

FINAL SCIENTIFIC REPORT

FCT PROJECT PEst-OE/EEI/LA0009/2011

2011 -2012

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EXECUTIVE SUMMARY

The LARSYS Associate Lab was founded in 2011, partly resulting from the re-organization of a previously existing Associate Lab and the consolidation and extension to new scientific areas.

The research activities of the Associate Laboratory LARSYS are organized in five thematic areas, that encompass cutting-edge, multidisciplinary research problems, while addressing several societal challenges:

- A-Complex Systems in Engineering and Fundamental Sciences;
- B-Sustainable Urban Systems and Technologies;
- C-Sustainable Energy, Environment, and Economic Development;
- D-Ocean Systems Technology; and
- E-Ocean Resources and Ecosystems.

These thematic areas are scientifically supported by the eleven research groups that compose the AL (IMAR- Centre of IMAR of the University of the Azores; CREMINER- Centre of Mineral Resources, Mineralogy, and Crystallography of the University of Lisbon; LEES-Laboratory for Energy and Environmental Studies of the Center for Innovation, Technology and Policy Research at Instituto Superior Técnico (IN+/IST); LTPM- Laboratory of Technology Policy, and Management of Technology of IN+/IST; LTCES-Laboratory of Thermofluids, Combustion and Energy Systems of IN+/IST; DSOR - Dynamical Systems and Ocean Robotics Laboratory of the Institute for Systems and Robotics at IST (ISR/IST); ESBE-Evolutionary Systems and Biomedical Engineering of ISR/IST; IRS-Intelligent Robots and Systems of ISR/IST; SIPG-Signal and Image Processing Group of ISR/IST; VisLab - Computer and Robot Vision Laboratory of ISR/IST; and CAMGSD-Center for Mathematical Analysis, Geometry and Dynamical Systems of IST.

This report provides a comprehensive description of the scientific activities of LARSYS during the period 2011-12.

1. RESEARCH GROUPS

IMAR – Centre of IMAR of the University of Azores

Main Achievements

Main effects of human activities on seamount communities

Part of this objective intended to assess threats and impacts of current anthropogenic activities on seamounts. Mainly comparing data collected from seamounts with different states of exploitation to infer the impact of fishing activities on seamounts ecosystems. In this contest we propose a framework for applying the CBD EBSA criteria to locate potential ecologically or biologically significant seamount areas based on the best information currently available. This framework also allows the identification of seamount EBSAs and threats considering different ecological groups in the pelagic, benthic of both realms. Therefore, this framework represents an important tool to mitigate seamount biodiversity loss and to achieve the 2020 goals. The first EBSA at the CBD repository is a product of our group, the Josephine seamount.

Seamount Ecosystem Evaluation Framework (SEEF)

Significant progress on the seamount Ecosystem Evaluation Framework (SEEF) was made, by finishing all data entry into the main database. We have applied SEEF to seamounts in the North Atlantic Ocean and the Mediterranean Sea, compiling available information from a range of sources. The degree of seamount knowledge was evaluated regarding 36 attributes, and variation between geographical areas assessed. By the end of 2011, 157 seamounts in the North Atlantic Ocean and 22 in the Mediterranean Sea have been evaluated through SEEF. Additionally, SEEF now also includes 406 seamounts in the Pacific Ocean and 26 in the Southern Ocean.

These studies were reckoned as opposing the 'seamount island hypothesis'. Another example is data reporting increased abundances of benthic fauna or the presence of visiting organisms (large pelagic or air-breathing species) and aggregating fish species that were used to validate the 'seamount oasis hypothesis'. Abundances of benthic invertebrate fauna have been assessed comparatively for 26 seamounts, and among these the majority were either inferred to host increased abundances the values are averages for a large group of seamounts) or faunal abundances were found to be similar to or lower than comparable areas. In order to facilitate the public use of SEEF interactive maps were created in Google Earth (version 6,2010). The maps also contain information for each seamount regarding the name, position, depth of the peak, height of the seamount, and the proportions of attributes scored in the four disciplines Geology, Oceanography, Ecology and Threats.

Decreasing seawater pH effects on coral growth as assessed from experiments.

Aquarium experiments on the effects of decreasing seawater pH on coral growth of the solitary scleractinian coral *Desmophyllum cristagalli* are now completed and results are currently under

analysis and write-up. This experiment consisted of a long-term experiment to compare the calcification, basal metabolism (measured as respiration rates) and gene expression responses *D. dianthus*, at pH levels of their natural environmental (pH=8.1) with those predicted for the year 2100 (pH= 7.8). Corals were collected from 450 m depth in the Azores (NE Atlantic) and maintained in aquaria under controlled pH levels using a CO₂-bubbling system in flow-through aquaria under constant water temperature, over a period of 9 months. Gene expression profiles were studied by means of RT-qPCR, targeting representative genes involved in biomineralization, cellular stress and metabolism.

Acidification experiments with the gorgonian *Dentomuricea* sp. were undertaken. Results of both of these experiments report on decreasing seawater pH effects on coral growth as assessed from experiments.

Chemosynthetic Ecosystems

We continued to analyze our transcriptome data and carried out the validation of immune-related genes involved in defence and stress related reactions in vent mussels. Research involves the elucidation of biological capacities of *Bathymodiolus azoricus*, particularly, the immune responses to *Vibrio* infections. Host responses against own endosymbiont bacteria were further investigated at the level of the gill tissue section structures. We found that there is a tissue specific gene expression distribution along the anterior-posterior axis of the gill tissues.

We actively pursued the characterization of other immune genes, namely lectins and their role in immune recognition events. We also concentrated on sequences from genes expressed by bacteria, present in vent mussel gill tissues, and conducted in-situ hybridizations.

Other studies

Biotelemetry involved studies on large pelagics (e.g. fish as jamantas, blue sharks, whale sharks; whales: e.g. blue and fin whales; and seabirds), and deep-sea fishes (e.g. *Pagellus bogaraveo*). In a shorts synthesis: 1) we were intrigued by the need of blue and fin whales to balance energy reserves during migration since this is a critical factor for most long-distance migrants and an important determinant of migratory strategies. These large baleen whales migrate annually between foraging and breeding sites, crossing vast ocean areas where food is seldom abundant.

We knew they spend sometime in the Azores; 2) Ecological interactions in the deep ocean remain largely unknown despite the large biomass of fishes and squids residing there and the likely importance of this resource to a suite of pelagic predators, including commercial fish species, endangered marine mammals and seabirds. We studied devil rays (*Mobula tarapacana*) in the central North Atlantic Ocean in view to evaluate horizontal and vertical movement patterns for up to 9 months. Our results provide evidence of a new and completely unexpected link between pelagic predators in the surface ocean and forage fishes occupying deep pelagic habitats in the world ocean.

CREMINER – Centre of Mineral Resources, Mineralogy, and Crystallography of the University of Lisbon

The group has achieved internationally recognized success with its studies on i) ore-forming processes and resource characterization on land, including metallic and non-metallic resources; ii) submarine hydrothermal resources and the deep biosphere; iii) uranium deposits. related not only to the strategic character of this energy resource but also to the uranium mining impacts. and iv) experimental and geochemical modeling of low-temperature processes related with environmental impacts due to heavy metal contamination in landfills and old mining areas. Experimental evidence of the mechanisms of Cu adsorption onto illite edge surface sites and the influence of solution pH and ionic strength. Computational study of idealized edge-surfaces of phyllosilicates with molecular dynamics and ab-initio DFT. Preparation of experimental materials to be measured by EXAFS spectroscopy. Detailed evaluation of the chemical and mineralogical data to unravel the relationship between the Cu and Ba uranyl-phosphate minerals. First topographic characterization and dissolution experiments of torbernite surfaces using a fluid-cell in an AFM. Growth of several Ba and Cu uranyl-phosphate crystals in doubly diffusion silica gel tubes and in reactive silica gel environment. There are already very significant (published) results. The main components of these studies are mineralogy and geochemistry, including isotopic geochemistry.

Combination of i) and ii) led to original proposals for the exploration for submarine massive sulphide deposits, ready to be tested in actual seafloor and subseafloor exploration campaigns. Current work includes comparisons with the Azores MoMAR examples and the Arctic Loki's Castle and Jan Mayen hydrothermal fields and development of analytical techniques with portable equipment, for use during cruises at sea, with portable equipment, producing results in minutes to a few hours. The main limiting factor, for Creminer as for other research institutions in Portugal, is access to shiptime and submersible use.

Public outreach efforts have strengthened further, largely related to the Centro Ciencia Viva Mina de Ciencia (Mine of Science Live Science Centre) already acclaimed as a landmark of capacity for the original production of scientific contents in hands-on exhibits. J Relvas and A Pinto are directors of the Centre. Creminer considers Lousal as one of its main achievements.

Concerning the new experimental facilities, the Stable Isotope lab is now installed and properly run. AmbiTerra (run by R Fonseca) gained expertise and general recognition as a top quality laboratory for soils and sediments. including marine sediments. for which AmbiTerra may already be a leading national laboratory. These labs are beginning to perform analyses not only for Creminer's research but also in the framework of external contracts for applied studies and surveys.

The ongoing research on geo-archeology has been primarily focused on Roman archaeometallurgy of copper at Vila Velha de Ródão.

DSOR - Dynamical Systems and Ocean Robotics Lab

The key objectives of the R&D work carried out at the DSORL are twofold: i) to study a number of challenging theoretical problems in the areas of advanced robotic vehicle systems design, navigation, and control and ii) to exploit the theoretical methodologies developed to yield faster, cheaper, and far more efficient systems and tools for ocean exploration and exploitation and critical infrastructures inspection than those that are available today. The tools include networked surface and underwater robots working in cooperation, as well as aerial vehicles acting as communication relays or re-directing the operations of marine vehicles upon detection of relevant episodic events. The most relevant theoretical and practical achievements in 2011 and 2012 are described next:

THEORETICAL ACHIEVEMENTS

1. Development and test of novel Multiple-Model Adaptive Control (MMAC) and Multiple Model Adaptive Estimation (MMAE) architectures for plants subjected to structured and unstructured uncertainty and sensor noise. Selected algorithms were successfully tested during experiments of Dynamic Positioning of a scale model of a surface ship at the Norwegian University of Science and Technology (NTNU).
2. Study of new algorithms for control and state estimation on SE(3). Development of a method to solve constrained cooperative motion planning problems for multiple vehicles (undergoing translational and rotational motions) by using a new group projection-operator approach.
3. Development of a projection-operator approach (In Euclidean space) for multiple vehicle cooperative motion planning with temporal or energy cost criteria, with due account for full vehicle dynamics, temporal or spatial deconfliction, and communication and navigation-related constraints. The present algorithm is capable of solving dynamically constrained trajectory planning problems by minimizing a cost functional that, in a representative example, is taken as the overall energy required by all agents to maneuver and arrive simultaneously at specified target sites.
4. Development and field testing of robust decentralized strategies for cooperative path-following control and time-coordination of unmanned air vehicles (UAVs) over dynamic communications networks (work done in cooperation with the Naval Postgraduate School, Monterey, CA and the Univ. Illinois, Urbana, USA).
5. Study of nonlinear filter algorithms for combined Terrain-Aided / Single-Beacon based navigation in the presence of unknown marine currents; assessment of their performance in field tests using an autonomous marine vehicle equipped with an acoustic ranging device and a bottom-looking echosounder.

6. Development of a new nonlinear filter structure for Terrain-Aided Navigation (TAN) for the case where distributed sensing over networked vehicles is available. The scenario considered addresses the case where a vehicle improves its navigational capabilities by incorporating - in its navigation system - the range to another companion vehicle and the information that the latter one obtains on the altitude above the terrain using an echosounder. The performance of the filtering structure proposed was assessed in field tests.
7. Development of novel techniques for navigation and source localization by mobile agents based on the range to a single source, in addition to relative velocity readings. The contribution of the developed strategy is two-fold: i) necessary and sufficient conditions on the observability of the nonlinear system are derived, which are useful for trajectory planning and motion control of the agent; and ii) a nonlinear system, which given the input and output of the system is regarded as linear time-varying, is proposed and a Kalman filter is applied to successfully estimate the system state.
8. Autonomous underwater vehicle (AUV) range-only localization and mapping using relative range measurements to stationary beacons whose locations are also unknown. Using the concepts of minimum energy estimators applied to continuous processes with discrete measurements (not necessarily with a fixed sampling time), adaptive multiple models estimators, and simultaneous localization and mapping techniques, we proposed an observer that (under observability-like assumptions) drives the estimation errors to a small neighborhood of zero, where the size of the neighborhood depends on measurement noise and disturbances.
9. Further development of nonlinear filtering structures for USBL tightly coupled inertial navigation and development of nonlinear GPS/IMU based observers for rigid body attitude and position estimation.
10. Development of a novel integrated navigation strategies based on a combined Long Baseline / Ultra Short Baseline (LBL/USBL) acoustic positioning system with application to underwater vehicles. With a tightly-coupled structure, the position, linear velocity, attitude, and rate gyro bias are estimated, considering the full nonlinear system dynamics without resorting to any algebraic inversion or linearization techniques. The resulting solution ensures convergence of the estimation error to zero for all initial conditions, exponentially fast.
11. Development of robust take-off strategies for a quadrotor unmanned aerial vehicle in critical scenarios, such as in the presence of sloped terrains and surrounding obstacles. Throughout the maneuver, the vehicle was modeled as a hybrid automaton whose states reflect the different dynamic behaviors exhibited by the UAV. The original takeoff problem was then addressed as the problem of tracking suitable reference signals in order to achieve the desired transitions between different hybrid states of the automaton. Reference trajectories and feedback control laws were derived to explicitly account for uncertainties in both the environment and the vehicle dynamics.
12. Further developments on rotorcraft and aircraft image based controllers for extended flight envelope coverage. The proposed solution consists of a nonlinear state feedback controller for thrust and torque actuations that uses directly the image features in the control loop.

13. Further development of new methods to prove almost input-to-state stability (ISS) and almost global stability of nonlinear –rotational motion- systems by exploiting the combined use of Lyapunov Functions and Density Functions. The idea is to combine both techniques, to yield stability results that are valid for almost all the solutions of the system. Based on the combination of Lyapunov and density functions, analysis methods were proposed for the derivation of almost input-to-state stability, and of almost global stability in nonlinear systems.
14. Development of algorithms for Nonlinear Attitude Estimation Systems. By directly exploiting Active Vision and Inertial Measurements a stabilizing feedback law was introduced, and exponential convergence to the origin of the estimation errors was shown. Additionally, an active-vision system was proposed that relies on an image-based exponentially input-to state-stable control law for the pan and tilt angular rates of the camera to keep the features in the image plane.
15. Developments on Networked and Event Based Control Systems. Within the framework of hybrid systems to model several networked control scenarios, and the machinery of Volterra equations, piecewise deterministic processes, and dynamic programming new developments were obtained for a class of systems that is especially suited to model networked control systems utilizing CSMA-type protocols, with stochastic intervals between transmissions and packet drops.
16. Developments on continuous-time consensus with discrete-time communications. Optimal acoustic sensor placement: study of the performance that can be achieved with networked acoustic sensors to track multiple underwater targets by resorting to tools from estimation theory and multiple-objective optimization (Pareto-optimal solutions).
18. Development of novel fault detection and isolation methods using set-valued observers, for uncertain linear parameter-varying systems. The proposed method relies on SVO-based model invalidation to discard models incompatible with measured data. The proposed approach: i) under suitable conditions, guarantees false alarms are avoided; ii) unlike residual-based architectures, does not require the computation of thresholds to declare faults; iii) has applicability to a wide class of plants.
19. Cooperative path-following control with logic-based communications: development of an event driven communication logic for decentralized control of a network of nonlinear systems (agents). The newly introduced communication logic takes into account the topology of the communication network, the fact that communications are discrete, and the cost of exchanging information. The objective is to reduce the amount of information exchanged among the vehicles. We also address explicitly communication losses and bounded delays. Conditions were derived under which the overall closed loop system is input-to-state practically stable.
20. Range-only formation control: design, development, and in-the-water testing of algorithms for relative motion control. The problem addressed falls in the category of Range-Only Formation (ROF) control, whereby a group of autonomous vehicles keeps formation by using information about the relative distances among them. This is in striking contrast to by now classical

cooperative formation control systems, where it is commonly assumed that all vehicles in the formation have access to their inertial positions.

PRACTICAL ACHIEVEMENTS

1. Further redesign, development, and test of an autonomous quadrotor for the inspection of critical infrastructures. The aerial vehicle, developed under the AIRICI project, is equipped with video cameras and lasers that, together with advanced control and navigation algorithms, will enable the robot to operate close to walls or under bridges without GPS.
2. Demonstration of the cooperative operation of two Marine Robots with Dexterous Manipulation for Enabling Autonomous Underwater Multipurpose Intervention Missions, under the framework of the European TRIDENT project. Multi-vehicle robotic navigation, control, and mission control systems have been developed and validated at sea, with a surface vehicle operating in cooperation with an autonomous underwater vehicle. This AUV was equipped with a specially designed ultra short based line positioning system, for surface/underwater vehicle cooperation, and a manipulator resulting in a new tool for multipurpose underwater intervention tasks, with diverse potential applications such as underwater archaeology, oceanography and offshore industries.
3. Design, development, and full demonstration of the capabilities at sea of a small fleet of three autonomous surface vehicles named MEDUSA and related systems for cooperative mission programming and mission execution. The vehicles are equipped with acoustic devices for underwater target tracking and cooperative, complementary terrain-based / single beacon navigation.
4. Development and demonstration of an integrated system for assisted diving operations, illustrating joint robot/human missions (final demo in the scope of the EU-CO3AUVs project): a diver was guided along a path underwater by relying solely on information issued by a small fleet of MEDUSA vehicles in charge of tracking him. The information was transmitted via the acoustic channel and, after being processed, displayed as heading commands on an array of LEDs placed on the diver's mask.
5. Demonstration of cooperative range-only formation control using a set of MEDUSA autonomous marine vehicles exchanging inter-vehicle ranges over an acoustic network. This milestone paves the way for the development of a new breed of systems for marine habitat mapping that will rely on the use of multiple vehicles undergoing formation control for mapping missions in complex 3D underwater environments, a key objective in the European MORPH project.

Development of an inexpensive single pan and tilt camera based indoor positioning and tracking system, supported on a functional architecture where three main modules can be identified: one related to the interface with the camera, tackled with parameter estimation techniques; other, responsible for isolating and identifying the target, based on advanced image processing techniques, and a third, that resorting to nonlinear dynamic system suboptimal state estimation

techniques, performs the tracking of the target and estimates its position, and linear and angular velocities.

Evolutionary Systems and Biomedical Engineering

1. Objectives

Besides the enhancement of current research work on agent based modeling and human sleep analysis, the future main research activities of the group are oriented towards the development of novel and integrative approaches for modeling, simulation and optimization of biological and green energy systems. A new initiative is the research and development of advanced Neuroimaging analysis methodology for Biomedical Applications namely fMRI and combined EEG+fMR (possibly Optogenetics). The future research goals defined for the next years are a natural consequence of the work developed so far.

Results 2011-2012:

1.1 Development of a third framework for the simulation of biological systems based on agent based methodologies – this framework aims to assist the biological research in test qualitatively and quantitatively new biological theories and to model and optimize a Farm of Wind Generators (under the Fluctwind project). This section will integrate Multi-Core, GPU, Cloud and Cell computing systems to speedup the simulations and optimizations.

1.2 Start a research on Visualizing Biological Data. Experimental biology delivers increasing data volume and complexity, the need for effective visualization tools to help benefit from these data becomes increasingly urgent. This research aims to develop a set of interrelated tools that streamline common steps in visual analyses (Integrated Visualization tools through Reflect, Aquaria, etc).

Sustained Line: Strengthen the research line on Bio inspired optimization and Modelling. The main activities of this line will be on the development of new paradigm, new operators, efficient algorithms with synergies of different paradigms. A new topic of research is the investigation on higher level swarm intelligence and multi and many objectives paradigms.

1.3 Development of new methodologies for analysis and exploration of Bio Feedback and Neuro Feedback together with fMRI imaging analysis, namely for personal performance enhancing, high competition athlete training and rehabilitation therapy. Collaborative work with BME lab of University of Macao, Dep Neurology, UNESP, Botucatu, SP, Brazil.

1.4 Development of a fully automatic analysis system for Advanced Diagnosis of Sleep Disorders in collaboration with industry partners incorporating a new model for the micro structural organization of the Sleep process in partnership with Stanford University and State University of Sao Paulo, culminating with the proposal of a new Paradigm for Sleep Classification.

1.5 Research in Neuroimaging will be conducted along two main orientations: quantitative functional MRI (fMRI) and simultaneous EEG-fMRI. Both ASL and BOLD image acquisition and analysis protocols will be continuously developed and implemented on a 3T MRI system (Hospital da Luz), including optimized functional activation paradigms as well as novel model and estimation techniques [e.g., Pimentel et al., ISMRM 2010; Santos et al., ISBI 2011; Sousa et al., ISMRM 2011], with the perspective of clinical applications in cerebrovascular disease and dementia. An MRI compatible EEG system will be purchased (through FCT funded Project PTDC/SAU-ENB/112294/2009) and installed on a 3T MRI system (Hospital da Luz), in order to allow the simultaneous acquisition of EEG and fMRI signals. Methodological developments will be aimed at improving the sensitivity of EEG-fMRI recordings, while gaining insight into the spatio-temporal dynamics of brain activity. These will involve both the development of appropriate artifact correction and signal processing techniques, as well as the integration of electrical and hemodynamic data through fusion models, particularly aimed at the study of epileptic activity [e.g., Leite et al., HBM 2011; Murta et al., HBM 2011]. In parallel, research will also be conducted using a 7T MRI system, in collaboration with the Centre d'Imagerie Biomédicale (CIBM) (EPFL / CHUV, Switzerland), in order to take advantage of the increased SNR at ultra high-field to be able to study the coupling between neuronal and vascular events in the brain [e.g., Jorge et al., ISMRM 2011].

IRS – Intelligent Robots and Systems

Main Achievements

2011:

- In the project ITER CPRHS/CTS, complete studies on motion planning methodologies for the mobile vehicles CPRHS and CTS operating in the Tokamak and Hot Cell buildings of ITER (The International Thermonuclear Experimental reactor) were conducted, in particular those that explore the full flexibility of the rhombic kinematics of the vehicles and allow for each wheel to follow a different path. More than 500 trajectories were generated for all ports in Tokamak Building and Hot cell Building. Update of the Trajectory and Evaluator Software tool (TES) aiming at providing, in CATIA format, the volume occupied by the CPRHS vehicle when following a 2D path was carried out.
- Within the FCT BioInst-Bots project, we developed a detailed stochastic simulator of T helper (Th) cells, in collaboration with biologists at the Gulbenkian Institute of Science. Discrete events at multiple time scales were simulated within each cell. The simulator was further improved with a novel implementation of the Gillespie Stochastic Simulation Algorithm, to scale the system to very large number of Th cells. In addition, classical immunology experiments were replicated to calibrate the parameters of the simulator.
- We devised a bio-inspired algorithm that simulates the interactions between different effector and regulator Th cells using a limited number of robots, for the detection of novel

features. The dynamics of the interactions between the cells would allow our collective robotics system to discriminate between features without the need for any hard-coding of the feature vector.

- We published a paper in RSS2011, where we extend our work on supervision of robot tasks represented as Petri nets by introducing a methodology to build a Petri net realization of a supervisor that, given a Petri net model of a (multi)- robot system and an LTL specification, forces the system to fulfil the specification. The methodology encompasses composing the Petri net model with the Buchi automaton representing the LTL formula and trimming the result using a known method to reduce the size of the supervisor.
- We have been developing theory as well as solution methods for multiagent planning under uncertainty, advancing the state of the art significantly. We developed the currently fastest optimal planner for general Dec-POMDPs (IJCAI 2011).
- We have been working on developing methods for multiagent planning under uncertainty for multi-robot systems. Such real-world systems violate several assumptions typically made in the field. For instance, synchronization issues between agents are not considered or when communication is available it is assumed to be flawless and instantaneous. We published a paper in NIPS 2011 where we assume Factored Dec-POMDPs and we allow inter-robot communication, which turns the problem into a centralized Multiagent POMDP (MPOMDP). The key point is that when sparse dependencies between the agents' decisions exist, often the belief over its local state factors is sufficient for an agent to unequivocally identify the optimal action, and communication can be avoided.
- We published in ECMR2011 an algorithm that handles Cooperative Perception problems under a common Bayesian framework, based on particle filters, for moving targets and observer sensors. The paper was selected as one of the ECMR2011 best papers, and invited for submission to a Special Issue of the Elsevier JRAS
- We published in ECAL2011a formalism for institutions in the Institutional Robotics model using the abstract representation of Executable Petri Nets. We assessed the ability of our formalism to replicate results obtained with other approaches to the modelling of swarm robotics systems. We also assessed if institutional controllers can be used in modelling and analysing the distributed robotic system they control by providing the necessary structure to build macroscopic models of that system. The paper was selected as one of ECAL2011 best papers and invited for submission to the ALife journal.
- The research project MAIS+S, funded by the CMU-Portugal program, has been very positively evaluated by an international panel of reviewers. Within the project, we have defined some reference scenarios and started networking several cameras in the 8th floor of ISR/IST, together with 3 quad-core servers, that will be used for image processing and planning under uncertainty, the project main research activities.
- In joint work with researchers from Universidad Carlos III de Madrid, we published a journal paper (Elsevier JRAS) where we introduced the application of the Voronoi Fast Marching (VFM) method to path planning of mobile robot formations. The navigation

function can be classified as a type of potential field, but it has no local minima, it is complete (it finds the solution path if it exists) and it has a complexity of order $n(O(n))$, where n is the number of cells in the environment map.

- We have started a collaboration with CMU on the area of symbiotic interaction with Manuela Veloso group, following the participation of Rodrigo Ventura in the Faculty Exchange program of CMU-Portugal. We constructed the ISR-Cobot platform as experimental platform for this line of research
- We started the 3-year FCT project “Human-robot interaction with field robots using augmented reality and interactive mapping” (PTDC/EIA-CCO/113257/2009), in collaboration with the Madeira Institute of Technology (M-ITI). This project is focused on the research and development of effective Human-Robot Interfaces for Urban Search and Rescue
- We proposed a dynamical systems approach to online event segmentation in cognitive robotics, having published the method in the journal *Paladyn. Journal of Behavioral Robotics*.

2012:

- Two EU projects submitted to the 9th Call of FP7 ICT (Cognitive Systems and Robotics), coordinated by ISR researchers of the IRS group, were approved and will start in January 2013: “RoCKIn - Robot Competitions Kick Innovation in Cognitive Systems and Robotics” (CA) and “MONarCH - Multi-Robot Cognitive Systems Operating in Hospitals” (STREP). This is particularly remarkable not only because the projects are coordinated by ISR/IST but also because these were the only projects with Portuguese partners approved in this call.
- Within the FCT BioInst-Bots project, we developed further the work on using dynamic models of Th-Cell populations in the immune system (Cross Regulation Model – CRM), previously introduced by researchers from the Instituto Gulbenkian de Ciência (IGC), to enable robot swarms discriminate between features extracted from the observation of teammate behaviours, without the need for any hard-coding of the feature vector. This allowed the robust recognition of normal and abnormal behaviours of team members not previously classified as such. The paper was published in AAMAS 2013 as joint work with IGC biologists.
- Also within the FCT BioInst-Bots project an intensive set of simulations demonstrated how the use of institutional robotics approaches to the solution of problems requiring the collaboration of several robots/agents can improve efficiency and sustainability, for given ratios of the percentage of short-sighted (i.e., that take into account only immediate rewards) and far-sighted agents (i.e., that weight future collective rewards more) in the robots/agents population. This is a crucial part of the PhD thesis of José Nuno Pereira, a student of the IST/EPFL Joint Doctoral Initiative, which is almost finished.
- The paper “Robust Acoustic Source Localization of Emergency Signals from Micro Air Vehicles”, co-authored by ISR researchers from the IRS group Meysam Basiri (IST/EPFL Doctoral student) and Pedro Lima (other co-authors were F. Schill and D. Floreano) got the

Best Application Paper Award in IROS 2012 - IEEE/RSJ International Conference on Intelligent Robots and Systems..

- The papers selected from last year's conferences ECMR2011 and ECAL 2011 were accepted for publication in the Artificial Life, and Robotics and Autonomous Systems journals, respectively.
- Under the research project MAIS+S, most of the reference scenarios defined in 2011 were implemented successfully, using networked cameras and a Pioneer mobile robot in the 8th floor of ISR/IST, together with 3 quad-core servers, where novel image processing and planning under uncertainty algorithms, resulting from the project fundamental research activities, were implemented.
- The paper "Robot task plan representation by Petri nets: modelling, identification, analysis and execution", by former IRSg researcher Hugo Costelha and Pedro Lima was accepted in the Autonomous Robots journal – this is the first journal publication with a comprehensive and detailed description of our approach to the use of Petri nets for the modelling, analysis and execution of robot tasks, a topic whose work of the IRSg has deserved considerable international recognition over the last few years.
- Research activities on the use of robots for Urban Search And Rescue has awarded four papers published in the IEEE International Symposium on Safety Security and Rescue Robotics (SSRR'12), College Station, TX
- We have proposed an interactive mapping method, for the semi-automatic registration of 2D and 3D scan data, having published it in three papers in international conferences and one journal paper
- The paper "Flexible path Optimization for the Cask and Plug Remote Handling System in ITER" co-authored by Isabel Ribeiro presented at SOFT-27 was accepted for publication in the journal Fusion Engineering and Design.

Laboratory for Energy and Environmental Studies

Energy Planning

High fuel costs, increasing energy security and concerns with reducing emissions have pushed governments to invest in the use of renewable energies for electricity generation. However, the intermittence of most renewable resources when renewable energy provides a significant share of the energy mix can create problems to electricity grids, which can be minimized by energy storage systems that are usually not available or expensive. An alternative solution consists on the use of "*demand side management strategies*", which can have the double effect of reducing electricity consumption and allowing greater efficiency and flexibility in the grid management, namely by enabling a better match between supply and demand (Pina, Silva and Ferrão, 2012).

However, making use of renewable energies and "*demand side management strategies*" requires advanced energy systems modelling capacities, which were developed at IN+ in several studies

(Abreu, Pereira and Ferrão, 2012; Suomalainen, Silva, Ferrão and Connors, 2012). They ranged from synthetic wind speed models, to global energy system models with emphasis on upgrading the “TIMES model” to a high temporal resolution, compatible with hourly renewable energy fluctuations (Souza, Pina, Leal and Silva, 2012). We developed the capacity to model renewable energy including the operation of wind and hydro plants together with energy use scenarios, deployment of demand response technologies in the domestic sector and behavioral changes to eliminate standby power. The results obtained show that “*demand side management strategies*” can lead to a significant delay in the investment on new generation capacity from renewable resources and improve the operation of the existing installed capacity (Pina, Silva and Ferrão, 2012).

Urban Metabolism and Sustainable Cities (UMSC); Industrial ecology

Major urban areas in the world are facing huge changes in land use and on their interaction with the environment, mainly due to increased levels of economic development, resulting in most cases in a huge urban sprawl and changes in their form. This clearly establishes an intertwining between economy, environment and quality of life at an urban level, whose understanding requires a new set of tools that may correlate the use of natural resources, economic activities and consumption patterns (Niza, Rosado, and Ferrão, 2009).

The *urban metabolism* concept is grounded on the analogy with the metabolism of living organisms', as cities can transform raw materials into infrastructures, human biomass and waste. It quantifies the amount of materials that are consumed by each economic activity in urban areas. We have developed a set of new methods for quantifying *urban metabolism* making use of national statistical data publicly available and scaling it down to an urban level (Marteleira, Pinto and Niza, 2012).

Considerable advances were achieved aiming to develop straightforward methodologies to model the urban metabolism of world urban regions. The Lisbon Metropolitan Area (LMA) was the main case study for the validation of the methodology supported by EU and national statistical data. Additional studies for urban sustainability include the uncovering of opportunities for industrial symbiosis in the LMA and rainwater reuse in buildings (Patricio, Costa and Niza, 2013).

Ecological Economics

Research in *Ecological Economics* had results in three main lines, as follows:

1. The theoretical work on fair indicators of carbon responsibility developed in Rodrigues et al. (2006, 2008) was empirically applied. Patterns of international flows of carbon responsibility were identified, through the development and use of a “Multi-Regional Input-Output model” (Marques et al., 2012, Marques et al., 2013) and the concept of income responsibility was clarified (Marques et al., 2012).
2. Life cycle assessment of bioenergy solutions were carried out, in a consequential perspective, including the effects of direct and indirect land use change (Gonçalves et al., 2013).

3. Environmental impacts of the internet were estimated (Coroama et al., 2013; Müller et al., 2013).

Ecological Metabolism

Research work on ecological metabolism was continued, both from the theoretical and modelling point of view, based on DEB theory (Saraiva et al., 2011a,b), and from the empirical point of view (Yuan et al., 2011). Carbon cycle measurements and modelling were carried out for two pools (soil, trees) in two systems: eucalyptus forest (Pita et al., 2011; Rodrigues et al., 2011); sown biodiverse permanent pastures rich in legumes (Teixeira et al., 2011). The latter work led to the establishment of “Terraprima – Environmental Services”, spin-off at IST, which now manages carbon sequestration contracts with around 1000 farmers and c. 100 000 ha (>1% of the country).

Waste characterization and management: physical and chemical processing

Substantial research efforts have been dedicated to recycling and valorisation of residues, which required spread knowledge in several domains, including materials characterisation, physical-chemical and environmental analysis, physical separation (minerallurgical and other related techniques), chemical and metallurgical engineering, modelling, process development and design. Besides the characterization of secondary resources, natural raw materials have also been studied taking into account related interfaces with the environment (Madrid, Nogueira and Margarido, 2012).

Other areas of specialization include recycling processes of metallic residues in the scope of mercury removal from waste sources (Margarido and Nogueira, 2011), recycling of sealed Ni-Cd and Zn-Mn type batteries (Nogueira and Margarido, 2012), valorisation of residues from military activities, and waste of electric and electronic equipment, among other waste streams (Nogueira and Margarido, 2012).

Laboratory of Technology Policy and Management of Technology

Science, higher education and policy

Research on “science, higher education and policy” has focused on broad and overlapping issues between science and technology systems and higher education systems (Heitor and Horta, 2012; Heitor, 2012). It has contributed to the knowledge pool in both literatures, providing informed evidence with a key practical relevance for emerging and developing regions worldwide (Heitor, Horta and Mendonça, 2012; Jung and Horta, 2012). We follow a systemic and thematic approach to our studies that are synergetic and feed into each other area (Heitor and Horta, 2012).

The systemic approach tends to analyze from a historical perspective the evolution of science and higher education systems and the roles of policies, resources, investment and reforms on the

development of those systems. Current challenges facing those systems in developed and developing countries have been characterized and policy implications have been discussed.

Thematic studies performed over the last years tend to focus on relatively understudied issues such as academic inbreeding (Horta, 2013), the teaching-research nexus (Horta, Dautel and Veloso, 2012), or knowledge sources, with a mix of methodologies (Horta and Lacy, 2011). The dialectic between these approaches leads to a rich analytical set that has a level of complexity meeting the growing complexity of knowledge systems, as well as the uncertain and complex conditions that societies in general are experiencing under globalized dynamics (Heitor and Horta, 2012).

Industrialization and innovation dynamics; technical change and entrepreneurship

The rationale for this research theme on industrialization and innovation dynamics is driven by the observation that industrialization has been the main driver behind rapid productivity growth achievement and social well-being improvements in different countries in the last 200 years. However, the weight of manufacturing in the economy has been decreasing substantially in many countries and regions, and production has been concentrating in certain regions, while others have been increasingly losing their productive ability, leading to changes in employment, and raising new concerns.

The research agenda has addressed issues associated with industrialization dynamics (and related desindustrialization risk), considering development patterns through technical change, integrating emerging science and technology capacity, the role of entrepreneurial activity and the creation of new firms and industries (Mendonca and Faria, 2012). In particular, the research work has focused on economic impacts of entrepreneurship in terms of employment generation and innovation (Baptista and Preto, 2011), as well as on the value of entrepreneurial human capital, exploring its linkages with firm performance and quality of job creation (Baptista, Lima and Preto, 2012). The role of the new technology based firms is acknowledged and its relationship with FDI, internationalization and knowledge creation has also been explored, with emphasis on Portugal and on the basis of specific employment data sets.

A particular attention was considered for the study of biotechnology and related entrepreneurial activities, with emphasis on the analysis of emerging regulatory frameworks (Couto, Perez-Breva and Heitor, 2012). A new concept of technological adjacency for emergent therapies has been discussed, in terms of knowledge creating market strategies for small biotech start-ups (Couto, Perez-Breva and Heitor, 2012).

Risk Governance, science systems and the social appropriation of knowledge

The rationale for research has been driven by the need to help facilitating the social appropriation of knowledge towards designing resilient cities. During 2012, the focus was on launching a team

for innovative “hands on” approach based on the design of new engineering-based products and processes to help shape perceptions and peoples’ behavior.

Two areas of intervention were chosen in terms of risk mitigation, including energy consumption and non-communicable diseases (e.g., diabetes). The main goal is to assess risk perceptions of lay people belonging to vulnerable communities and, in the process, to examine strategies of risk communication towards these groups. While early studies on risk perception were based on “unilateral” expert views (i.e., “methods of expert elicitation”), it has become more and more clear that the involvement of lay people in the process is critical for risk governance (i.e., to ensure their participation). But, and despite these new trends, vulnerable groups remain an outlier category of this type of analysis (Pádua and Custodio, 2012).

The research team used the knowledge representation approach developed by Morgan (2002) to identify misconceptions of groups from different cultural backgrounds towards diabetes. In summary, a major initiative on learning for uncertainty in urban contexts was developed, including actions to look at risk perceptions, risk communication and stakeholder engagement of lay people from vulnerable communities. The *Mouraria* neighborhood, in Lisbon, has been used for preliminary fieldwork, which was focused on two distinct areas for risk mitigation, namely: i) non-communicable diseases, such as diabetes (Pádua, Santos, Horta and Heitor, 2013); and ii) patterns of consumer behavior in energy usage.

Our research hypothesis is associated with the idea of “indwelling”, firstly introduced by Polanyi and recently explored by John Seely Brown in terms of understanding learning through processes of knowing, playing and making. We are attempting to provide new evidence on related learning processes through the distinct experiments mentioned above.

First, regarding non-communicable diseases, such as diabetes, interviews with targeted communities reveal that many misunderstand the risks they face. Through our experiment, lay people has been encouraged to ride a “stand-alone” bicycle, facilitating physical exercise and making a smoothie (healthy fruit based drink) through the preparation of crushed fruit, yoghurt or milk. This begins a learning and revelatory process concerning adequate diet, exercise and successful ways of reducing their risk by having fun together. But, above all, it facilitates making people aware of diabetes risks and to introduce the debate on the topic among specific and target communities. Experiments were successfully conducted with the elderly and specific muslim groups (Pádua, 2012).

Second, consumer behaviors of energy usage in domestic and public spaces were assessed and monitored through the application of smart energy meters and the consequent attempt to design new products to help lay people to save energy and reduce their energy bill. Three different consumer typologies were assessed in residential properties, including two families in social housing and an apartment with Erasmus students. In addition, energy consumption in a “tasca” was monitored. In both examples, participants learn about energy flows, energy conservation, cost

saving and reducing avoidable energy wastage.

Our experiments were conducted by mobilizing groups of university students in a way that also provided new insights into university learning methods. In addition to look at ways of lay people addressing risks, our results provide new insights into the modernization of university education through “hands-on” experimentation in vulnerable communities and the socialization of knowledge and knowledge networks.

Laboratory of Thermofluids, Combustion and Energy Systems

Two-phase flows and heat transfer; surface microstructuring; fluids and flows for smart structures

The research program addresses the study of transport phenomena (continuum mechanics) focusing on momentum, energy, and mass transfer at fluid flow interfaces. It follows an interdisciplinary approach focusing on physical, chemical and biological properties of surfaces. New results focused on flow phenomena occurring in microfluidic devices aiming to provide insight into the background physics towards the development of new theoretical and empirical models for micro-scale flow phenomena, as well as the design of new practical systems. It is a research program combining branches of physics, mechanics, optics and fluid dynamics with material science and chemistry.

Experiments have been designed taking into consideration the specific boundary conditions of specific applications, including HCCI engines (Panão, Moreira and Durão, 2012). Experimental techniques were developed to allow characterizing the processes occurring in the region immediately adjacent to the interface between phases (Moita, Teodori and Moreira, 2012). The experiments performed included the measurement of multiphase flow quantities, such as liquid and vapor concentrations, and chemical species concentration and temperature maps with enough spatial and temporal resolution (Moita, Moreira and Roisman, 2012), using Laser Induced Fluorescence (LIF), high-speed thermography, Particle Image Velocimetry (PIV) and Phase-Doppler Interferometry (Teodori, Moita and Moreira, 2012).

Flame diagnostics, propagation and control; Flame acoustics

The research work was centered on the analysis of the competing effects between heat- mass- and momentum transfer on the dynamics of laboratory flames for different type of fuels (solid, gaseous mixtures). It considered the development of flame diagnostic sensors. The research work has addressed the following topics:

- *Study the ignition process of blended fuels on lean mixtures:* In the context of advanced control of NO_x emissions, the ignition of lean flames poses a challenge because it requires a large amount of energy, which is also largely dependent on flame sensitivity to local stretch ratios (depending on Le number) and fuel mixtures (biofuel type). All together, they inhibit initial

flame kernel development conditioning flame ignition. This work under progress aims to study the spark ignition process under reactive lean mixtures.

- *ThermoAcoustic Instabilities – Flame Transfer Function of impinging flames*:The challenge here was to evaluate the influence of flame deformation on flame response to upcoming oscillations (due to stretch effect). Various experimental setups were used to evaluate the burning of biomass and burning gun-powder with emphasis on situations characterized by unsteady combustion (Mericia, Trindade and Fernandes, 2012; Fernandes and Leitão, 2012).
- *Chemiluminescence*:The main objective of this research task has been to evaluate the extent to which the chemiluminescence diagnostic concept can be used to monitor the oxidation of fuel blends (CH₄/C₃H₈/H₂). Although established correlations between chemiluminescence signals and heat release and equivalence ratio exists for pure fuels, it is not certain whether a straightforward synthesis of these individual signals remain valid for practical fuel blends. The work has involved non-separable thermal and chemical effects and possible kinetic-interaction effects.
- *Development of High speed Uv-Vis spectrophotometer*:Design, assembling and testing of a High speed Uv-Vis spectrophotometer to be used in the analysis of unsteady flames and fast luminiscent processes such as flame ignition (Aleksenko, Fernandes and Shtork, 2011).
- *Development of mini sound probes- Mathematical and Experimental analysis*:The device studied is a pressure probe which configuration is modeled mathematically based on the low reduced frequency model, where the viscous acoustic shear layer is taken into account in the analysis of sound propagation inside capillary tubes, before being calibrated experimentally.

Signal and Image Processing Group

Main Achievements

The Signal and Image Processing Group's activity clusters around four main topics 1) Fundamentals 2) Sensor Networks 3) Image Analysis 4) Ocean Acoustics. The main achievements, in line with past activity are the following:

Fundamentals

A new, explicit and direct proof of the classical Carlson problem, by using only elementary matrix completion tools and combinatorics. This work was published on Springer's LAA journal.

Sensor Networks

We designed a novel distributed optimization algorithm for solving convex optimization problems in networks of agents. The algorithm is implementable by the popular gossip protocol and converges even with random asymmetric link failures between agents. Several articles on IEEE-TSP were published and 3 PhD thesis were completed in the framework of the Carnegie Mellon|Portugal Program.

We developed centralized algorithms, based on semidefinite relaxations of likelihood functions for Gaussian or Laplacian noise, for target or node localization using range measurements. These exhibit very good accuracy and the convex nature of the associated optimization problems dispenses with prior information on the target or node positions. The algorithms for Laplacian noise are particularly useful for accommodating outlier measurements that occur in practical ranging systems. One significant contribution to this work was done in through the PhD thesis of Pinar Oguz-Ekim, recipient of the IBM Science Prize 2012.

Image and Video Analysis

We showed how to uniquely define the orientation of an arbitrary 2D shape in terms of what we call its Principal Moments. We further show that a small subset of these moments suffices to describe the underlying 2D shape, which is particularly relevant when dealing with large databases. We also designed a feature extractor methodology that is able to handle several types of matching problems for which the system has not been trained, and proposed an efficient representation/normalization procedure for arbitrary 2D shapes and images. We also developed new techniques for image retrieval on large databases. We organized an ECCV2012 workshop on this subject, besides several publications on ICIP and ECCV publications.

We developed a model for the description of human trajectories and activities based on multiple parametric motion fields. The model is able to represent a wide variety of motion regimes due to its ability to switch among different motion fields.

Biomedical Engineering

We studied the diagnosis of Alzheimer's disease (AD) and mild cognitive impairment (MCI) using FDG-PET images. We showed that the texture of FDG-scans contains distinctive information about the presence of both AD and MCI. Texture analysis was performed using a novel 3D extension of the well-known 2D texture descriptor local binary patterns (LBPs). In LBPs, the concepts of uniformity and rotation invariance are of fundamental importance. We show that the proposed approach, unlike other 3D extensions found in the literature, closely replicates these concepts, as originally proposed in the 2D settings. Several conference papers and one journal on "Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization".

Underwater Acoustic

In underwater communication networking, a common understanding was reached on the perturbations of time variable channel impulse responses between moving nodes of a network deployed on a shallow water area, leading to a series of mitigation measures implemented with a time-reversal based equalizer. The algorithms were implemented and tested at sea during an experiment in Norway and to date the only known experiment with a functioning full IP - layered underwater network incorporating fixed and moving nodes. The development of environmental inversion algorithms pointed towards the usage of ambient acoustic noise sources for environmental monitoring by estimating the channel Green's function between two underwater

sensors arbitrarily located, which is novel for determining water column properties along time and space.

A tomographic framework was developed for localizing a source based on the observed pattern of wavefronts impinging upon a receiver array. Using a combination of semidefinite relaxation and inverse problem methods. This enables useful positioning and navigation data to be extracted with no overhead from high-frequency transmissions used in underwater acoustic communication systems.

VisLab – Computer and Robot Vision Laboratory

1. Objectives

One of the key objectives of the VisLab is to conduct research in computer and robot vision aiming at (i) the development of new methodologies and tools for computer and robot vision and the (ii) demonstration of such methodologies in challenging applications.

We take a multidisciplinary perspective encompassing areas ranging from engineering to neuroscience or linguistics. On one hand we look at biological systems to understand how vision has developed to become a powerful sensing modality. On the other hand we use our computational and embodied models based on biological plausible principles to better understand biological systems or human cognition

Our research is organized in two main lines:

- Vision Based Control and Navigation
- 3D Reconstruction, Motion Analysis and Surveillance

a) Vision Based Control and Navigation

We address the problem of understanding how to use visual information to control an artificial system (robot) in order to perform a given task. This research is very often inspired on biological systems and aims at designing more flexible and robust artificial vision systems and to improve the understanding of biology. Thanks to massive developments in computing power we can now employ powerful learning techniques in the context of vision and robotic problems. The following topics are currently addressed:

- Learning and cognition for (humanoid) robots
- Design of visual geometries and camera networks
- Vision based control, active vision and navigation
- Feature learning and object recognition

b) 3D Reconstruction, Motion Analysis and surveillance

Vision allows us to retrieve information about the scene structure (geometry) or camera motion from video sequences. Amongst other topics, we are currently investigating the following problems:

- a. Video surveillance systems able to learn and understand patterns of human activity
- b. Calibration of camera networks and nonconventional camera systems
- c. Model based tracking and object recognition
- d. Gesture analysis and recognition

2. Main Achievements

The work at VisLab aims to develop new methodologies for computer and robot vision as well as to address several applications with societal impact. The approach followed is strongly multidisciplinary with close links to biology, neuroscience or psychology. The group is regularly involved in large-scale, ambitious projects with international partners (e.g. EU).

Some of the main achievements are listed below:

Humanoid robotic platforms

The iCub humanoid platform available at the lab has been upgraded to include force/torque sensors, touch sensors and a second generation head. The setup is once again fully functional and serving as a testbed for research in the broad areas of cognitive systems. The research conducted with the iCub involves both methodologies and software for perception, learning and control of the platform. During 2011 and 2012, we have continued the development of the mobile humanoid platform (Vizzy) and started using this platform for research on gesture recognition.

Cognitive systems and vision

We have pursued efforts to develop methods for sensorimotor learning and coordination with complex humanoid platforms. A substantial amount of research has now to do with manipulation. One research direction is that of modelling the manipulation skills of humans and transfer those skills to humanoid robots. Another line of research is to detect grasping points and grasping strategies from object models, hoping to generalize such capabilities across different objects.

Human activity analysis

We have continued the development of computer vision methods able to provide an interpretation of the observed scenes. Some of this work was developed in the previous EU Project URUS and, more recently, in the MAIS-S project integrated in the CMU-Portugal partnership.

Camera design and camera networks - We developed methods for the calibration of novel camera geometries and networks of cameras from extended observation of video streams. This work is the core of a new national project (DCCAL).

Participation in EU Projects - In addition to key contributions to our EU Projects (FIRST-MM, HANDLE, ROBOSOM), we have started two new EU Projects (DICORE2S and POETICON++) on the topics of visual shape analysis and on the understanding of the role of language as the support for cognition in humanoid robots.

International Partnerships - We have also actively participated in the IST-EPFL Joint PhD Initiative with students involved in the joint doctoral studies between IST and EPFL as well as in the CMU-PT dual doctoral program.

Center for Mathematical Analysis, Geometry and Dynamical Systems

The areas of activity of the Center are central in mathematics itself and are fundamental for many applications in science and engineering. In fact, they play a major role for several areas of Theoretical and Experimental Physics, and for important areas of Chemistry, Geological Sciences, Marine Sciences, Sciences of the Atmosphere, and Life Sciences. They are crucial for several areas of engineering and technology, namely for Control Engineering and Robotics, Signal and Information Processing, Communications Engineering, Mechanical Engineering, Aeronautical and Aerospace Engineering, Materials Engineering and Nanotechnology, Biological Engineering and Biotechnology. They also play a significant role in recent developments of economics, financial system, and logistics.

One of the main objectives of the Center is to promote research and graduate studies in its areas of activity with excellence of high international quality. Over the past years, the Center has developed an intense activity, with objectives and organization close to the best research centers of mathematics in the world. The activities include a postdoctoral program, a program of invited researchers, and several regular seminars, some of which are held every week. The Center organizes on a regular basis international colloquia, conferences, and short courses, some of them within series of European or international conferences and workshops. It regularly hosts postdoctoral fellows and also invited researchers for long periods, as well as PhD students. It also promotes concentration periods and Summer schools on specific subjects, involving also PhD students and postdoctoral fellows.

The Center thus ensures the development of research in Portugal in areas of mathematics necessary for the scientific and technological development of many other areas of science, engineering, and economics, including those regarded as priorities.

The Center also promotes mathematics as a whole. It regularly contributes to the stimulation and development of young talents in mathematics, to the promotion of quality of teaching of mathematics, and to the promotion of mathematical culture in general. This includes the participation of members of the Center in the New Talents in Mathematics Program of Fundação Calouste Gulbenkian, the project of scientific initiation of high school students that has been organized every Summer within the activities “Ciência Viva nas Férias”, the participation in projects “Ciência Viva” related to the teaching of sciences in collaboration with high schools, the collaboration of some of its members in the preparation of new elements of study for high school students with the purpose of overcoming the insufficiencies detected in the first undergraduate year, the activities of several of its members for the promotion of mathematical culture in the general population, namely through the participation in conference series and the publication of books disseminating mathematics to wide audiences.

In 2011 the members of the Center authored or edited 5 books and published 82 articles in international journals. In 2012, the numbers were: 7 books (13 if we count the translations of some the books) and 100 peer-reviewed articles.

Members of the Center participated in the Mathematical Routes of the Technical University of Lisbon in February 14-17, 2011, and in February 29–March 8, 2012, and in the Mathematics Winter School at IST in February 9-12, 2011, and in February 6–8, 2012.

M-ITI Madeira Interactive Technologies Institute

M-ITI operates in the interdisciplinary domain of Human-Computer Interaction (HCI), encapsulating contributions from the disciplines of computer science, psychology and social sciences, and design, with the goal of engaging in important scientific and technological challenges. M-ITI’s vision is to become an influential and internationally recognized centre for research and education in HCI, wherein M-ITI will serve as an “innovation engine” for driving leading-edge research and advancing the strategic development of the University, the region of Madeira and LARSyS. We seek to do this through achievement of the following goals:

- Develop capacity in a sustainable setting that welcomes interdisciplinary research and innovation in interactive systems and services through Information and Communication Technologies (ICT).
- Advance education in the fields of HCI and computer science through international multidisciplinary graduate programs, in which fields new leaders and pioneers will be formed.
- Explore and expand the potential of technology to enhance human interaction by designing and developing novel systems and services and by investigating their use and effectiveness in real-world contexts.

- Bridge the gaps between the application domains of software engineering, interaction design, and service design by developing practical tools, techniques, theory and practices centred on meeting genuine human needs.

Research

Advances in ICT have fundamentally changed the way people work and live across the globe, a trend that is accelerating as the influence and impact of ICTs spread to ever greater scopes of activity. Computing has moved beyond merely increasing productivity at work to providing individuals with unprecedented access to information and powerful new ways to communicate. In the decades since the computer became personal, the relevance and scope of the field of HCI has grown in tandem with computing technology. Research in ICT no longer asks "what can we build?" but instead "what should we build?" HCI researchers and practitioners, with their focus on user needs, tasks and experiences are well suited to address these new kinds of questions.

HCI is the discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. Accordingly, M-ITI rests on the following principles:

Computing technology must match with human capabilities, taking into account the needs and desires of users and other stakeholders, and economical, cultural and social constraints.

To achieve this goal, we need to: i) understand human behaviour and development through social and ethical analyses based on empirical studies of how people adapt and use technology, ii) develop technology, tools and design methods that support efficiency and creativity in design, and iii) adopt a risk-taking attitude based on creative ideas for new ways of envisioning interactive technologies and services that have an impact in the world.

–Attempts to reach this goal will lead to general theories and methods that enhance and broaden the field.

The positioning of M-ITI generates a unique combination of strong research and innovation potential. It enables interdisciplinary work among scientists and engineers examining and communicating the impact of emerging technologies in key areas of contemporary life (such as aging populations, sustainability, and deep ocean exploration). Leveraging on design thinking and innovation, M-ITI is well positioned to generate informed speculations on the products, systems and services these emerging technologies might support. These speculations function as plausible, tangible and accessible demonstrations that can be used to examine how contemporary scientific research could transform our lives in the near as well as distant futures. The potential of HCI to reshape the current interdisciplinary research landscape lies in a novel relationship between science and design used to support interdisciplinary work and foster dialogue with the population of users.

- Assistive technologies for Aging Population – One of the most promising application areas for ICT involves assistance to aging populations, social inclusion, and the prevention, diagnosis and

management of medical conditions. ICT solutions prolonging independent living, extending active working life and enabling accessibility for people with disabilities is one of the primary challenges for the European Research Area (ERA). At M-ITI, we are exploring the combination of these fields in the domain of monitoring and rehabilitation technologies for patients with motor, cognitive and perceptual deficits. Mental illness, which is the second major cause of disability and premature mortality in the developed world, is another key focus area for which M-ITI is exploring interactive technologies to enhance neuro and biofeedback in therapy. Madeira has a large elderly population, as it attracts many retirees and elderly travellers. Madeira also has one of the highest stroke incidence rates in Europe. Therefore, it provides an ideal setting for the large-scale deployment and testing of assistive technologies for the elderly.

- Creative Media in Digital Culture – The role of technology is ever expanding, making it essential that we apply it in ways that enhance our daily lives, our creativity, and our ability to connect with one another. M-ITI trains HCI and interactive technologies professionals at the graduate and postgraduate levels and is pushing the boundaries of Creative Media and Digital Culture research in these areas with cutting-edge research projects (WESP, Logica Service Design Labs, Madeira Life). As an independent research institute, we are actively engaged in the design and development of technologies that serve education, culture and new creative industries, particularly as these relate to M-ITI's core research areas: sustainability, tourism and digital culture. With a growing reputation for excellence, strong ties to top-tier institutions (e.g. Carnegie Mellon University and through LARSyS), and the ability to attract international talent, M-ITI is in a prime position to expand in the direction of Creative Media and Digital Culture. This is not merely a re-ordering of words but a re-orientation of focus. In addition to enhancing use value from digital artefacts and making them more accessible, M-ITI is dedicated to the use of digital technologies for uncovering hidden potential and investigating complex problems, such as the design of sustainable entertainment for Madeira and its tourism industry, the collection and delivery of the island's traditional culture through digital and interactive media, and the introduction and integration of digital learning tools into kindergartens and primary schools.

- Sustainability for Smartcities – ICT for sustainable development is one of the four flagship i2010 initiatives of the EC, underlining the potential of ICTs to improve quality of life. Although sustainability is often discussed in terms of political and engineering challenges, the HCI community embodies knowledge and expertise that will be crucial to addressing the design, interaction, and usage issues surrounding sustainable technologies and practice, in particular their positive impact on future generations. The overarching research goal of contributing to the development of sustainable behaviours, practices and products/services is particularly salient given the isolated, untouched nature of Madeira. M-ITI is exploring this domain through the development of resource monitoring solutions, the design of novel sustainable services and the use of eco-feedback technology to reduce and motivate sustainable behaviour both individually and (via group studies and social network services) in families and communities. In the urban age, where more than half of the population lives in cities, economic prosperity and quality of life depends on the potential to support both complex underlying infrastructures and rich interactions

between humans and the surrounding environment. The Madeira Living Lab for Interactive Technologies and, in particular, the urban capital of Funchal provide a unique environment for test beds reconciling humans and technology in the urban age where people can exploit their creative potential and lead a self-determined life. Through the application of the HCI human-centred design approach M-ITI is well positioned to explore design-driven innovation models in mobility, privacy and security, social inclusiveness, and many other domains where increasingly urban spaces are becoming interactive and reflecting complex social networks blending real and virtual spaces.

Achievements 2011-12:

Publications:

2011: 51 publications, 1 book, 17 journal papers, 33 conference papers

2012: 72 publications, 3 books, 23 journal papers, 46 conference papers

Ongoing Projects:

Zon Service Engineering, Industry Funded, Knowledge+

Madeira Life, Industry Funded, Knowledge+

Logica SD Lab, Industry Funded, Knowledge+

AEminium: Freeing Programmers from the Shackles of Sequentially Carnegie Mellon | Portugal FCT

Affidavit: Automating the Proof of Quality Attributes for Large Scale Software Architectures, Carnegie Mellon | Portugal FCT

AURERO: Interação homem-robô com robôs de campo usando realidade aumentada e mapeamento interativo, Carnegie Mellon | Portugal FCT

FAVAS: A Formal Verification Platform for real-time Systems, Carnegie Mellon | Portugal FCT

RehabNet: Neuroscience Based Interactive Systems for Motor Rehabilitation, FP7 – People – 2011

SINAIS - Interação Sustentável através de Redes Sociais, Detecção de Contexto e Inovação em Serviços, Carnegie Mellon | Portugal FCT

WeSP: Web Security and Privacy: Weaving Together Technology Innovation with Human and Policy Considerations, Carnegie Mellon | Portugal FCT

2. THEMATIC AREAS

A – Complex Systems in Engineering and Fundamental Sciences

This research line includes the following three areas: Nonlinear Systems and Optimization, Fluid Dynamics and Turbulence, and Mathematical Methods for Fundamental Science and Engineering. Research in these areas was very productive with an output of two research books, a research monograph, and about two hundred papers in international research journals. These publications are detailed in the Productivity sections of the Research Groups and in the output of this Research Line.

A Series of research talks on areas of common interest for different groups, namely the LARSyS Lecture Series in Engineering and Mathematics, was initiated in 2011. Three short courses were already organized since the series started: Complex Networks: an Introduction by José Fernando Mendes (U. Aveiro); Games with infinitely many players: the mean field games approach by Olivier Guéant (U. Paris Dauphine); Determining nodes for regulatory networks by B. Fiedler (Free University Berlin). During a Workshop on Operator Theory, Complex Analysis and Applications, held at IST in July 11-13, 2012, a LARSyS Special Course was delivered by Jonathan Partington (U. Leeds) on delay systems. At the annual Iberian Strings meeting 2013, held at IST in January 22-25 2013, two LARSyS special courses were delivered, one by Óscar Dias (CEA Saclay) on the fluid/gravity correspondence, and another one by Frederik Denef (U. Leuven) on holography and complex systems.

One jointly supervised MSc thesis has been concluded and one PhD thesis is in progress. Several joint papers have appeared at international conferences, namely at the 9th Allerton Conference on Communication, Control and Computing, and at Netgcoop 2011. A number of research papers has appeared in international journals.

B – Sustainable Urban Systems and Technologies

We have conducted multidisciplinary research, in the context of international projects and academic partnerships with CMU, MIT and EPFL, including joint PhD supervision.

The main activities during the years 2011-12 are listed below:

- i. Surveillance and activity monitoring – novel methods for tracking and modeling of human activities from video, in cluttered scenes and robustness to occlusions.

- ii. Urban metabolism: new methods to quantify material/energy flows in urban systems to improve the design of energy/waste management infrastructures both in Portuguese and Asian cities (funded: Asia Development Bank).
- iii. Networked robot systems - methods for distributed perception, decision making and control in robot networks (e.g. CMU-PT MAIS-S proj.); development of tourism information services through location-aware mobile technologies; two EU-FP7 projects approved (MONarch and RoCKIn) , coordinated by ISR.
- iv. Cognitive systems for human-machine interaction – multidisciplinary research in engineering, neuroscience and linguistics to model how the brain solves certain cognitive/manipulative tasks and transfer human skills to humanoid robots (EU-Projs ROBOSOM, HANDLE, FIRST-MM and POETICON++)
- v. Distributed inference in sensor networks and environmental surveying - New algorithms for inference in networks with random links. Diffusion in graphs (virus propagation) and pollution profiles/models built for Lisbon (URBISNET proj. (FCT) and cooperation with EPP/CMU).

This research has led to a number of publications in top international journals and conferences, listed under the corresponding section of this report. It is also worth mentioning that these research activities were developed in the context of international collaborations at the level of doctoral training with the MIT, CMU and EPFL.

The activities developed within this Thematic Area involved groups from ISR, IN+ and M-ITI.

C – Sustainable Energy, Environment, and Economic Development

Several areas connecting Research Groups (Green economy, economic growth, technological change and energy demand) had published works in 2011-12. Funding was obtained for projects on Technological change and economic development. Work in carbon sequestration and storage was made. ISRs spin-off Terraprima received an award for carbon sequestration in pastures.

Topics like Energy consumption, urban growth and modelling energy systems span different Research Groups like ISR/IST and LEES/IN+/IST. Renewable energies connect weather forecasting (meteo.ist.utl.pt), wind power generation and irradiator models (project “Energy Wars” is building a model about efficiently managing energy resources).

LEES/IN+/IST and IRS/ISR/IST collaborated in the “Life Engine” project. M-ITI/UM's work on advanced consumption monitoring and SIPG/ISR/IST's work on information networks and social media are connected to LEES/IN+/IST's simulator models aiming at behavioural change. Rural

Value (the first Facebook game about sustainable farming, www.facebook.com/RuralValueGame) and CityON (www.cityon.pt) were created with considerable media impact.

LEES/IN+/IST and CREMINER/FCUL worked on the environmental impacts of soil use. International success came with modelling processes related to environmental impacts and evaluation of the anthropogenic impact on the geochemical cycle of elements. AmbiTerra Lab was recognized as a top quality laboratory for soils and sediments. Public outreach strengthened further, largely related to Centro Ciencia Viva do Lousal and its highly successful rehabilitation program.

The 2nd International Symposium and 6th International Course on the Dynamic Energy Budget theory (DEB) took place. DEB applies to simulator models and living organisms, for example for modelling marine ecosystem trophic chains and ecosystem services (a common theme to LEES/IN+/IST and IMAR/DOP-UAz).

CREMINER/FCUL and LEES/IN+/IST worked on the reduction of negative impacts of mineral resource use.

D – Ocean Systems and Technology

This research line arose out of the partition of the old thematic area of Technologies for Ocean Exploration into ocean-related areas. In its present form the focus of research line D is on the development of advanced tools and methods for ocean exploration and exploitation. Naturally, there are strong connections with the research line E entitled OCEAN RESOURCES AND ECOSYSTEMS, in which the focus is on the scientific aspects of ocean-related research. From a technological point of view, the following achievements in the form of demonstrations at sea are worth stressing:

- 1) Design, development, and full testing at sea of a small fleet of three autonomous surface vehicles named MEDUSA and related systems for mission programming and mission execution. The vehicles have been playing a key role in a number of research lines and projects that require the concerted operation of multiple marine vehicles.
- 2) Demonstration of cooperative autonomous surface vehicle control for optimal multiple underwater target localization and guidance (in the scope of the European CO3AUVs project partners, with the participation of IMAR and IST).
- 3) Demonstration of assisted diving operations, illustrating joint robot/human missions (in the scope of the European CO3AUVs project partners, with the participation of IMAR and IST). To the best of our knowledge, this was the first time that a cooperative mission scenario involving a human in the loop was performed.

- 4) Demonstration of an advanced custom-designed ultra short based line (USBL) positioning system for surface/underwater vehicle cooperation (with the participation of IST and the partners of the EC TRIDENT project).
- 5) Cooperative Autonomous Vertical Profiler operations for oceanographic studies (with the participation of IMAR, IST, and the National Institute of Oceanography, Goa, through the INDIA-Portugal Cooperation Program).
- 6) Demonstration of cooperative range-only formation control using a set of MEDUSA autonomous marine vehicles exchanging inter-vehicle ranges over an acoustic network, in the scope of the European MORPH project in which IST and IMAR participate. This milestone paves the way for the development of a new breed of systems for marine habitat mapping that will rely on the use of multiple vehicles undergoing formation control for mapping missions in complex 3D underwater environments that can be encountered near vertical cliffs, in the Azores. To date, no systems exist that can perform this task safely, reliably, and efficiently.

E – Ocean Resources and Ecosystems

General Objectives

Given the extremely high demand for natural resources, and raising concerns on environmental impacts, this Thematic Area continues devoted to research on geochemical systems and to the genesis, evolution and use of crustal resources, from land and the ocean floors, with emphasis in fluid-rock interaction processes.

Taking the opportunity of the missions at sea and the conditions available at labHorta we continued to develop advanced experimental research in the areas of genomics, proteomics, immunology, eco-toxicology, molecular biology, physiology, processes of calcification, etc. The studies were primarily done under controlled experimental conditions and were intended to explore new molecules for bio-technology with from organisms living at the deep-sea both in chemosynthetic and photosynthetic driven environments. Our research will be focused deep-seahabitats like seamounts, deep-water corals and sponges, hydrothermal vent organisms, and microbes of the deep-sea.

Main Achievements

The main focus of the research was dedicated to the functioning of the deep-sea environment, in particular the functioning of the seamounts and hydrothermal vent habitats. We have been working under international scope, mainly from France, on the conception and installation of an observatory at the Lucky Strike hydrothermal vent field. We kept the endeavor of understanding the trophic links between deep-sea ecosystems, and the role of the organic matter that falls from surface, either as marine snow, either as large falls. An area of research that we have been working were the links between chemosynthetic and non chemosynthetic environment, surface

and deep benthic communities. The goal is to understand how the deep sea is affected by the global changes.

From an Earth Sciences point of view, Creminer is pursuing studies on hydrothermal systems, with great emphasis on the role of the deep biosphere. Public outreach through Creminer continued to be particularly noteworthy, with involvement in the National Museum of Natural History and in the setting-up of the Lousal "live science" center in Southern Portugal. In MNHN a new exhibition on seafloor resources is approved and been prepared. Analytical facilities, including the new Stable Isotope lab, the Soil and Sediment lab AmbiTerra and the Mobile Lab are all equipped and starting to be extensively used.

During the period of this report, a project aiming to endow the scientific community with new moderate cost robotic tools able to track multiple tagged marine animals supported on USBL aided INS systems, has been developed. The Robotic Tools have been designed and validated in sea missions with augmenting degree of risk and complexity, involving several resources and strategies. The detection and identification of an acoustic tag, moored at the sea bottom, with the measurement in real time of range and bearing has been validated at sea. The tool is composed by an USBL aided INS system, with the capability of emitting a specific signal that allows the surface craft to track the diving operation.

Preliminary tests with one fixed tag in the bottom, with a human SCUBA diver carrying the tag in a pre-specified trajectory, and with one or more marine animals have been conducted. Data from the robotic tools has been processed to obtain full 3D position and velocity trajectories with data rates and accuracies not possible from the commercially available systems.