate, masters and PhD students. Our teaching activity is varied and active. The number of PhD students and PhD theses defended has increased in the last years. Furthermore, we also support students who work in their master theses and final year projects.

TEACHING ACTIVITIES

We are committed to excellence in higher scientific education, through the mentoring of undergraduate, masters and PhD students. Our teaching activity is varied and active. The number of PhD students and PhD theses defended has increased in the last years. Furthermore, we also support students who work in their master theses and final year projects.

UNDERGRADUATE STUDIES:

Our faculty teaches undergraduate courses at UPC in:
- Industrial Engineering (ETSEIB, ETSEIAT)
- Informatics Engineering (FIB)
- Mathematics and Statistics (FME)
- Industrial and Aeronautic Engineering (EIEAT)
- Industrial Electronics and Automatic Control Eng (EET)

MASTER STUDIES:

Our postgraduate teaching activities at UPC are included in:
- Master in Automatics and Robotics
- Master in Artificial Intelligence
- Master in Engineering of Automatic Syst. and Power Electr.
- Master in Industrial Engineering
- Master in Chemical Engineering

STUDENT SUPERVISION IN 2015 / 2016

15 PhD THESES

Eduard Trulls, Enhancing low-level features with mid-level cues
Juan Manuel Grosso, On model predictive control for economic and robust operation of generalized flow-based networks
Edgar Simo-Serra, Social robot navigation in urban dynamic environments
Gonzalo Ferrer, Understanding human-centric images: from geometry to fashion
Agustin A. Ortega, Perception and interpretation of dynamic scenarios using lidar data and images

Congcong Sun, Multi-layer model predictive control of complex water systems
Maria del Carmen Ortega, Sintesis y caracterización de un nuevo polímero conductor basado en biomoléculas
Manuel Iglesio Ganzo, El modelo eléctrico de conducciones aplicado al isomorfismo de grafos: el método de la estrella
Ernesto Homar Teniente, 3D mapping and path planning from range data
Damiano Rotondo, Advances in gain-scheduling and fault tolerant control techniques

Valeria Javalera, Distributed large scale Systems: A multi-agent RL-MPC Architecture
Feran Dachs, Multiplier ideals in two-dimensional local rings with rational singularities
Patrick Grosch, Parallel Robots with Unconventional Joints to Achieve Under-Actuation and Reconfigurability
Sergi Fox, Task-oriented viewpoint planning for free-form objects
Syed Farzad Husain, Perceiving dynamic environments: from surface geometry to semantic representation

26 MASTER THESES

23 UNDERGRADUATE / LAST YEAR PROJECTS

HUMANOID LAB INITIATIVE

The Institute hosts the Humanoid Lab, an initiative to mentor undergraduate students interested in learning basic concepts of robotics.

Its goal is to introduce engineering and mathematics students to the robotics world.

Humanoid Lab members develop small projects and participate at humanoid robot competitions. In the last few years, different Humanoid Lab teams from IRI have won contest as CEABOT.
Through agreements with industrial partners we promote technology transfer of the Institute’s achievements on excellence research. One of the main objectives for the Institute is to promote cooperation and find common solutions between industry needs and the research done. Since 2015, IRI is carrying out an action plan to foster our technology transfer.

### TECHNOLOGY TRANSFER PROJECTS IN 2015-2016

#### SMART FACTORY

Research on enabling technologies for intelligent systems in the factories of the future

This a CDTI project cofunded by CDTI (Spanish Government) and led by the company LEYTEC where IRI acts as subcontractor. Its objective is to conduct research in Industry 4.0, i.e. to design robotics systems to cooperate with human workers.

**Period**
- October 2015 / September 2019

**IRI Budget**
- 30,000 €

**P. Investigator**
- Alberto Sanfeliu

#### VW_Vehicle-Robot

Development / innovation on “robot-vehicle”

This collaboration is in the framework of the CARNET project for Volkswagen R&D and managed by CIT UPC. IRI’s role is to propose and analyze a future vehicle-robot concept.

**Period**
- September 2016 / February 2017

**IRI Budget**
- 50,000 €

**P. Investigator**
- P. Investigator

#### LCAS

Object localization with LiDAR for the validation of a CMS system

LCAS is a project contracted by the company FICOSA ADAS. Its objective is to develop a system for the detection and localization of road vehicles relative to a moving vehicle using LiDAR data.

**Period**
- January 2016 / June 2017

**IRI Budget**
- 37,590 €

**P. Investigator**
- Joan Andrade

#### 3T-SLTE

Tractor unit for lifts with integrated intelligent energy management

3T-SLTE, is a project from the company SU-MASA with CDTI funding. It aims at applying artificial intelligence methods to the energy management in elevator systems.

**Period**
- March 2016 / March 2016

**Budget**
- 25,000 €

**P. Investigator**
- Guillem Alenyà

#### TERMOSOLD

Development of a system based on artificial intelligence techniques for welding inspection in horizontal packaging lines

This CDTI project funded by the company VOLPAK aims at developing a system for detecting anomalies in sealing / welding of flexible packaging that could lead to leakage or contamination of the packaged product.

**Period**
- March 2015 / October 2017

**IRI Budget**
- 75,000 €

**P. Investigator**
- Guillem Alenyà

#### PERSEO

Robust scalable package targeted specific solutions

PERSEO is a CDTI project where IRI is subcontracted by the company CIRCUTOR. It deals with the energy management in instrumentation equipment.

**Period**
- May 2016 / May 2016

**IRI Budget**
- 70,000 €

**P. Investigator**
- P. Investigator

### PLATT

Technology transfer action plan for TECNIO candidates

In this plan we are carrying out actions to define and strengthen the technology transfer strategy of the institute. Its main objective is to better valorize our scientific expertise and capacities for the industrial sector. At the same time, we aim at receiving the TECNIO certification, a technology transfer quality seal awarded by Government of Catalonia, through ACCIÓ.

In addition, a Marketing Plan will be defined and a Quality Management System based on ISO 9001:2015 has been deployed.

**Period**
- October 2016 / May 2016

**Budget**
- Year 1: 51,875 €
  - Year 2: 44,451 €

**Funding organization**
- Year 1: IRI
  - Year 2: IRI

**P. Investigator**
- Guillem Alenyà

**Period**
- October 2015 / May 2018

**IRI Budget**
- 51,875 €

**P. Investigator**
- Alberto Sanfeliu

**Period**
- September 2016 / February 2017

**IRI Budget**
- 50,000 €

**P. Investigator**
- Joan Andrade

**Period**
- January 2016 / June 2017

**IRI Budget**
- 37,590 €

**P. Investigator**
- Guillem Alenyà

**Period**
- March 2016 / March 2016

**Budget**
- 25,000 €

**P. Investigator**
- Guillem Alenyà

**Period**
- March 2015 / October 2017

**IRI Budget**
- 75,000 €

**P. Investigator**
- Guillem Alenyà

**Period**
- May 2016 / May 2016

**IRI Budget**
- 70,000 €

**P. Investigator**
- P. Investigator
<table>
<thead>
<tr>
<th>Period</th>
<th>Budget</th>
<th>Investigator</th>
<th>Title</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 2015 / March 2017</td>
<td>60,000 €</td>
<td>Guillem Alenyà</td>
<td>CRISTALBREAD</td>
<td>Research on technologies for the intelligent robotic manipulation of highly-hydrated bread dough</td>
</tr>
<tr>
<td>March 2015 / March 2017</td>
<td>60,000 €</td>
<td>P. Investigator</td>
<td>AUTOMATIC TV</td>
<td>Algorithms for automatic audiovisual production</td>
</tr>
<tr>
<td>October 2015 / March 2016</td>
<td>24,900 €</td>
<td>Francisco Barció</td>
<td>This project aims at improving the state of the art in getting automated segmentations of neural circuits from brain tissue. Its funding comes from Howard Hughes Medical Institute at Janelia Research Campus, USA.</td>
<td></td>
</tr>
<tr>
<td>September 2015 / September 2016</td>
<td>50,000 €</td>
<td>Vicenç Puig</td>
<td>IRI-CETAQUA</td>
<td>Contribution to the promotion and supervision of research projects on the field of water distribution networks</td>
</tr>
<tr>
<td>September 2016 / August 2017</td>
<td>30,200 €</td>
<td>Carlos Ocampo</td>
<td>SENECA</td>
<td>Semi-automatic neuron reconstruction in CATMAID</td>
</tr>
<tr>
<td>September 2016 / August 2017</td>
<td>34,866 €</td>
<td>Gabriela Cembrano</td>
<td>SITVIA</td>
<td>Adaptive artificial pad printing inspection system</td>
</tr>
<tr>
<td>September 2017 / December 2017</td>
<td>90,000 €</td>
<td>Carlos Ocampo</td>
<td>MODCON</td>
<td>Modeling and control of sewage networks in Bogota, Colombia</td>
</tr>
<tr>
<td>October 2014 / March 2015</td>
<td>28,800 €</td>
<td>Francesc Moreno</td>
<td>This project is focused on developing control systems to be applied to the new advanced manufacturing technologies that are being developed in R&amp;D Unit of the company Iriupe.</td>
<td></td>
</tr>
<tr>
<td>September 2015 / August 2016</td>
<td>38,220 €</td>
<td>Carlos Ocampo</td>
<td>IKERCON</td>
<td>Advanced control of complex manufacturing processes</td>
</tr>
<tr>
<td>June 2007 / June 2018</td>
<td>90,000 €</td>
<td>Gabriela Cembrano</td>
<td>RCT1201</td>
<td>Ph2-Optimal and predictive RTC module interfaced to SWIP</td>
</tr>
<tr>
<td>June 2017 / June 2018</td>
<td>50,000 €</td>
<td>Vicenç Puig</td>
<td>This project addresses the global control of sewer networks using a predictive optimal control approach. The sewer network is modelled using a conceptual modelling approach based on decomposing the network in catchments and representing them as virtual tanks.</td>
<td></td>
</tr>
</tbody>
</table>
TECHNOLOGICAL EXPERTISE

MECHANISM DESIGN & ANALYSIS
Mechanism design and construction
Molecular modelling
Analysis and planning of mechanism motion

AERIAL ROBOTICS
Aerial robot localization, mapping and navigation
Aerial perception and manipulation
Aerial robot control and planning strategies

SOCIAL ROBOTICS
Robot companion

ASSISTIVE ROBOTICS
Proactive assistance to disabled users
Perception and manipulation objects

URBAN MOBILITY
Autonomous navigation
Drive assistance (ADAS)
Urban service robotics
Heavy vehicle automation

ENERGY SYSTEMS
Fuel cell systems
Energy management

ADVANCED TECHNIQUES IN VISUAL PERCEPTION
Deep learning applications
Geometric computer vision

COMPLEX SYSTEMS CONTROL
Modelling, control and supervision of complex systems

SMART FACTORIES (INDUSTRIES 4.0)
Human-Robot cooperation
Factory automation

WATER CYCLE CONTROL SYSTEMS
Drinking waters network
Urban drainage systems

SERVICES OFFERED TO COMPANIES

- INNOVATIVE RESEARCH PROJECTS
Answers to singular needs at the state-of-the-art, providing solutions with added value.

- INDUSTRIAL DOCTORATES
Supervision of company-hired or grant-supported industrial PhD students.

- CONSULTING
Industrial and technical advice to companies to help them develop new products and services.

- PARTICIPATION IN PROJECT CONSORTIA
We often take part in collaborative projects and initiatives participated by industrial partners (Horizon 2020, CDTI, ...).

- USE OF LABORATORY EQUIPMENT
Facilities are open to our industrial collaborators for project development.

- PROTOTYPING
Design, rapid prototyping and testing of devices to address specific needs.

SOME OF OUR COLLABORATORS AND CLIENTS

- **TECHNOLOGICAL EXPERTISE**
- **AERIAL ROBOTICS**
- **SOCIAL ROBOTICS**
- **URBAN MOBILITY**
- **ADVANCED TECHNIQUES IN VISUAL PERCEPTION**
- **SMART FACTORIES (INDUSTRIES 4.0)**
- **ENERGY SYSTEMS**
- **COMPLEX SYSTEMS CONTROL**
- **WATER CYCLE CONTROL SYSTEMS**

- **SERVICES OFFERED TO COMPANIES**
- **INNOVATIVE RESEARCH PROJECTS**
- **INDUSTRIAL DOCTORATES**
- **CONSULTING**
- **PARTICIPATION IN PROJECT CONSORTIA**
- **USE OF LABORATORY EQUIPMENT**
- **PROTOTYPING**

- **SOME OF OUR COLLABORATORS AND CLIENTS**
6. OUTREACH

WHY WE DO IT?
At IRI, we think that it is good to involve all our members in scientific dissemination activities that attempt to bring our science to all audiences. For this reason, our staff participates frequently in many events such as seminars, workshops, talks, exhibitions and competitions.

OUTREACH ACTIVITIES IN 2015 / 2016
- Setmana de la Ciència
- European Robotics Week
- Festa de la Ciència
- Barcelona Robotics Meeting
- Smart City Expo World Congress
- CEABOT
- Periodical guided visits to IRI
- Maker Faire Barcelona
In order to better reach the society with today’s technology, we have decided to become part of social networks. Starting in 2011, we maintain Twitter and Facebook accounts as well as a YouTube channel, LinkedIn and the IRI webpage.

Nowadays, we have developed an integrated communication plan which is helping us to disseminate science in a social way.

We use our Twitter account to publish our job offers, to inform about the celebration of our research seminars, and to announce all the international visitors we receive. We also inform about our attendance to different outreach events, the day to day activities in the centre, news and curiosities about robotics.

At the beginning, our Facebook account was used to publish images and answer questions and comments from many users. Now, we combine Twitter and Facebook depending on the communication needs. YouTube is mainly used by our researchers, to share videos of their demonstrations and work.

**MEDIA APPEARANCES**

During the years 2015 and 2016, the presence of IRI in the media has been remarkable, appearing in several newspapers, television and radio programs. This increases the visibility of our research activities to a general audience.

**SOCIAL NETWORKS**

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**MEDIA APPEARANCES**

During the years 2015 and 2016, the presence of IRI in the media has been remarkable, appearing in several newspapers, television and radio programs. This increases the visibility of our research activities to a general audience.
Funding sources of our center are diverse. CSIC and UPC finance salaries of permanent staff belonging to these institutions. In addition, CSIC and UPC also make contributions for general operating expenses of the institute.

Our scientific personnel is committed to excellence in research, and that is why half of our budget is obtained through competitive calls for projects and personnel programmes, as well as technology transfer contracts. This self-funding percentage over 50% is a high figure for a public research institute.
PHOTO CREDITS

Pages / Description
2 / 3  Darwin and Tena. educational robots from HumanoidLab.
4  Juan Andrade. IRI's Director at the biennial period 2015 - 2016.
6  Workstation at the Fuel Cell Lab.
12  Kinton aerial robot at Mobile Robotics Lab.
14  IRITIC Computer server.
15  IRI services staff.
19  From left to right (front line): Porta, Juan Viana and Xiaoxuan Hu.
20  From left to right (second line): Ferrán Cortés, Patrick Grosch and Daniel González.
26 / 27  Paralell robot detail at the Kinematics and Robot Design Lab.
30  From left to right (front line): Víctor Vílchez, Sergi Hernán Cesas, Pablo Jiménez, Carme Torras, Guillem Alenyà, Fran
32  From left to right (second line): Alejandro Suárez, Gerard Cembrano, Congcong Sun, Joaquim Blesa, Tom Crema
ders, Wicak Aranuntha and Víctor Fox.
39  From left to right (front line): Tibi, Kinton and Teo.
41  Teo Robot at Mobile Robotics Lab.
42 / 43  From top to bottom: 1 - Reference frames 2 - Results of the simulated grasping task and the GAZEBO simulator.
44  Toma Pippia, Unnikrishnan Raveendran and Attila Husar.
46 / 47  From left to right (front line): Carlos Ocampo, Víctor Sanz, Vicente Roda, Massoud Pouraghbarh Mary Serrà, Gabriela Cembrano, Congcong Sun, Joaquim Blesa, Tom Crema
ders, Wicak Aranuntha and Víctor Fox.
48  From left to right (second line): Julián Barrene, Fatemeh Karrari, Jenny Lorena Díaz, Maite Urrea, Brais González, Toma Pippia, Unnikrishnan Ravindran and Attilla Husar.
50  Water tank at the Water-cycle Control Systems Lab.
54 / 55  From left to right (front line): Carlos Ocampo, Víctor Sanz, Vicente Roda, Massoud Pouraghbarh Mary Serrà, Gabriela Cembrano, Congcong Sun, Joaquim Blesa, Tom Crema
ders, Wicak Aranuntha and Víctor Fox.
56  Fuel cell at Fuel Cell Control Lab.
57  Alejandro Suarez disassambling a hard drive for the Ima
gine project.
58 / 59  IRI PhD Students defending their PhD Thesis at FME.
68  Attila Husar taking notes in a seminar at IRI main meeting room.
70  Port crane.
73  Vicente Roda working with a fuel cell at Fuel Cell Control Lab.
75  Collaborator logos:
From left to right (first line): Google, Volkswagen R&D, SEAT, Volvo, Etze-Tar and Sada
dako Technologies.
From left to right (second line): Idiada, Eurecat, Ficosa, CATEC, AENOR and Ajuntament de Barcelona.
From left to right (third line): PAL Robotics, Mediapro, Wide Eyes, LETIT, Signadyme and ALSTOM.
From left to right (fourth line): CETAQUA, AQUALOGY, ArL, SITEL, Fundació ACE and Fadis

Media appearances:
From left to right (first line): Alberto Sanfeliu (El Periódico - 02/01/2015); Tibi at Smart City Expo World 2016 (El País - 14/1/2016).
From left to right (second line): Carmen Torres (El Periódico - 27/03/2016), Tibi at CARMET Project (El Mundo - 03/06/2016 ), IDRESS Project (El Periódico - 05/1/2016).
From left to right (third line): Anaí Sanfeliu (TeVe - 28/02/2015); Alberto Sanfeliu (RTVE - 25/10/2015) Edgar Simo-Serra (TeVe - 08/07/2016) and Michael Villamizar (TeVe - 28/02/2015).

Detail of the E-bola robot.

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