13th WORKSHOP

EU PROJECTS RESULTS IN THE FRAME OF THE MADRID'S REGIONAL ROBOTIC HUB ROBOCITY2030

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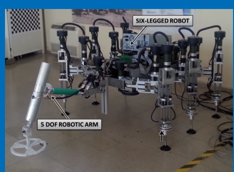

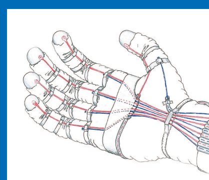

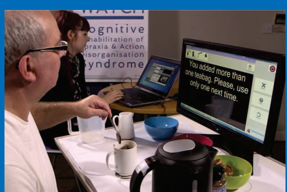

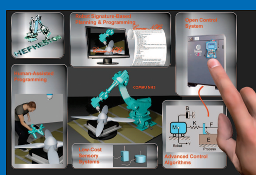

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EU Projects Results in the Frame of the Madrid's Regional Robotic Hub RoboCity2030

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Prologue

It is my pleasure to present this 13th RoboCity2030 Workshop, a programme co-funded by the Community of Madrid and the Structural Funds of the EU.

RoboCity2030 is the biggest regional robotic long term hub in Europe since 2006. It is formed by the six leading R&D robotics centers in Madrid with more than 100 researchers in the field, half of them PhDs. The main objective of the hub is the development of robotic projects and related technologies in order to increase the quality of life of citizens living in metropolitan areas. The hub also includes more than 20 companies from different sectors interested in robotic applications, a business incubator with about 10 robotic spin-offs and several local authorities involved in testing the robotic solutions in their municipalities.

The aim of this 13th Workshop is to present the results of several running EU projects of the members of the RoboCity30 hub, some of them developed jointly by universities, companies, spin-offs and municipalities. The creation of synergies at regional – Madrid – and European levels is the main added value of this hub. The projects presented in this forum deal with different aspects and applications of robotics in the fields of assistive and hospital robotics, infrastructures inspection by robots, humanitarian issues, environmental protection and new actuators and sensors technologies.

Some of the projects that will be discussed are the following ones: MONARCH (UC3M), ROBO-SPECT (UC3M), TIRAMISU (CAR-CSIC), STAMAS (UC3M), CROPS (CAR-CSIC), RHEA (CAR-CSIC), HEPHESTOS (CAR-UPM), COGWATCH (CAR-UPM), STAMS (UC3M), etc.

This one day – single track Workshop will be held in the Leganés Campus of the University Carlos III of Madrid and will be open to researchers, students, industrial professionals and, in general, to the audience interested in robotics. The Workshop sessions will be organized by university authorities and representatives of the Madrid's Community Government, the Ministry of Economy and Innovation, the Centre for Industrial Technological Development (CDTI) and the local authorities.

Carlos Balaguer
Robocity2030-CM Coordinator

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RoboCity2030-III-CM project (Robótica aplicada a la mejora de la calidad de vida de los ciudadanos, fase III; S2013/MIT-2748) is funded by Programas de Actividades I+D en la Comunidad de Madrid and cofunded by Structural Funds of the EU.

CHAPTER 1

COGWATCH: TOWARDS A HOME-BASED AND PERSONALISED COGNITIVE REHABILITATION

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A high percentage of stroke survivors in the EU suffer from cognitive impairments such as Apraxia or Action Disorganisation Syndrome (AADS), which affect their ability to carry out common daily tasks. For that reason, the goals of the recently finished CogWatch project were to advance knowledge of AADS and develop a smart rehabilitation system to monitor behavior and task execution in real time and help the patients regain independence, reducing carer burden, and increasing rehabilitation efficacy by enabling healthcare professionals to work with more patients and restore more of each patient's skills. Additionally, CogWatch project has originated new alliances for new grant applications by using the current know-how to continue advance in cognitive rehabilitation applications.

1 Introduction

While the personal and economic cost of Apraxia and Action Disorganization Syndrome is widely acknowledged (Foundas et al., 1995; Hanna-Pladdy, Heilman and Foundas, 2003), until CogWatch there had been no systematic classification of AADS patients that could lead to more effective rehabilitation technologies and disease management strategies. Moreover, there were no published figures about the number of AADS patients in the UK. Given the incidence of AADS, an important point is that such patients do respond to rehabilitation and demonstrate improved performance in Activities of Daily Living (ADL) (Smania et al., 2006). Current rehabilitation methods and practices provide evidence for short-term improvements in ADL; that is, patients show improvement when assessed immediately after the intervention (Cochrane Review: Bowen et al., 2009).

However, retention of rehabilitation gains seems to depend on multiple patient related factors such as extent and type of lesion (Goldenberg and Hagmann, 1998). Therefore, at the start of the CogWatch project there was a clear need to characterize AADS and to explore the effects of long-term, continuous intervention.

The CogWatch project adopted an integrated approach to solve the problems that have hindered current approaches to rehabilitation which are three-fold involving patients, professional healthcare and rehabilitation technologies.

First, AADS patients may exhibit different types of cognitive errors when performing previously familiar tasks as part of ADL. There is evidence that when patients are provided with appropriate feedback they can correct their own action and complete the task. Second, healthcare professionals recognize that stroke care is typically short-term, hospital based and largely focused on physical rather than cognitive rehabilitation. There is fragmentation between services as the patient is often discharged on physical grounds regardless of their functional state on the basis that other aspects of therapy can continue at home. Finally, most common stroke rehabilitation systems, such as robotic arms and virtual environments (VE) are focused on physical impairments (i.e., hemiparesis) of stroke patients (e.g., MIMICS, REHAROB, ARMin, iPAM, Mitsubishi Pa10) and largely ignore the cognitive impairments of action comprising AADS. Even though, they seem to be effective in re-establishing arm movement range, they operate as workstation platforms which the patient has to access and adapt. This results in fragmented rehabilitation activities which reduces the rehabilitation outcome of stroke patients.

Therefore, it is evident that a new personal healthcare system (PHS) is needed to provide cognitive rehabilitation in familiar, everyday environments allowing the patient to carry out his/her ADL and rehabilitate at the same time (continuous rehabilitation). Thus, the system has to be portable, wearable and ubiquitous. Moreover, it has to be adaptable and customizable to maximize effectiveness and reduce unnecessary costs.

2 CogWatch goals, concept and advance beyond the state of the art

2.1 Project technical objectives and strategy within the European Framework Programme

The overarching goal of CogWatch was to design and develop a PHS that would provide customized cognitive rehabilitation of ADL skills at home through instrumented tools/objects, wearable and ambient devices. These devices would form part of the patient's familiar environment and would allow persistent, continuous and long-term rehabilitation. At the same time, the PHS would allow remote monitoring of the progress of the patient. In order to reach this goal, CogWatch elaborated the scientific and technical objectives depicted in Fig. 1:

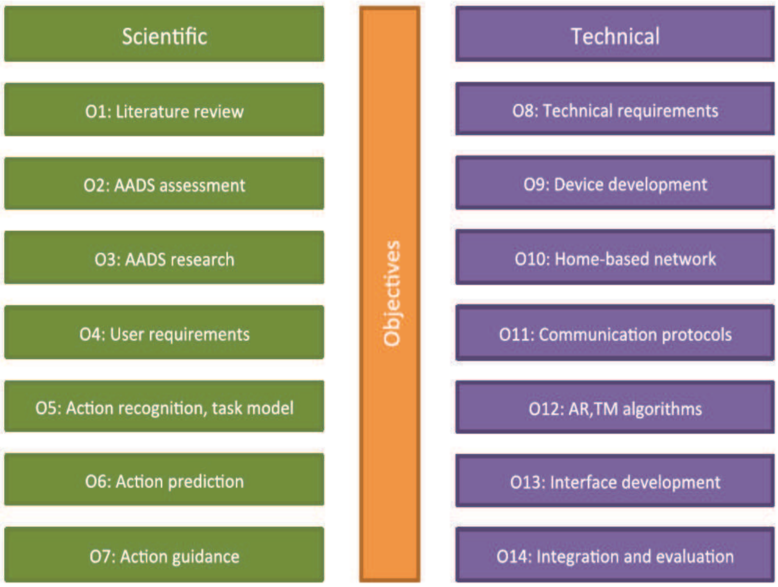

Fig. 1. CogWatch scientific and technical objectives

The scientific work aimed, firstly, at gaining knowledge about the requirements of the users including patients, healthcare professionals and caregivers (O1-O4). Secondly, the science focused on modeling AADS patients' behavior in order to build an automatic action recognition system and task model that would drive the CogWatch system and allow action guidance, error correction and risk reducing feedback to be given (O5-O7).

The technological effort was concerned with the design and development of instrumented tools and objects, wearable devices and ambient systems that would collect behavioral and physiological data during everyday tasks and deliver appropriate multimodal feedback (O8, O9). The technological work also involved designing and developing the communication interface and network for remote assessment and tele-supervision (O10-O13). The technical objectives were completed by prototype integration and evaluation (O14).

Additionally, CogWatch consortium carried out focused research to address the topics in the objective *ICT-2011.5.1; a2): Personal Health Systems (PHS); Rehabilitation of stroke and neurological conditions*. The actions to fulfill them are summarized in the following Table 1:

Table 1. Strategic objectives and actions to implement

Strategic objectives	CogWatch proposal
Provide patient services at home, with tele-supervision by health professionals when required.	The system comprises of sensorized everyday familiar objects. Thus, it increases the independence of the patients and reduce hospital visits. Meanwhile, it transmits the data to the hospital server to enable tele-supervision through cognitive and physiological assessment.
Solutions may build on robotic and haptic technologies, wearable systems, implants, human-computer interfaces, web services or virtual reality environments to facilitate continuity of personalized cognitive and functional rehabilitation.	The instrumented tools and objects incorporate sensors to measure forces, acceleration and orientation, and pressure. Sensors installed on wearable devices monitor heart rate and blood pressure. They will also include actuators for vibro-tactile feedback, when appropriate. The ambient systems include cameras, motion detectors, object positioning system and displays for virtual task execution simulation and telecommunication.
Heterogeneous data (e.g., biofeedback, monitoring of limb movements, behavioral monitoring and analysis) and predictive models should be used to assess patient sta-	An action recognition system is developed which identifies actions (and intentions) to be grouped to define task initiation, execution and completion. Then advance statisti-

tus and progress, monitor risk factors and predict new episodes.	cal techniques develop an action prediction model which is used to drive rehabilitation through action guidance, error correction and risk avoidance feedback. In addition, key physiological data (e.g., heart rate and blood pressure) are also collected to predict potential new TIAs. These data are transmitted and stored in a remote server at a hospital site to facilitate its assessment by health professionals.

2.2 Description of the solution adopted

In order to achieve the main goals of the project, CogWatch has taken a multi-disciplinary and multi-sector approach that includes medical doctors and neuropsychologists (University of Birmingham (UoB) and Technische Universität München (TUM)), healthcare professionals (Headwise (HW)), a stroke charity (The Stroke Association (TSA)), engineers (Universidad Politécnica de Madrid (UPM) and also UoB) and industrial partners with expertise in commercial exploitation (BMT) and medical devices markets (RGB Medical Devices).

Fig. 2. CogWatch architecture for rehabilitation of daily tasks

CogWatch (see Fig. 2) uses sensors embedded in everyday tools and objects (e.g., cups, jugs, kettle), vision-based sensors (e.g. Kinect™) and wearable devices to acquire multi-parametric behavioral (e.g. hand and object movements) and physiological (e.g. blood pressure) data. These data are processed and analyzed locally by a home-based processor which applies action prediction algorithms to deliver multimodal feedback through speakers and visual displays that implement a Virtual Task Execution (VTE) module. The feedback serves the following functions:

- Guides patients' actions.
- Makes patients aware of cognitive errors when they occur.
- Makes patients aware of the actions that they need to take in order to correct the errors.
- Alerts patients if their safety is at risk when handling tools and objects inappropriately.

The behavioral and physiological data are transmitted to a database at a healthcare centre or hospital where they are made available for assessment and tele-supervision by medical and healthcare professionals.

2.3 Progress beyond the state of the art

The CogWatch project advanced beyond the state of art in every aspect of setting up a new pervasive computing environment affording ambient intelligence for tracking movements, recognizing actions, predicting out comes and guiding actions with directed cues. Both the ground work for system development and the testing of system prototypes will contribute to understanding of AADS.

Specifically, instance of advances in state of art are summarized as follows:

- Description and classification of cognitive problems affecting action in relation to language and attention problems.
- Modeling of AADS action deficits and documentation of AADS treatment approaches.
- Availability of patient data for immediate assessment and classification.
- Systematic records documenting day-to-day variability available for first time on AADS.
- Concurrent feedback and guidance with potential for errorless learning.
- On demand home therapy and support for ADL.
- Persistent and continuous rehabilitation.

- Adaptable methods with potential application to sustaining independence in degenerative disorders.

3 Technological impacts in the cognitive rehabilitation industry and market entry

3.1 Benefits for stroke patients

The development of a modular, low-cost ICT system suitable for cognitive rehabilitation of AADS for stroke patients at home could have a significant impact on their personal life and on their families. In the first place home rehabilitation allows more sessions to be managed by patients in their own time without the need for transport to the hospital clinic. This gives opportunity for more practice (e.g. daily sessions) with potential for greater improvement than in a weekly clinic. In the second place, recovering the ability to carry out ADL tasks is a major step towards full physical independence which improves the emotional life of the patient by improving self-image and confidence. This will boost a patient's motivation to continue rehabilitation. Increasing independence also assists patient inclusivity leading to greater socializing with family members and friends rather than being served by them.

Greater personal independence also has significant implications for the healthcare system that provides care for AADS patients. By offering a customized tele-supervisory rehabilitation system, CogWatch has the potential to reduce hospital attendance rates and the number of home visits by healthcare professionals. This will have significant economic benefits for national healthcare systems. It is expected that CogWatch could also be used to monitor and assist other neurological conditions, such as dementia or closed-head brain injury, showing similar disruption to actions as occurs with AADS due to stroke.

3.2 Exploitation of results

In the UK, there are approximately 360 NHS hospitals, and probably as many privately run centres. At a conservative estimate, if CogWatch systems were purchased by 10% of the hospital market, it would involve about 70 CogWatch systems. In addition, there will be take-up by individuals at home or purchasing agencies on their behalf. As there are approximately 2.2 million stroke discharges per year in the EU, conservatively assuming a 50% survival rate, and an AADS incidence rate 50% rate of AADS after stroke, which becomes chronic in 50% of patients, this suggests a potential EU market of 275,000 individuals per annum (given that no competitors operate in the same market).

In principle, the CogWatch system (or its components) could be explored commercially using at least the following two routes: first, commercial partners (HW, BMT and RGB) incorporate CogWatch solutions into their individual business model for healthcare services and, second, creation of a new company (a start-up or a spin-off) to exploit CogWatch solutions. Incorporating CogWatch technologies and approach to rehabilitation into an existing business model may be the quicker route to market.

In Spain, marketing CogWatch technologies can be done on a business-to-consumer (B2C) or business-to-business (B2B) basis. In the first case, the devices are sold directly to the individual customer while in the second case they are sold to healthcare service providers.

To sum up, the strengths CogWatch present at this stage can be summarized as follows:

- CogWatch is innovative. It is using unobtrusive sensoring to monitor complex ADL task progress in real time. Currently, there are no other cognitive rehabilitation and monitoring tools available with the same features.
- Health practitioners recognize the need for a system with the features of CogWatch.
- It is relatively cheap. The ‘headroom’ analysis has shown that CogWatch could be potentially cheaper and more effective than the current practices.
- CogWatch can be installed at home or at the hospital.
- CogWatch can be adapted to suit the needs of individual patients.
- The concept of embedded sensors in everyday objects means that the patients will not feel ‘stigmatized’ while retraining to complete ADL tasks.
- Innovative one-size-fits-all design with one-hand removable electronic module means that CogWatch can be practical as well as affordable to produce and maintain.

4 Management of Ethics and interaction with real stroke patients

The role of Ethics and Safety Officer has been to ensure that appropriate ethics and safety procedures are in place when patients were involved in the project. European Commission have been provided with all appropriate ethical and safety approvals regarding the participation of stroke patients in the planned studies which took place in UoB, TUM and several hospitals such as Moseley Hall Hospital or Wolverhampton West Park Hospital, placed in Birmingham and Wolverhampton, respectively. The Safety Officer also put in place the rules to ensure that patients' data have been managed appropriately, remained confidential and used suitably by health professionals, scientists and engineers.

5 New alliances and follow-on strategies post CogWatch

The CogWatch approach to rehabilitation has many novel science and technology aspects whose potential has been properly appreciated at the end of the last year. Accordingly, the project partners have been driven to capitalize on the momentum of the work and there have been 11 follow-on grant applications submitted (plus 2 planned submissions) to EU, UK public and private funding sources based on, or incorporating aspect of, the CogWatch concept. The proposals comprise:

- Four H2020 proposals (CogDial - Multi-modal Daily Living Assistance for Language, Speech and Planning Impairments H2020 3.6M€; OLIVA - Older Living Intelligent Virtual Assistant H2020 3.9M€; PIERRE - Parkinson's disease IntElligent Robot for Rehabilitation Exercise H2020 4.7M€; AiDA - Advanced Intervention based on Early Detection of Functional Decline in the Ageing Population H2020 4.0M€).
- Two UK stroke Association proposals (General cognitive training contributes to specific skill rehabilitation UK Stroke Assoc £625k; ASTech - Efficacy of new technology for ADL skills training in acute stroke UK Stroke Assoc £264k).
- Two large German proposals (Neural correlates of tool use DFG 400k€; ACTIVE HANDS – Evaluation, rehabilitation, and assistance of hand function in ageing and chronic CNS diseases EIT-Health 1.0M€).

- Five smaller projects (We can cook Nesta UK £69k; Baking with CogWatch SBRI UK £97k; Investigating Barriers to Assistive Technology ABIA £20k; Automatic Analysis of Fidelity of Motivational Interviewing with Diabetes Patients Google Faculty £52k; Effectiveness of animated avatars in cueing actions for patients with apraxia and action disorganisation syndrome TUM Foundation 60k€).

Acknowledgements

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CHAPTER 2

SENSING WITHIN THE EUROPEAN PROJECT CROPS: RESULTS AND CONCLUSIONS

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CROPS was a large-scale integrating project funded by European commission in the 7th Framework Programme. The objective of this project was to develop scientific know-how for highly configurable, modular and clever robotic platforms capable of harvesting in a selective way high value crops such as greenhouse vegetables, fruits in orchards and grapes for premium wines. Within this project, the Centre for Automation and Robotics CAR-CSIC was focused on the design, implementation and validation of the sensing system for detection and localization of fruits, as well as the sensing system for estimating the ground bearing capacity. This paper summarizes the main results obtained with the proposed multi-sensory systems and some recommendations for future work in this research area.

1 Introduction

During the last 30 year, around 50 harvesting robots, capable of operating autonomously under a certain range of environmental conditions, have been designed and implemented. However, none of them has been able to be commercialized with success, mainly due to the limited performances achieved. The CROPS project was conceived with the aim of addressing this problem, developing capabilities for robots operating in unstructured environments and dealing with the highly variable objects that exist in agriculture and forestry. CROPS (Intelligent sensing and manipulation for sustainable production and harvesting of high value crops – clever robots for crops) was a large-scale integrating FP7 EU project (Grant Agreement No 246252) in the theme Nanotechnologies, Materials and new Production Technologies within the call: Automation and Robotics for Sustainable Crop and Forestry Management. The project started in October 2010 and was accomplished in September 2014. The objective of this project was to develop scientific know-how for highly configurable, modular and clever robotic platforms capable of harvesting in a selective way high value crops such as greenhouse vegetables, fruits in orchards and grapes for premium wines. Another objective of CROPS project was to enable successful autonomous operation of the robotic platforms in plantations and forest, taking into consideration that agricultural and forestry applications share many common research areas, primarily regarding sensing and learning capabilities. The consortium consisted of 14 partners, including universities, research institutes, and large agro-forestry equipment companies and SMEs, and it was coordinated by the Wageningen University and Research Centre. CAR-CSIC, as one of these partners, was leader of the WP2, devoted to the design, implementation and validation of efficient, adaptable and robust sensing systems for the CROPS robotic platforms. With this sensing technology, the CROPS robotic platforms would be able to: (i) detect and locate fruits, which are the most basic requirements for harvesting robots; (ii) estimate the ground bearing capacity for forestry applications.

This paper presents the challenges and the main difficulties that the CAR-CSIC had to confront during the course of the project, the major results obtained with the designed and implemented solutions, the main lessons learned for future projects, as well as some recommendations for future work in the addressed research area.

The manuscript is organized as follows. Section 2 describes the research carried out for the design, testing and validation of the sensory system for detection and localization of fruits, as well as the features of the sensory system proposed for estimation of the ground bearing capacity. Section 3 lists the main challenges and difficulties confronted, and finally, Section 4 summarizes conclusions and recommendations. For more detailed information about other aspects of the CROPS projects, readers can visit the web page http://www.crops-robots.eu/

2 Sensing in CROPS

Within the CROPS project, the Sensing Work Package was devoted to the research and development of low cost, efficient, adaptable and robust solutions that provide to the different robotic platforms the required information from the environment to facilitate the intelligent behaviour expected for the consecution of the desired tasks. Configurable and modular designs were required to enable the sensory systems to adapt to variations in plants, crops, trees and fields. In addition, designs had to ensure fast operation while meeting precision requirements. Thus, the scope of the research carried out by CAR-CSIC included two objectives: sensing for harvesting and sensing for ground protection.

2.1 Sensing for harvesting

Three different crops had to be detected and located: sweet-peppers, apples and grapes. The detection and localization of these crops had to be done in both static and dynamic situation and under partial occlusion. Sweet-peppers would be detected in controlled indoor environments (greenhouses) while apples and bunches of grapes would be detected outdoors.

A progressive colour camera, a multispectral imaging system and a Time-Of-Flight (TOF) 3D camera were selected as primary sensors for the stated purpose. The high resolution colour camera was not only utilised for the acquisition of RGB images, but also as part of the multispectral system, in which case it was set in the monochrome mode. The reflectance measurements in the visible region provided by the progressive camera were used as basic input for the detection of areas of interest where the colour of fruits is obviously different from the rest of the plant. Multispectral imaging technique enabled improved discrimination and classification of targets with similarities by analysing spectral information. This multispectral system, which is shown in Fig. 1, consisted of the progressive camera set in monochrome mode, a filter wheel and a servomotor that was responsible for the accurate positioning of the filter wheel. This positioning could be achieved with a maximum angular velocity of 40rpm and a position error of 0.001°. A hyperspectral system was used in preliminary lab experiments in order to determine the relevant wavelengths that permit the discrimination of the different elements of the plant, and therefore, the proper selection of the filters that were installed in the multispectral system. The TOF 3D camera supplied simultaneously fast acquisition of accurate distances and intensity images of targets, enabling the localisation of fruits in the coordinate space.

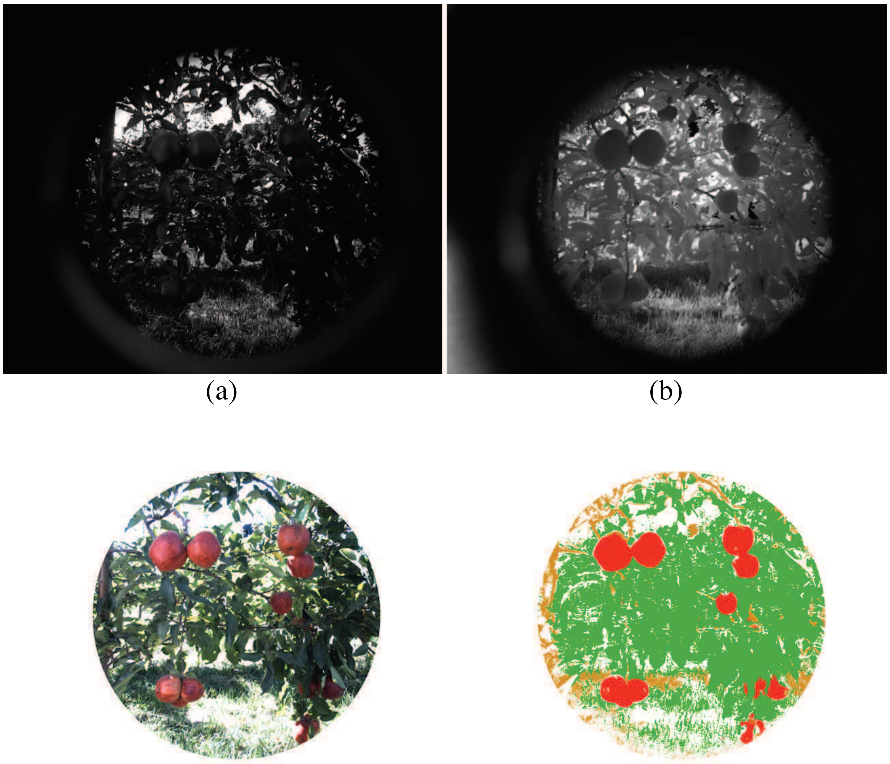
In addition, two pre-processing algorithms were designed and implemented for the proposed sensory system: a pixel-based classification algorithm that labelled areas of interest that belong to fruits and a registration algorithm that combined the results of the aforementioned classification algorithm with the data provided by the TOF camera for the 3D reconstruction of the desired regions. In this way, a direct correspondence was obtained, so range data could be associated to pixels labelled as fruit.

The feasibility of the sensory system and the associated set of pre-processing algorithms for detecting and locating fruits from different kinds of crops in natural scenarios was validated and evaluated through an extensive experimental stage.

Fig. 1. Sensory system for detection and localization of fruits

After evaluating the experimental results, we obtained mean detection precisions of 99.8% for apples and 97.6% for grapes, and mean position errors of 0.8 cm in the x-axis, 1.5 cm in the y-axis and 2.3 cm in the z-axis. Therefore, the proposed pre-processing algorithms attained a high level of correctness in classifying the pixels of images that belong to the target fruits and allowed the spatial localization of the regions of interest classified as fruits with enough accuracy. Some examples of these experimental results are displayed in Fig 2.

For a more comprehensive review of the proposed multisensory system and the pre-processing algorithms for detection and location of fruits, readers are referred to (Montes et al., 2012, Fernández et al., 2013; Fernández et al., 2014a; Fernández et al., 2014b; Salinas, 2015).



(a) (b) (c) (d)

Fig. 2. Experimental results. (a) 635 nm image. (b) 880 nm image. (c) RGB image of the apple orchard. (d) Classification map.

2.2 Sensing for ground protection

The use of wheeled and tracked vehicles is a widespread practice in agriculture and forestry applications (Ampoorter et al., 2009). These practices with manual or autonomous machines can cause severe soil damage (Sutherland, 2003; Jansson and Johansson, 1998; Arredondo-Ruiz et al., 2014). The ability of the soil to carry a certain weight without being damaged depends primarily on the soil type and the soil water content, which varies over the time. Knowledge of these parameters can contribute significantly to reducing soil damage during mechanical operations. Ground penetrating radars, microwave, infrared, and near infrared measuring techniques were evaluated during the course of the project to accomplish the proposed tasks.

However, the final solution proposed a sensory system based on VIS-NIR, SWIR and LWIR imagery and a sequential algorithm that combined a registration procedure, a multi-class SVM classifier, a K-means clustering and a linear regression for estimating the ground bearing capacity. The presented solution can be utilized in natural scenarios, in real-time and in a non-destructive manner. Therefore, the proposed sensory rig and the cited algorithm can be installed on-board a mobile robot or vehicle for estimating ground conditions before traversing the field, avoiding disturbances of the site and significantly reducing ground damages.

An extensive experimental campaign was carried out not only for acquiring the data required for the design phase but also for assessing the capabilities of the proposed approach. Experimental results showed that both the multisensory system and the sequential algorithm exhibited a satisfactory performance.

For a more comprehensive review of the proposed solution for estimation of ground bearing capacity, readers are referred to (Fernández et al., 2015).

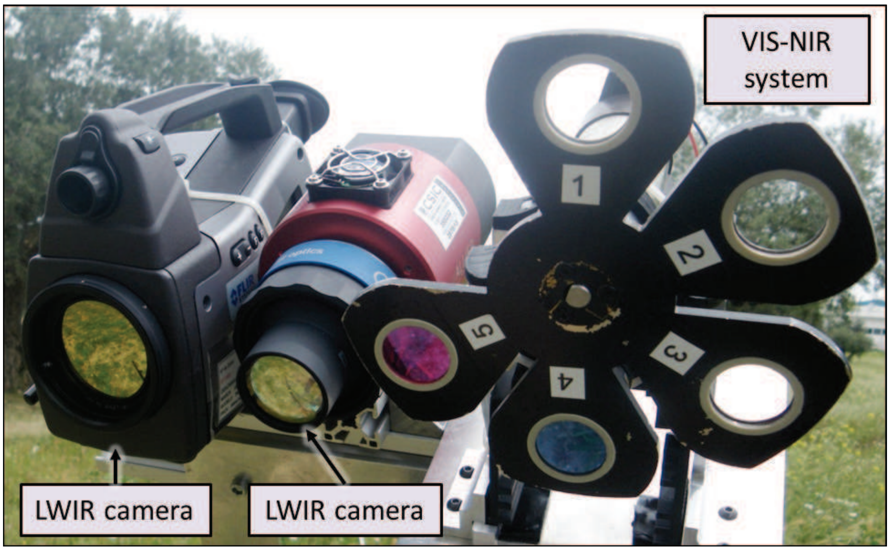


Fig. 3. Sensory system for ground protection

3 Challenges, difficulties and lessons learned

The design of the sensory systems described in Section 2 presented various challenges and difficulties. The first challenge was that the sensing concept should be developed simultaneously for several crops (sweet peppers in greenhouses, and grapes and apples outdoors) and several applications (harvesting and forestry) to ensure the generality of the solutions developed. Secondly, the fundamental sensing technologies should be able to deal with several factors that vary both spatially and temporally (occlusions, illumination), the environment (location, soil properties, and weather), the delicate nature of the products, and hostile weather conditions (dust, dirt, and extreme temperatures and humidities). In addition, dynamic, real-time interpretations of the unstructured environment and the objects, as well as easy adaption to new tasks, were features required for the proposed systems. Finally, since the agricultural products being dealt with are of relative low cost, the cost of the automated system must be also low, in order for it to be economically justified.

Detection and localization of fruits in natural scenarios encountered several difficulties, since most fruits are partially occluded by leaves, branches or overlapped with other fruits (Plebe and Grasso, 2001). These occlusions eliminate the direct correspondence between visible areas of fruits and the fruits themselves by introducing ambiguity in the interpretation of the shape of the occluded fruit (Kelso, 2009). In addition, colours of fruits cannot be rigidly defined because the high variability exhibited among the different cultivars within a same species and the different levels of ripeness. Moreover, fruits can be found in quite random positions and orientations in trees of various sizes, volumes and limb structures. Despite these difficulties, the proposed solution exhibited a satisfactory performance, showing a great versatility in dealing with different crops in natural conditions.

On the other hand, the presence of shadows and overexposed areas in the scenes can affect the estimation of the ground bearing capacity. For this reason, the proposed solution was designed in such a way that these effects were minimized. Even in the worst scenario, the proposed approach is still quite conservative, because these external factors would tend to decrease the magnitude of the ground bearing capacity, what is still a beneficial result from the point of view of the soil protection.

One of the reasons for the success of the proposed solutions was the extensive experimental campaigns that were conducted in order to acquire training data for the design of the classifications algorithms. However, these experimental campaigns for the acquisition of training data were severely constrained by the time of harvesting of the crops involved. Therefore, one of the major lessons learned in this project was that for agriculture applications, strict guidelines, field protocols and planning are required in order to carry out the best acquisitions of data for training and validations purposes coinciding with the dates when the crop is in the proper stage of development.

4 Conclusions and recommendations

A modular and easily adaptable sensory system and a set of associated pre-processing algorithms were proposed for the detection and localisation of fruits from different kinds of crops. The solution included a colour camera, a multispectral system and a TOF camera. The pre-processing algorithms consisted of a classification that identified pixels that belong to fruits and a registration algorithm that combined the results of the aforementioned classification algorithm with the data provided by the TOF camera. This solution, implemented in CROPS project, increased the fruit detection rates to 90-99%, and showed a great versatility in dealing with different crops.

A second sensory system, based on the combination of LWIR, SWIR and VIS-NIR imagery, and a sequential algorithm that combined a registration procedure, a multi-class SVM classifier, a K-means clustering and a linear regression were proposed for estimating the ground bearing capacity. This solution, which minimizes the disadvantages and maximizes the strengths of each independent system, can be utilized in natural scenarios, in real-time and in a non-destructive manner. Therefore, the sensory rig and the cited algorithm can be installed on-board a mobile robot or vehicle for estimating ground conditions before traversing the field, avoiding disturbances of the site and significantly reducing ground damages.

If higher detection rates are required for precision agriculture applications, it would be interesting to gain understanding on which parts of the proposed algorithms are more responsible for the misclassification errors. In that case, research can be directed to break-down the algorithms and to evaluate the performance on each step, in such a way that the cause source that contributes to reduce the overall performance can be more easily determined.

In the proposed solution for the estimation of the ground bearing capacity, it should be taken into account that the prediction model obtained from the linear regression mainly relies on experimental data. Therefore, in order to guarantee a robust estimation of the ground bearing capacity, data acquisition should be extended to different types of terrains.

Acknowledgements

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CHAPTER 3

HEPHESTOS: HARD MATERIAL SMALL-BATCH INDUSTRIAL MACHINING ROBOT

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Hard material machining has recently attracted great attentions from advanced industries, in particular, the European automotive, the aerospace and biomedical industries. However, the existing technology failed to provide these industries with a cost efficient solution to cope with small-batch production of large and complex-shaped products. The project Hephestos, with its focus on developing sophisticated methods in robotic manufacturing, shall give rise to a cost efficient solution in hard materials machining for this small-batch production of highly customized products through the application of industrial robots.

1 Introduction

In order to keep and strengthen the leading position of European industry in developing, producing and using industrial robotic systems, the improvement of industrial robots functionalities, the evolution of new robot paradigms and the enlargement of robot applications spanning all areas of modern life have been identified as crucial goals. To meet these goals it is widely recognized that new robotic systems capable of cooperating and assisting the human, susceptible to percept the environment and adapt their behavior to changes, as well as to the requirements of novel tasks and the human, are urgently needed.

For these reasons, a group of European companies, research centers and universities joined in the FP7 European Project Hephestos.

The Hephestos project focuses on developing novel and sophisticated methods (for planning, programming, real-time control) that allow efficiently deploy of industrial robots in applications which are of considerable commercial potential, and in pertinent to the large scale flexible robotic machining technology (e.g. milling, grinding, polishing) of customized low-volume high-variant products with special emphasize on hard materials group (e.g. inco, hardened steel, granite etc.).

To cope with high dynamic interaction and loads during material cutting process, as well as with uncertainties in environment and robotic system, it is widely recognized that some kind of compliance inherited in the system (e.g. workpiece, robot, tool etc.) is essential for robot finishing tasks accomplishment. The state-of-the-art solutions, such as compliant additional axes or tools, support considerably robot application in specific operation (e.g. de-burring, grinding), however in general, are not sufficient to cope with complex manufacturing problems, without taking advantages from robot flexibility and reprogramability. Furthermore, an arbitrarily added compliance reduces the robot accuracy, which is conventionally essential in robot machining (akin to traditional CNC machining).

Hard machining is a recent technology focusing on materials in constant use by automotive, aerospace, biomedical and other advanced industries. Insufficient rigidity and accuracy have been widely identified as major obstacle of widespread use of robots for metal-removal jobs, making robotic machining of hard materials quite difficult. To cope with these problems the robot industry has established new trends towards high-precision robots, refining the robot accuracy by combining structural improvements (e.g. closed kinematic chains), calibration procedures and position mastering, as well as new joint encoder technology, to achieve accuracy within the range of 0.3 to 0.5 mm. Several research efforts recently address these problems using external tracking sensors and high dynamic compensation mechanisms (e.g. active workpiece carrier) to achieve accuracy comparable with NC machines. However, such solutions that move robotic systems toward NC machines would considerably increase the system costs and complexity and are difficult to be implemented in SMEs.

The aim of Hephestos is to provide a novel robotic manufacturing technology paradigm that optimally combine standard industrial robots, automatized and optimized motion planning and programming based on established CAM frameworks taking into account specific robot performance, advanced control strategies for interaction control between robot and cutting material, as well as multi-step task replanning and reprogramming supported by available sensor technology. The Hephestos optimally takes advantages of flexible human-like strategies (dexterous artisan and workmen) and combine them with robot advantages to develop a plug-and-play flexible robotic metal removal system intended for low volume, high variant and high quality products made of hard materials. The key of the Hephestos is to develop better understanding of hard material robotic machining application segments by shifting in focus away from how robots can replace CNC machines to the issue of how robots can compliment traditional CNC machining and human in high variant low-volume production.

2 Project Consortium

The Hephestos project has been coordinated by the Fraunhofer IPK (Germany) research center and has been formed by 5 companies: Comau SPA (Italy), Jot Automation-MAG OY (Finland), ME Messysteme-MEM GMBH (Germany), Easy-Rob (Germany) and G-Robots KFT (Hungary), one other research center: VTT (Finland) and 2 universities: Universitetet i Agder-UiA (Norway) and Universidad Politécnica de Madrid-UPM (Spain). Table 1 shows the project consortium and the main role of the participants.

Table 1. Hephestos Consortium

Name	Type	Business Activities	Main Role in the Project
Fraunhofer IPK	RTD	Applied research	Coordinator, Control technology developer
Comau	Industry	Control System Supplier	Robot technology provider and developer
MAG	Industry	Automation Systems Integrator, Vendor.	Prototype integrator and End-user
MEM	SME	Sensory Systems	Low-Cost F/T sensors for machining.

Easy-Rob	SME	Robot simulation tools	Planning and programming interfaces
G.Robots	SME	Manufacturing robot cells integrator and vendor	Use-case integration and validation
VTT	RTD	Applied research	Sensory technology developer
UiA	RTD	University / Basic Research	Developer of planning systems
UPM	RTD	University / Basic Research	Developer of human interfaces and control

3 Project main objectives

Hephestos' main objective is to develop novel technologies for the robotic hard material removal that will provide standard industrial robots with advanced techniques in production planning, programming and real-time control, and make available a promising and practical use of industrial robots for machining applications that is not possible at present.

The distinctive conceptual project goals are:

- To apply conventional industrial robots, flexible and open planning/programming and control systems, and affordable sensors to keep the costs of robotic machining systems 5-10 times cheaper in comparison to that of CNC machines. To make usage of the system possible, simple and intuitive to ensure practical use in SMEs. To achieve the cost-efficient robotic applications in industry for hard material machining.
- To combine specific machining processes (milling, grinding and polishing) and tools in order to achieve optimal material removal rates, surface quality, cycle times, tools and robot life- cycles that are competitive to that of CNC machining.
- To improve and make robot planning and programming efficient and promising for batch production of all scales. To optimally combine standard planning tools, robot and process models with sensory feedback and human knowledge and experience in order

to reduce the planning and programming costs by means of intuitive novel programming methods (e.g. manual or sensor guided).
- To reach high process stability and robustness by integrating sophisticated robot control methods based on impedance and force/feed control.

To meet the main project objectives and goals, the specific Hephestos S&T objectives concern the following prototypes developments (WHAT):

- An open and flexible hard-material machining planning and programming framework with a Toolbox - based on standard and truly open robot simulation and developing environments. The tools ensure automatic generation of feasible and reliable robotic manufacturing programs that are optimally adjusted to the specific robotic system performance (robot signature) taking into account all major errors causes. The generated programs include new programming instructions to support robot adaptation to the real process based on advance sensing and control strategies (e.g. impedance and force-feed control) as well as for easy re-planning (based on quality monitoring).
- Application programming interfaces (APIs) - to integrate novel and efficient intuitive on- line programming methods, as well as sensory feedback about actual machining state in order to support re-planning and reprogramming. The APIs provide also a human-interface for technological instructions and rules provided by human experts in order to obtain a more efficient and feasible programming. Finally the interfaces to an augmented reality programming environment that facilitate testing, evaluation and optimization of manufacturing programs and system real-time machining performance.
- Integrate advanced but nevertheless low-cost sensing techniques to collect iteratively information on production process quality and accuracy in order to adapt the strategy and re-plan/re- program the robot manufacturer taking into account specific metal removal operations (e.g. milling, grinding, polishing, drilling) and tools.
- To disseminate to industrial robot machining the advanced compliance (impedance) and force control to optimize highly dynamic interaction and suppress chattering during hard material robotic machining.
- To develop safe and flexible human-machine interfaces for dynamic cooperation to support on-line programming, efficient

work-piece alignment, as well as including of the human expert knowledge for an efficient programming.

- To integrate the entire Hephestos development modules in prototype systems of high flexible reconfigurable robotic cells for hard material manufacturing and demonstrate their applicability in small-batch production segments. To devise standardized benchmark tests to qualify and evaluate robot system performance in hard material machining tasks.
- To disseminate potential, advantages and applicability of the novel robotic machining technologies to a large-scale end-user community. To elaborate business plans and marketing strategies for disseminating the novel robot machining system in large industry and SMEs for different application segments.

Figure 1 shows the scheme of the Hephestos project objectives

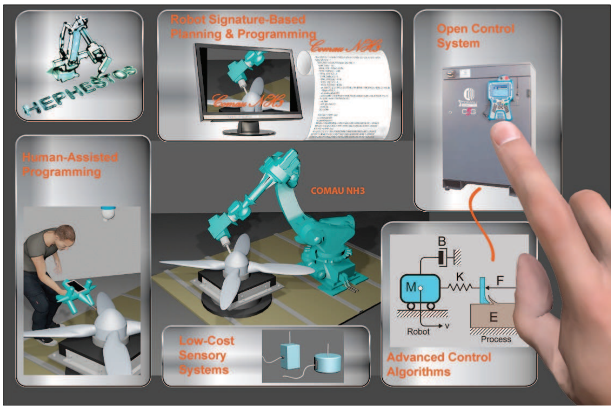

Fig. 1. Hephestos objectives

4 Methodology and work plan

The scientific and technical work project plan has been set up in 8 different Work Packages (WP) (see Fig. 2). Following this plan, the project starts with specification of development requirements (WHAT should be done) and conception of the industrial machining robots and cells architectures (HOW it will be done) in WP1. The system's main modules considering both HW and SW components, as well as specific applications scenario, are addressed in the main RTD packages WP2, WP3, WP4 and WP5 respectively. The management of the project is established within WP8. Finally, the prototype testing and the technology dissemination and exploitation are elaborated as important outputs of the HEPHESTOS projects in WP6 and WP7 respectively. Each WP is sub-divided into a number of tasks, which are carried out by researchers (with experience that comes closest to the scientific and technical requirements of each task) and SMEs.

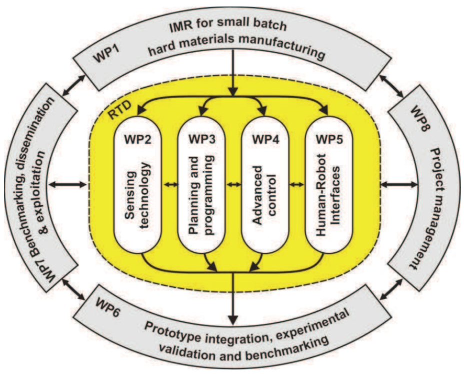

Fig. 2. Hephestos workpackage structure and relationships

5 Industrial demonstrators

The developments within Hephestos project have been validated in industrial environments by means of two basic use-case applications. The demonstrators have been presented to the machining and robotics research and industry in a workshop that was held at MAG installations in Finland.

5.1 Use case 1: Flexible robotic machining cell

A flexible robotic machining cell based on standard robotic cells architecture developed at MAG (Fig. 3, 4 and 5) for large parts manufacturing. The applications involve: machining of large parts such as propellers blades, motor blocks etc. mainly for ship-building and aerospace applications. The novel Hephestos cell integrates the entire Hephestos development: planning using computer-aided- design and –manufacturing (CAD/CAM) systems, automatic programming and program optimization for specific robot manufacturing (robot signature), sensory systems, advanced control techniques and human-machine interfaces and interaction (for iterative reprogramming).

Fig. 3. Use case 1 scenario

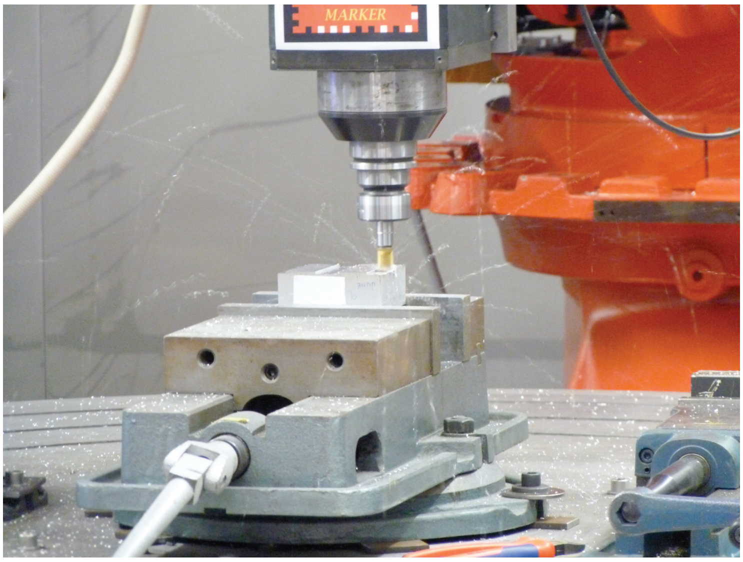

Fig. 4. Use case 1 hard material machining task

Fig. 5. Use case 1 advanced HMI

5.2 Use case 2: Flexible robotic system for small-batch machining

This demonstration scenario includes a fenceless flexible robotic system for machining of relatively small and unique hard-material parts such as granite sculptures manufacturing or repair of turbine blades etc. The demonstrator has been developed at G-Rob premises (see Fig. 6). The demonstrator shows the entire production cycle starting from scanning of initial parts, planning and program generation, iterative machining with re-planning sequences based on human-robot interaction, up to complete finishing using advanced Hephestos control approaches. A special emphasize has been put on human-centered on-line programming and reprogramming by means of the developed sensors and interaction control system (manual guidance). The performance and cycle times of the Hephestos system have been compared with the existing separate robot manufacturing cells. It has been demonstrated that Hephestos development provides considerably reduction of planning and programming times ensuring complete product manufacturing by combining basic machining operations and reducing additional human post processing (manual interventions).

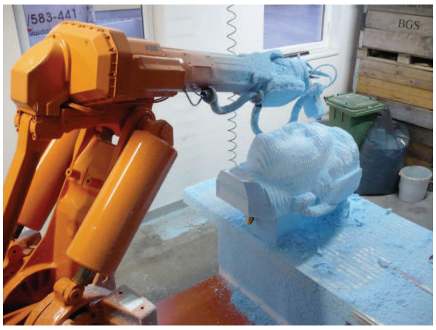

Fig. 6. Use case 2 scenario

Acknowledgements

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CHAPTER 4

HUMAN-ROBOT INTERACTION IN THE MONARCH PROJECT

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This paper presents the design of the human-robot interaction (HRI) architecture developed in the context of the European project MOnarCH. In this project a team of robots operates in the pediatric ward of an oncological hospital. In this scenario the robots operate for long periods interacting with the different people they encounter: children, staff, etc. We present an HRI architecture that is capable of managing the different situations that the robots might face while interacting with people. We model these interactions as multimodal dialogues in which the robot has to perceive the current situation and express itself in a cohesive and coherent manner.

1 Introduction

In Human-Robot Interaction (HRI) we try to emulate with robots the way humans communicate and interact among them. Therefore, we need to provide a system that is able to deal with the conditions of the environment and the diversity of human responses. This system is in charge of customizing the way the robot communicates. In this paper we present the approach followed in the MOnarCH Project to handle the HRI. The aim of this project is to develop a networked system of social robots targeted to interact and to engage children who are hospitalized in the pediatrics ward of an oncological hospital in Lisbon, Portugal. The interaction activities of the robots will consist in, mainly, edutainment (education plus entertainment) activities. We propose an HRI architecture to handle the interactions during the operation of the robots in the hospital. This architecture is based on Communicative Acts (CAs), which are the minimum unit of communication between 2 entities (in this case, a robot and a human). The CA idea in inspired in the ideas of Searle (Searle, 1969) and others (Austin, 1975; Jakobson, 1960),but adapted to the MOnarCH scenarios.

To understand our approach, we first describe the MOnarCH hospital environment together with the robots that operate in such hospital (both in Section 2). Following, we describe in Section 3 the HRI architecture that enables the MOnarCH robots to adapt to the variety of social situations that occur in the hospital. We finally conclude the paper in Section 4 stating the major contributions of the MOnarCH's HRI architecture.

2 The project MOnarCH

The European project MOnarCH targets: (i) the development of a novel framework to model mixed human-robot societies, and (ii) its demonstration using a network of heterogeneous robots and sensors, in the pediatric area of an oncological hospital. The robots will perform edutainment activities and will deal with the uncertainties introduced by people and robots themselves in order to obtain natural interactions.

Key properties of networked robot systems, such as robustness and dependability, are a major concern of the project. In addition, guidelines to translate the MOnarCH system to applications in hospital environments, and other scenarios sharing similarities with them, e.g., kindergarten, and personal assistance to elderly at home, will be delivered.

Moreover, innovation is expected mainly in: (i) the modeling and analysis of the dynamics of social organizations, and social individuals, (ii) the mapping between such models and implementable systems, (iii) the integration between models related to social and asocial behaviors, (iv) the introduction of creative methods of interaction between people and robots, based on models of the dynamics of social organizations and individuals, and (v) the adaptation of robots to individuals and groups of people.

2.1 The MBots

The MOnarCH robots (MBots) (Fig. 1) have been designed to establish social interactions with the children who are hospitalized in the pediatrics ward of the hospital. The MBots are 1m height robots equipped with 4 omnidirectional mecanum/wheels; 2 laser range finders (LRF) for 360º coverage; and an RGB-D (Red, Green, Blue, - Depth) sensor for close obstacle detection. They perceive the environment with a second on-board RGB-D sensor; several touch sensors in their shell; a microphone; and an RFID reader. The robots also get video information from network of distributed omnidirectional cameras installed in the hospital. For interacting the MBots are equipped with several devices: Two 1-DOF arms; a 1-DOF Head (pan); two speakers to reproduce verbal and non-verbal utterances; a touch screen in the robot's chest that enables it to show images, videos, and menus to get input from the user (buttons, sliders, etc.); a video projector; several RGB LEDs installed in the robot's eyes, cheeks, and base; and a LED matrix that acts as the robot's mouth.

Fig. 1. An MBot Robot interacting with a child.
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2.2 The hospital scenario

The robots operate in three different areas of the pediatrics ward of the hospital (Fig. 2): part of the main corridor (Fig. 2 down-left), the pediatrics ward playroom (Fig. 2 down-centre), and the pediatrics ward classroom (Fig. 2 down-right). Within these areas the robot's behaviors vary so they can adapt to the different situations they might encounter. In order to do that, the MOnarCH project defines three storyboards, where each one applies to a specific area of the hospital. The first one is the Joyful Warden, where the robots will patrol and socially interact with the people they encounter in the corridor and the playroom. The second storyboard is the Interactive Game, where the robots engage with the children in a collaborative game. The third scenario is the School Teaching Assistant, where the robot acts as a teaching assistant in the pediatrics classroom by projecting videos and animations related to the class content.

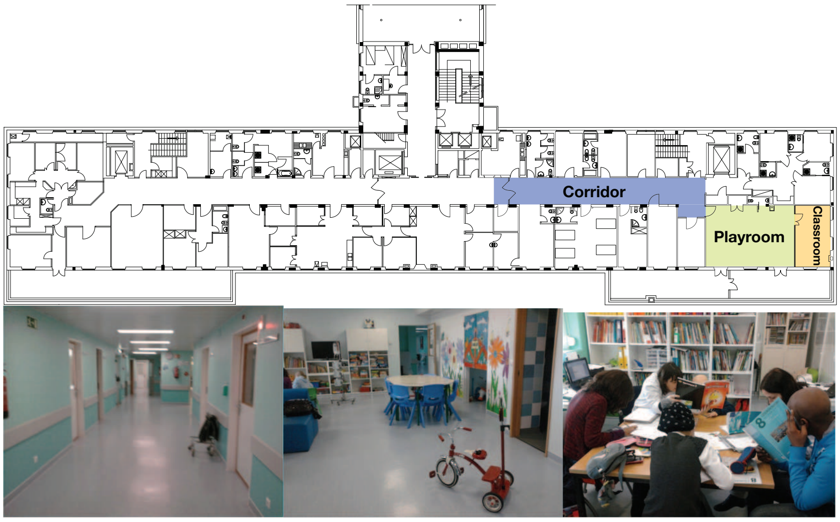

Fig. 2. The Hospital Scenario. The colored areas in the upper map correspond to the three scenarios in which the robots operate and move freely: corridor (down-left), playroom (down-centre), and classroom (down-right).

For some of these scenarios, we start developing the social interaction from previous work (Gonzalez-Pacheco, Ramey, Alonso-Martin, Castro-Gonzalez, & Salichs, 2011). However, in the MOnarCH scenarios, the robot's social behaviors must comply with different situations and social norms that might apply to each one of these scenarios. Also, the robots must be able to interact with children, hospital staff and bystanders. This means that the robots must behave in different manners depending on to whom they are interacting with, and on the current interaction context. In this way, we divided people in three different categories: hospital staff, children, and other people. We model these roles using the roles proposed in the literature (Scholtz, 2002) in the following way: hospital Staff will act as Supervisors and as Peers; children will act as Peers; and other people will be considered as Bystanders.

3 The HRI architecture for social robotics with children

The MOnarCH HRI architecture is depicted in Fig. 3. Its main components are the Dialogue Manager (DM) and the Multimodal Fusion (MFu) and Fission (MFi) modules. The DM receives the CA activations from the Socially Aware Planner (SAP). That is, the SAP1 is aware of which is the current storyboard and situation and decides which CAs might be appropriate for such context.

The Dialogue Manager (DM) is the element of the architecture that manages the execution of the MOnarCH HRI. By managing we mean that it does not execute directly the interaction but, rather, it orchestrates the actions that compose this interaction by sending the appropriate commands to the robot's Multimodal Fission (MFi) modules, which are actually in charge of the execution. In short, we can say that the DM decides what to do while the MFi knows how to do it. For instance, if the robot needs to say a something to a user, the DM decides which sentence to say, with which emotion, volume etc. Then, it sends this command to MFi, who knows how to perform the utterances of that phrase. The interaction can be executed, not only by voice, but using other interfaces such as gestures, led expressions, images in the screen, etc. This multimodality applies also to the inputs: besides of listening to what the user says, the robot also uses other sensors such as touch, RFID readings, cameras, etc. The multimodality is supported thanks to the use of the Multimodal Fusion (MFu) for inputs and the Multimodal Fision (MFi) for outputs (see Fig. 3).

1 The functionality of the MOnarCH's SAP goes far beyond than telling the DM which CA might be needed. However, here we only describe the functionalities related to MOnarCH HRI.

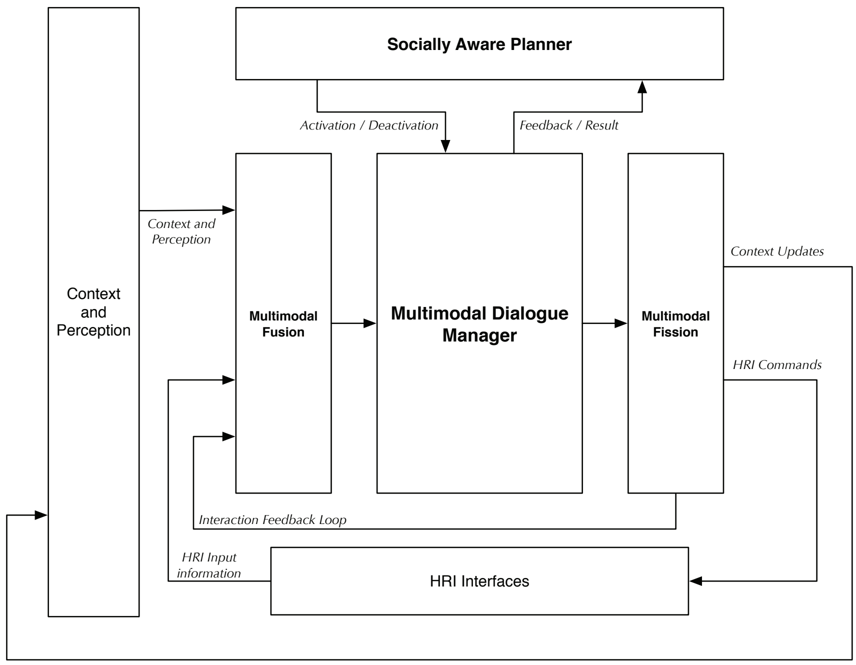

Fig. 3. Overview of the MOnarCH HRI architecture.

The MFu gathers the information coming from the input HRI interfaces and from the Perception, and second, aggregates and translates them into a format that is useful for the DM. With this information, the DM can decide what to do and send the appropriate commands to the MFi. The MFi is symmetric to the MFu but, in this case, is the DM who sends messages to the MFi, which is composed of translators that translate and forward the DM messages to the HRI interfaces. Using the two layers of translators (MFu and MFi) permits to keep the DM independent of the hardware that it is being used. For instance, it is possible to change the entire Automatic Speech Recognition system with only replacing the translator node of the MFu2.

The DM incorporates a rule-based production system inspired by the COLLAGEN plan trees (Rich, Sidner, & Lesh, 2001). The rules of the

2 However, note that the MFu is not only composed of translators. It also incorporates a layer of nodes that aggregate the information coming from the interfaces.

production system, which are called recipes or dialogues, enable managing the dialogues with aspects of finite-state, frame, and information-state-based approaches. These recipes are written in XML files, and define the preconditions that trigger the execution of a certain CA and the actions that should be executed in such CA. That is, these rules codify what to do when certain inputs are received. For instance, consider the case of a *give greetings* CA. Once this CA is activated by the Socially Aware Planner, we can write a precondition in the recipe which waits for the input from the perception indicating that a user is in front of the robot. Once this precondition is triggered, the recipe can contain different kind of actions. For example, to execute a greetings gesture, say a random greeting utterance, express a big smile, etc. Note that the MFu usually feeds the information that triggers the preconditions, while the actions to be executed are sent to the MFi. Once the recipe is ended, the results of the interaction are sent to the Socially Aware Planner.

4 Conclusions

We presented an HRI architecture that enables the robots developed in the MOnarCH project to establish social relations in different scenarios. The naturalness of these social interactions is quite important in the context of the project MOnaCH since the principal users are children who are hospitalized in the pediatrics ward of an oncological hospital. Since the main goal of these robots is to try to engage those children in edutainment activities, the HRI architecture presented in this work becomes one of the key points of the project.

Using the approach presented, the robot is able to communicate with the user in a very natural way thanks to the Multimodal Fusion (MFu), the Dialog Manager (DM), and the Multimodal Fission (MFi) structure at the core the HRI architecture.

The MFu module aggregates the information perceived and sends it to the MD that decides which message to transmit and then it communicates this message to the MFi. The MFi allows the robot to express the same communicative expression in different ways at different moments. Therefore, the resulting HRI architecture provides a natural, flexible, multimodal communication between the robots and the children.

Acknowledgments

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CHAPTER 5

PISA: FLEXIBLE ASSEMBLY SYSTEMS THROUGH WORKPLACE-SHARING AND TIME-SHARING HUMAN MACHINE COOPERATION

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The new generation of robotic system will take advantage of both, machine capabilities and human skills to improve productivity and reliability of automation systems. PISA is a European Integrated Project (IP) in the research area "next generation of flexible assembly technology and processes". The general aim of the project is to develop intelligent assist systems (IAS) in order to support the human worker instead of replacing him. Thus, flexibility should not be reached through fully automated assembly systems but should instead support the better integration of human workers.

1 Introduction

The growing number of product variants, smaller lot sizes, accelerated time to market and shorter life-cycles of products have lead to increasing demands on assembly equipment and concepts. They must achieve a high degree of flexibility with respect to variants, low-cost adaptability of products and quick amortization within a sustainable equipment concept. In order to master these challenges, innovative approaches and technologies are required. The performance of existing automation techniques is often insufficient. As a solution to this problem, hybrid, i.e. human-integrated, approaches are proposed. The idea is to combine human flexibility, intelligence and skills with the advantages of sophisticated technical systems. Such systems should help the human worker instead of replace him. Intelligent assist systems (IAS) offer a rational, advanced method for the assembly of complex products on demand and at significantly reduced cost. Since today neither the technology nor the tools for planning and managing IAS are available, the aim of the project is their prototypical development, including demonstration based on use-cases. One breakthrough of this project shall be to fill the gap between manual and automated assembly by introducing novel IAS technology and providing planning and integration tools to make this new technology applicable. A second breakthrough shall be the re- configurability of assembly systems and the reusability of assembly equipment. On the one hand this is related to a modular structure of assembly systems including standard hardware and software interfaces of assembly equipment. On the other hand, methods and tools are needed for reconfiguration planning, re-programming, life cycle and equipment management and knowledge-bases for assembly solutions. Each breakthrough shall lead to an increase in production capacity and productivity, to reduce the cost of investment and re-arrangement and to react more quickly to market demands.

2 Project Consortium

The PISA project has been coordinated by Volkswagen AG (Germany) and has been formed by 10 companies: Comau SPA (Italy), EADS CRC (France), SENUR Elektrik Mot (Turkey), All-Time-Zones Engineering GmbH (Germany), BGS Bilgisayar Sist. (Turkey), EICAS Automazione S.p.A. (Italy), pi4 Robotics GmbH (Germany), ProFactor Produktionsforschungs GmbH (Austria), Schmidt-Handling Gesellschaft für Handhabungstechnik GmbH (Germany) and Visual Components Oy (Finland); 4 research centers: VTT (Finland), Fraunhofer IPK (Germany, Fraunhofer IPA (Germany) and Fatronik (Spain); and 3 universities: Technische Universität Berlin (Germany), Tampere University of Technology (Finland) and Universidad Politécnica de Madrid-UPM (Spain).

3 Project main objectives

A skilled and motivated workforce still provides the most capable and reliable resource for the flexible (or customized) assembly of complex products. Recent studies have clearly demonstrated that flexibility can be improved by combining the benefits of human capabilities with sophisticated automation equipment in so-called hybrid flexible automation systems, providing a rational advanced concept for producing high-tech products with growing complexity at significantly reduced cost. However, a reliable technological basis for hybrid systems does not yet exist, and the performance of existing flexible automation techniques (e.g. industrial robots) is quite limited in their ability to cooperate with and assist the human worker in a shared and reconfigurable assembly space. The existing standards do not permit workspace-sharing and cooperation.

Therefore, the prime objective of the IP-PISA project is to establish a new generation of modular flexible assembly methodology by developing concepts, formal methods, standards and safety frameworks, tools and underlining technologies to allow integration and cooperation between human workers and highly flexible devices and equipment in a qualitatively new and efficient manner. The main idea is to make a break with traditional paradigms regarding flexibility, cost, accessibility and applicability of high-tech assembly solutions, as well as conventional human-machine interaction. The project development concerns the following next-generation flexible assembly equipment and planning tools:

i. A new generation of passive collaborative robots (COBOTS) and intelligent assist devices. They combine the benefits of industrial robots with those of passive handling devices. They also provide low-cost, operator- friendly solutions for the assembly of complex and variable volume products.
ii. Modular assembly robots, which represent the next generation of sensor-based robotic systems. They integrate visual and compliance control feedbacks, reconfigurable control systems and sophisticated grasping and tooling devices. They are capable of time-sharing with human workers and provide an efficient solution for capacity flexibility when workforce availability is lower or product volume varies.
iii. Assistant robots based on standard robotic systems. They are equipped with additional sensors and control functions and are capable of sharing the same workspace and assembly process operations with a human worker. This approach offers a promising short-term solution for flexible, reconfigurable assembly of highly customized products.
iv. Assembly process design and simulation tools involving the knowledge-base of standardized processes and environmental models; interactive robots and human-in-loop models which allow for a realistic design for assembly, planning and the optimization of assembly system structures and process variations (virtual as-

sembly system). These tools will also be very useful for the training and skill improvement of assembly workers.

v. Reusable and reconfigurable electro-mechanical and control equipment; design and planning tools, including tight interfaces to assembly processes and parameters. This includes concepts and methods, which support the planning and reconfiguration of new-generation hybrid flexible assembly lines for specific production systems and market demands.

The novel technology will be profitable for flexible assembly independently of capacity level or product and variant volume, whether used by SME or large-scale body shops in the automotive, aircraft or household appliances industries.

PISA objectives are shown in figure 1.

Fig. 1. PISA objectives

4 Methodology and work plan

Humans are the most flexible "components" of assembly systems, offering many advantages over machines. Rather than remove human workers and develop fully automated solutions, PISA aims to keep human workers in the loop and to support them with qualified tools. Such an integrative approach combines human creativity, intelligence, knowledge, flexibility and skill with the advantages of sophisticated technical systems and tools, such as electronic and physical power, speed and accuracy.

The scientific and technical work project plan has been set up in 9 different and interrelated Subprojects (SP) (see Fig. 2).

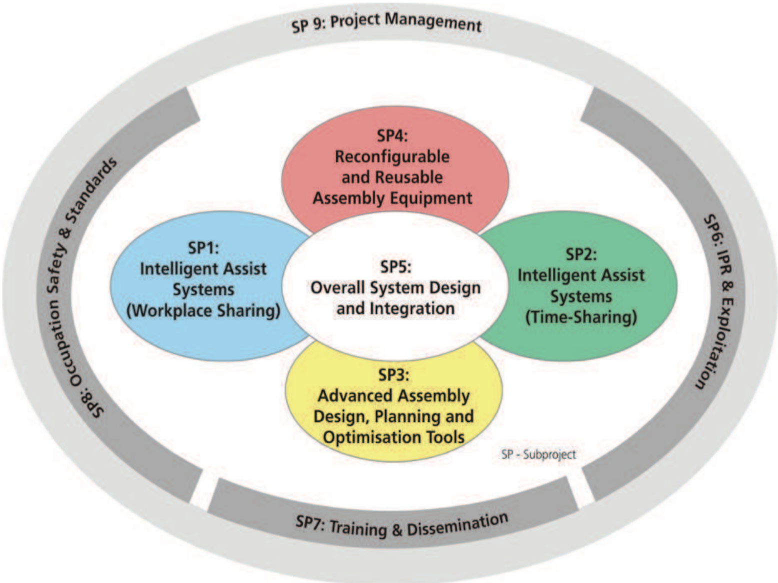

Fig. 2. PISA Subprojects structure and relationships

5 Robotic industrial demonstrators

Several robotic industrial demonstrators have been developed in PISA project. The objective is to apply IAS systems to several industrial sectors where humans and robots collaborate in different ways.

5.1 Demonstrator 1: Workplace-sharing scenario

The first demonstrator is based on new collaborating robot (COBOT) and it is capable of working jointly in a direct physical contact with the human operator. The Cobot system is based on a typical handling system, as it has been realized, tested and demonstrated in a typical example of car windscreen mounting system (Fig. 3).

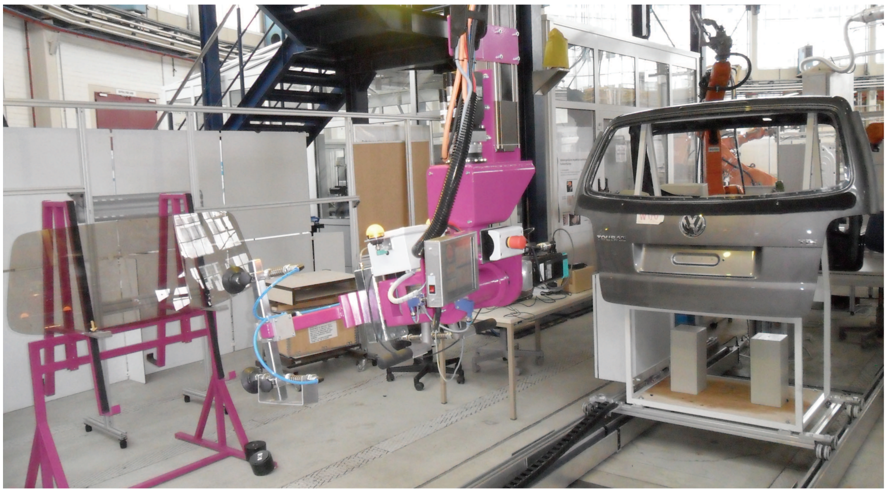

Fig. 3. Demonstrator 1 scenario

The Cobot prototype is based on a free standing structure consisting of a steel frame. This frame has the dimensions Length x Width x Height = 6 m x 4,5 m x 4 m. The Cobot can operate within an area of about 4,7 m x 2,4 m including a travel in Z-direction of about 1,3 m.

The Cobot has five powered axes driven by servo drives. The axes are the X-, Y- and Z-axes, rotation about the Z-axis and pivoting up and down of the end effector.

The end effector consists of a gripper with four spring loaded vacuum cups. It is designed to handle the front windscreen and the rear window of a passenger car that weights about 20 kg each.

The main human machine interface is a touch panel PC that provides a graphical user interface (GUI) that allows to start the Cobot, to program it, to switch between different modes and to provide user interfaces for different operators who have more or less limited access to the Cobot control.

The cobot control system (CCS) represents a central part of the Cobot prototype (Fig. 4) that integrates all system modules: the cobot mechanical part with digital drives (communication has been realized by EtherCAT), safety controller, assembly planning and programming environment and human-machine interface. The cobot controller provides a sophisticated PC based control system (running under Windows CE and integrated in the Beckhoff TwinCAT real-time environment) providing high level (at action-layer) robot/cobot programming and sensor-based control functions (compliance control, haptic rendering etc.). A special safety controller monitors all system components and human-operator caring for human and environment safety. The safety is not provided, as an add-on by the safety controller, rather is an intrinsic part of each module, which includes internal safety monitoring and exception handling functions. The safety controller provides additional system safety functions enabling the human operator to come into the robot-workspace in order to realize a task (e.g. interactive windscreen fine-positioning and final assembly). This system integrates additional safeguarding sensors (e.g. laser scanners) and via direct interfaces with the robot controller has the possibility to slow done, hold, stop robot motion or to start a reflective safety action (e.g. stop current motion and starting moving the robot in a contrary direction or to home position).

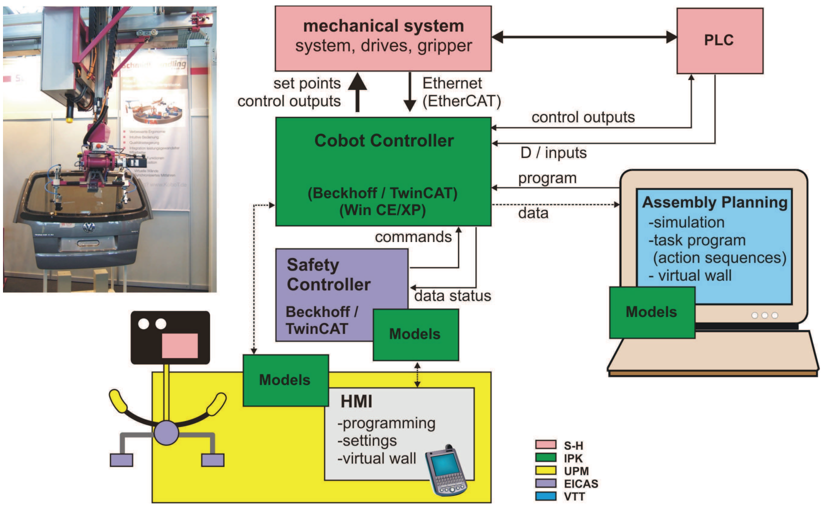

Fig. 4. Cobot control system architecture

The relevant external sensors integrated in the Cobot system are force-torque sensors supporting the control human-robot-environment interaction. Two F/T sensors are implemented: 6 DOF compliant sensor for human-robot interaction (manual guiding) integrated in the hand-grasping interface and 1 DOF contact for the contact detection and monitoring.

5.2 Demonstrator 2: Assistant robot

This demonstration scenario consists in a mobile platform equipped with a low weight industrial manipulator (Fig. 5). The system has been applied to the aeronautical sector developing a semi-autonomous system for riveting segments in a commercial airplane structure (Airbus A320). A special tool for drilling and riveting has been developed.

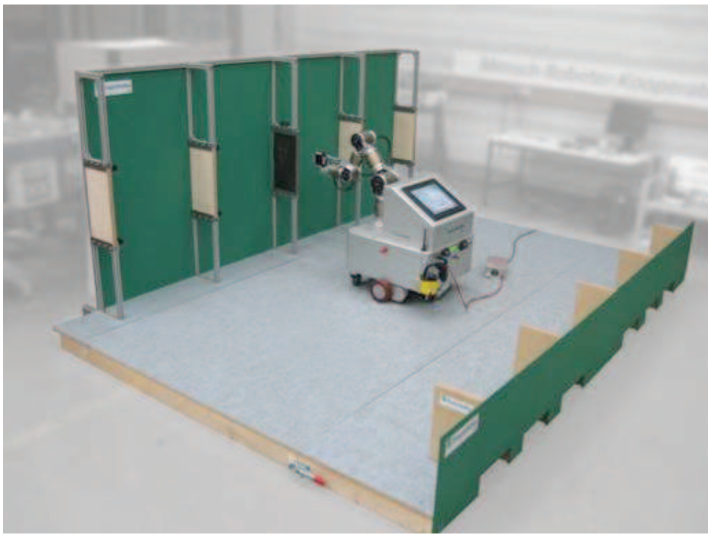

Fig. 5. Assistant robot scenario

5.2 Demonstrator 3: Time-sharing scenario

The last robotic demonstrator of the PISA project is a robot system that allows a Time-sharing work procedure, where a dual arm robot can share the working time with human operators.

A typical assembly operation of a vacuum motor has been chosen to test the system. Simultaneous collaboration between human operators and the robot is also allowed and the human can assist the robot task directly.

The dual arm robot is designed as an anthropomorphic upper-body system (Fig. 6) consisting of a mobile platform, fixed trunk and head, and two arms each with 7 rotational joints. In the PISA project the trunk and head will be fixed, while in following-on developments additional rotational degrees of freedom will be integrated for trunk rotations a pan-tilt head camera.

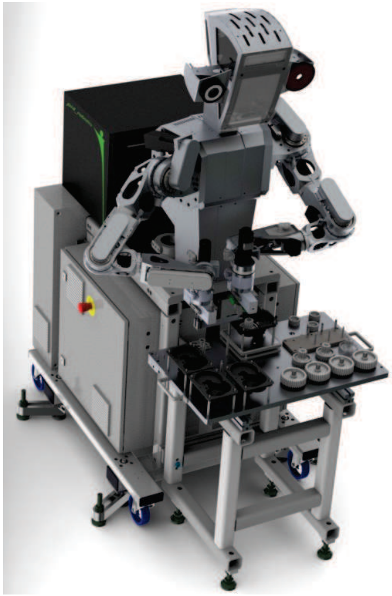

Fig. 6. Time-sharing scenario

The dual-arm robot can be programmed using a very intuitive, fast and easy to use GUI based on a touch screen and drag-and-drop program construction. Figure 7 shows an example of a robot program

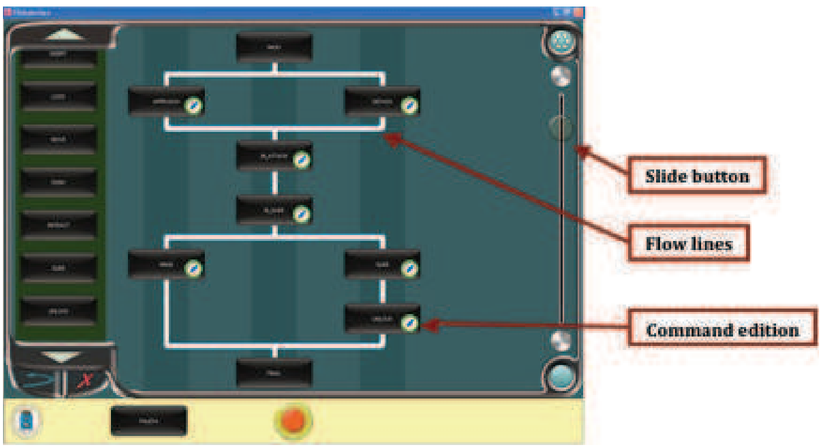

Fig. 7. Example of dual-arm robot program

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CHAPTER 6

AERIAL MISSION IN RHEA PROJECT

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The RHEA project is based on the cooperation among aerial and ground vehicles aiming at performing precision agriculture tasks, namely weeds removal and trees fumigation. More precisely, this work is focused on the description of the aerial mission in the mentioned project. The work includes a description of the units, the goals and mission types, the requirements involved in the mission planning as well as their supervision and monitoring. The missions are performed by using a fleet of last-generation hex-rotors that rely on high payload and extraordinary stability. These features allow taking steady pictures with high quality cameras in large extension fields. As result, high-resolution images of the field to cover are obtained in order to provide with weeds pots positions to ground units for their removal.

1 Introduction

The **R**obot Fleets for **H**ighly **E**fective **A**griculture and Forestry Management (RHEA) project was carried out under the 7th framework program, identified as NMP-CP-IP 245986-2. It finished on July 31th 2014. RHEA was focused on the design, development, and testing of a new generation of robotic systems for both chemical and physical (mechanical and thermal) effective weed management. The project was focused on both agriculture and forestry.

RHEA scope covers a large variety of European products, such as agriculture wide row crops (processing tomato, maize, strawberry, sunflower and cotton), close row crops (winter wheat and winter barley) and forestry woody perennials (walnut trees, almond trees, olive groves and multipurpose open woodland). The project aimed at reducing the use of agricultural chemical in a 75%, improving in that manner the crop quality that directly affects health and safety for humans. Moreover, this reduction in chemicals is reflected in production cost costs.

The sustainable crop management showed in RHEA by using a fleet of small, heterogeneous robots (ground and aerial) equipped with advanced sensors, enhanced end-effectors and improved decision and control algorithms falls within an emerging area (i.e., precision agriculture) of research and technology with a large number of applications

As previously mentioned, the key elements of the project are both the ground and the aerial fleets. Ground fleet is made up of three small tractors endowed with different tools so as to perform singular treatments (mechanical, chemical and thermal treatments). On the other hand, the aerial fleet consists of two hex-rotors that are in charge of carrying out aerial mission. The roll of the drones (aerial units) is focused on aerial image capturing. Therefore, they are required in order to take high-resolution multi-spectral pictures of the field from a high point of view. The pictures taken from aerial units are used for creating geo-referred mosaicking.

Agricultural experts are in charge of obtaining the position of the weeds pods by using this mosaic and advanced image processing computer algorithms. This information is the input for the ground units mission planner. Thus, considering the position and size of the targets (weeds) and the crop rows directions, the mission manager is able to define the optimal path for the ground units in charge of removing the weeds without damaging the crop.

All this information processing, which starts when downloading the pictures from the cameras cards so as to combine it with the information provided by drones during the flights for mosaicking creation, the weeds detection and ground vehicles path planning is performed by a Base Station computer. It is also in charge of sending the missions to tractors and the full mission supervising and monitoring.

The work presented is organized as follows. Next section is dedicated to describe the aerial units. Section 3 summarizes the definition of the aerial mission and its requirements. Section 4 describes how the problem was tacked and the results obtained. Finally, the conclusions and lessons learned during the project are presented in section 5.

2 Aerial Units description

The aerial vehicles that are in charge of performing aerial missions in the RHEA projects are the AR200 units (see **Fig. 1**); designed and currently commercialized by AirRobot company, which was the RHEA partner in charge of developing a drone capable of performing the mission according to the requirements stabilised by the experts in weeds detection.

Fig. 1 AR200 drone after taking off.

Finally, the AR200 turned out to be a six-rotor drone with a payload that depends on the battery required for the flights. Thus, two different setups were considered. The lightest battery allows a payload of 3 kg whereas the heaviest one allows 1.6 kg with a flight duration about 40 minutes in both cases. The MTOW (Máximum take-off weight) is 10 kg. This feature allows considering the drones as a capable of flight without requiring to be registered according to the Spanish regulation by AESA.

The drones rely on digital data transmission and control on a real-time basis that allows operating them up to a distance of 5 km. The GPS onboard features a CEP accuracy of 2.5m. An important advantage of the drones is their innovative folding system that allows a space-saving and comfortable transport to the field.

It is worth noting that a drone configuration with six-rotors allows certain redundancy. Thus, the drone will rely on the full manoeuvring capability if one of the motors fails. This feature is essential to reduce the damage to the drone or third parties in case of failure.

The drones are endowed with two cameras pointing downwards (**Fig. 2**), which capture visible and near infrared spectrum. They are mounted on a gimbal system in order to reduce the detrimental effect of vibrations on the high-resolution images obtained. This non-sophisticated mechanical system turned out to be very effective because the pictures are always acquired during hovering manoeuvres on the previously defined waypoints in a quite steady configuration.

Fig. 2. Perception system on-board the drone

Drones are able to carry out a mission defined by using a sequence of 3D way-points (latitude, longitude and height with respect to the take off position) and perform several actions on the payload in those points in a fully autonomous manner. Nevertheless, take off and landing have to be performed in a supervised mode. Thus, after loading the mission into the drone, a pilot (required by the UAV regulation) is in charge of commanding the drone during taking off manoeuvre. It is worth noting that a low-level attitude control is permanently in charge of drone stabilization (i.e., controlling the speed of the six motors). Therefore, the pilot merely provides vertical control commands. Once the drone reaches a safety height, the fully autonomous mode is enabled and the operator is able to start the mission just by pressing a button.

After finishing the missions, drones return to their home points and keep in hovering until the pilots take the control. Consequently, they have to send the orders for descending in a safe way. This operation is crucial, since the drones do not rely on perception sensors that allow detecting small stones allocated on landing position that could damage the cameras. Even if landing pots were carefully cleared, small errors in GPS could generate deviations from the pots that would result in damages for the sensors.

Drones provide telemetry information during the flight for supervision purposes, such as position estimation and battery level among others by using a specific hardware denoted “BKS” that is connected to the ground station computer by using USB connections and a proprietary protocol. This hardware ensures the communication to the drone not only for autonomous supervision (flight program downloading and parameters setup) from base station but also from manual control by using the remote controller by the drone manufacturer.

3 Definition of the mission and requirements established

The first step in mission definition should be performed by using the GUI (Graphical User Interface) provided by the base station computer. Unlike commercial systems where only rectangular working areas can be defined, the aerial mission of RHEA should be applied to any field shape.

Thus, the user is able to define the field to be studied in the mission by clicking several points on the screen with the aid of graphical tool. These points represent the vertices that describe a polyline that has to delimit any unshaped but closed polygon. Each point of the polyline contains its three UTM (Universal Transversal de Mercator) coordinates. The coordinates can be obtained from a geo-referred image if available. The planner was successfully checked again databases of fields with different sizes and shapes.

The aerial planner also allows defining areas where drones do not have to fly over. Firstly, in order to take into consideration some safety issues such as proximity of roads or inhabited zones next to the field, two additional polylines have to be introduced as safety borders. The area lying between the two safety borders will be considered as the area that occasionally it is possible to fly in order to take pictures whereas the outer border will define the area where drones are not allowed to enter. Obviously the field definition has to fall inside the inner boundary.

After defining the working area, and taking into consideration that drones of the fleet will perform their task simultaneously, the next step in the process should be the area repartition. It is worth noting that although all the real test in RHEA were carried out by using the two available drones, the software does not impose any limit to the number of members in the fleet.

Several approaches were developed during the project execution by the research group regarding area repartition according to different criteria, such as different endurance or battery level of drones (Valente, 2013 A-B). Nevertheless, the main criterion considered in the RHEA project was the safety. Considering that the drones do not rely on any collision detection system on-board and the safety falls on the backup pilot and mainly on a right path planning, the goal was to maintain the drones as far as possible from each other during the mission. It should be clear that since the cameras of the drones had the same resolution and focal parameters, the drones had to fly to the same height. This issue was crucial in the determination of the algorithm used for mission planning. The area repartition will be detailed at the end of this section.

On the other hand, nearly all the requirements of the mission arise from the spatial resolution required by the experts in weeds detection for creating the mosaic (i.e., 1 or 2 pixels/cm) and the cameras used (Sigma DP2 Merrill Compact Digital Camera). Accordingly, considering the resolution of the cameras: 4800x3200 pixels, each image would cover an area of 48x32 meters. Nevertheless, this theoretical value is reduced in practice in order to be successful on performing the mosaic. Thus, small errors in stabilization (i.e., attitude values different that zero for Roll, Pitch or Yaw angles during the camera shooting) and errors in position estimation due to the not-very-high precision of the single GPS shipped on the drones or simply control errors (i.e., difference between desired and obtained position) will displace the area actually covered with respect to the desired one. Therefore, a certain level of overlapping among contiguous images is required.

Moreover, this requirement of overlapping was increased so as to consider the unevenness of the fields. Accordingly, every point in the parcel has to be seen from at least two different points of view (two contiguous images) in order to build a 3D digital surface model.

The partner in charge of the mosaicking decided to use the open-source solution Micmac for ortho-rectifying and combining the images in a fully autonomous process. Finally, a value of 60% was established to fulfil of the requirements. This value directly reduces the theoretical maximum size of the pictures and determines the distance among waypoints along two planar dimensions, which are the points where the drone has to take the picture that finally was established in 19 meters.

Since a 3D model of the field was considered, the flight altitude, which depends on the altitude of the ground and the distance required to obtain an image with a specific resolution, is not constant. An estimate of the altitude of the ground in each waypoint was obtained by using an interpolation method with the points of the border defined by the user, whereas the distance to the ground (height) was determined by using the camera parameters. Thus, with a focal length of 30mm and a sensor size of 23.5 x 15.7 mm, a height close to 60 meters is obtained.

The last requirement established by the mosaic process was not to displace the pictures in order to optimize this number. Thus, the solution should have a matrix structure of waypoints (i.e., points separated nineteen meters where the drone has to take a picture) where not all the points will be required to take a picture (it will depend on the shape of the field).

4 Solution of the problem and results

The problem set up turned out to be not a simply one. Thus, it was tackled in two phases. Firstly, an optimally aligned SAER (Smallest Area Enclosing Rectangle) problem has to be solved. This problem is addressed in

(Valente, 2014). The second phase is to obtain which are the points of interest, since not all the points in the matrix are required to cover the full area.

Once all the required waypoints have been obtained, a path for each aerial unit in charge of performing the coverage has to be designed by the planner, considering their take-off and landing positions chosen by the user taking into account the restrictions to the access to the field, proximity to base stations and others safety issues.

Therefore, the objective for the planner is to create optimal paths. The optimality concept should involve not only performance criteria such as avoiding duplicated images or minimizing the execution time of the global mission but also safety issues.

Several techniques were tested in order to design an optimal path for a fleet of drones in charge of performing aerial coverage during the project (Valente, 2013 a y b). Nevertheless these solutions showed some shortcomings, mainly regarding their required processing time and the difficulty to implement time dependent safety criteria in their cost functions. Due to this, a solution based on back and forth motions was finally selected. The proposed solution has very low computational cost, performing the planning in real time without the necessity of long optimization process, which becames high time consuming.

Moreover, this solution allows addressing in a simple way the safety requirements of the mission: To maximize the distance among the drones during its execution. This is achieved by splitting a global path into "n" parts, being "n" the number of aerial robots available for the mission. Moreover, in order to maximize the distance, the back and forth motions are completed along the shortest dimension of the matrix. This criterion maximizes the number of the changes in direction, which is not a problem for a holonomic robot, but increases the geometrical distance among vehicles. Furthermore, when small areas are considered (in those cases, it does not compensate using a fleet), an additional safety criteria is to assign only full columns in the matrix to drones. In this manner, two drones will never fly along the same column simultaneously.

Finally, the number of waypoints assigned to each drone is modified depending on several factors, such as the initial and final distances travelled by the drones from and to their correspondent take off and landing positions or differences in battery level.

Since cameras used in RHEA require a long time for image saving into the memory card, a minimum time is required between shootings, and therefore between consecutive way points, in order to ensure that all the pictures are correctly stored. This time is controlled by planner by introducing delays in each way point.

An example of the resulting path for a mission of two drones in the CSIC facilities in Arganda del Rey (Madrid), where RHEA demonstration took place is shown in **Fig. 3**. Unfortunately, when RHEA final demonstration (May 2014) took place, a transitory regulation forbade the flights in Spain and it was no possible to obtain the corresponding permissions from AESA (Spanish Aerial Security Agency). Nevertheless, six five moths before, there was a winter demonstration to the European Commission and then it was possible to show the fully operational capability of the aerial system.

Fig. 3. An example of mission planning for two drones in CSIC facilities in Arganda del Rey (Madrid) where RHEA demonstration took place.

The planner was coded by using C++ language. It is designed allowing multi-platform compilation. Nevertheless, it currently runs under windows 7 operative system that was the OS selected for all the ground station development in order to execute all the process in a single computer.

Some other software modules were created in order to communicate with the drones and supervise the mission. A fully description of these modules can be found in (Cerro, 2013). The modular solution considered allows changing the drones used in the project in future applications just by changing the AUHLC (Aerial Unit High Level Controller) that acts as a "driver" for the units used.

5 Lesson learned and conclusions

Although nowadays UAVs are quite common tools, this project showed that there is a gap between commercial systems features and the real missions or applications for final customers. Carrying out this project allowed to cover the gap in aerial covering by performing a serious research work and providing with optimal tools to operators in charge or performing aerial coverage by using drones. The modular solution allows using the mentioned tools with other manufacturers of drones.

Acknowledgements

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Authors would like to thank all the RHEA partners, specially AirRobot for their collaboration in the project.

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CHAPTER 7

EFFECTIVE INTEGRATION OF AERIAL AND GROUND AUTONOMOUS VEHICLES TO ADDRESS AGRICULTURAL TASKS

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This paper presents the most relevant aspects of the Mission Manager, i.e. the system of the European project RHEA in charge of the full integration between the monitoring/inspection carried out by the aerial units of the fleet and the intervention/treatment carried out by the ground units. The end result is a system which allows executing an agricultural treatment task in a totally automated way, reporting in real time the status of all elements involved in the mission.

1 Introduction

Safe and effective control of weeds according to the principles established by the Precision Agriculture requires specific, advanced and reasonable cost technology. Using autonomous mobile platforms, both ground and air, equipped with innovative systems of perception, intelligent decision-making systems and tools that allow precise herbicide application can reduce the cost associated to the agricultural task, the potential damage to the environment and the risk for farmers.

The main objective of the RHEA project (Robot Fleets for Highly Effective Agriculture and Forestry Management), funded by the 7th Framework Programme of the EC was to design and develop a fleet of small/medium robots for both inspection (aerial units) and treatment (ground units) to minimize inputs (agrochemicals, fuel, etc.) while guaranteeing the quality and the safety of the yield. The RHEA proposal reduces the impact on soil compaction and interacts more safely with operators, because the fault detection and the interaction between vehicles and operator can be distributed in various detection and fault management systems.

This article presents the design, development and evaluation of the highest level of the RHEA architecture: the Mission Manager. Using the Mission Manager, a single operator can define the characteristics of the treatment, such as the type of crop, the type of task, the location, etc.; then the system allows linking the different steps to carry out the agricultural work in a fully automatic way, reporting in real-time the status of any element of the fleet involved in the mission.

The most important aspects of this system, which runs on the computer in the Base Station where the operator is also located supervising the work, are explained in the following sections.

2 The Mission Manager

The Mission Manager is designed to be a general proposal to integrate aerial and ground robots in those scenarios, common in environmental issues, which benefit from a first stage of monitoring and damage assessment, and a later stage of intervention aimed at alleviating the problem. In these cases, monitoring/assessment can be performed with aerial vehicles especially when the areas concerned are very extensive, and intervention with ground vehicles, since in most cases the solution requires a localized action with specific and heavy equipment. The modules proposed to integrate the Mission Manager are as follows (see Figure 1):

- Two planners, one for the aerial mission and the other one for the ground mission, which take into account the characteristics and limitations of each type of vehicle and mission.
- Two controllers, each dedicated to coordinate the vehicles as a fleet, for example to launch/pause/resume/stop the mission on all vehicles simultaneously. These modules are also responsible of recoding the plans using the repertoire of operations supported by the vehicles as well as retransmitting the new plans (sub-plans) to the different robots involved in the mission.
- A supervisor for the aerial mission and another for the ground mission, to guarantee that the units are accomplishing the tasks according to the plan generated and, if not, notify it by alarms.
- A system for processing data obtained during the inspection mission to generate new useful information for the later treatment mission.
- A dispatcher that encapsulates the connections to all the modules included in the Mission Manager. This module processes and redirects

queries from external systems, through the user interfaces (GUI), and manages the workflow. It is particularly important as it allows connecting to new modules to extend the Mission Manager functionalities.

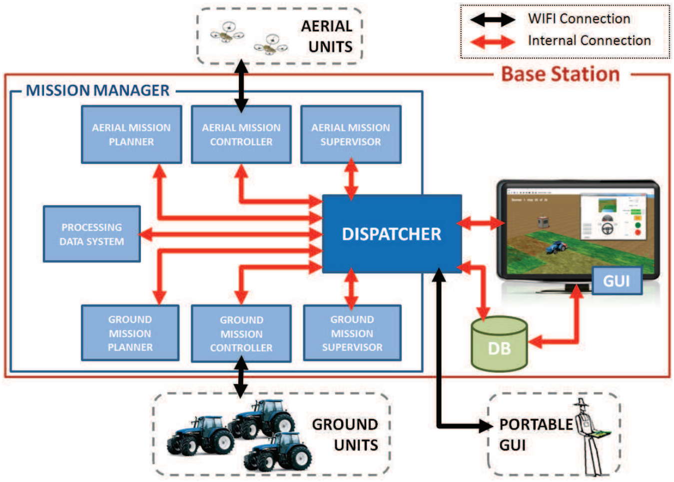

Figure 1. Internal structure of the Mission Manager as well as external systems with which it can interact.

The external systems that can communicate with the Mission Manager are the following:

- A graphical user interface (GUI) so that the operator can make requests to the Mission Manager, such as planning, mission execution, mosaics, remote control of a unit, etc. Furthermore, it displays the tracking of the requests and the information about the elements of the fleet during the mission execution.
- A portable GUI to be used in certain situations, such as breakdowns, equipment tests, etc., which require the presence of an operator in the field. The operator should be able to move through the field while he receives information from the mission and, of course, being able to take control of some vehicle, if it is needed.
- The fleet vehicles (drones and autonomous tractors) responsible for performing the tasks.
- A database (DB), where structured information of interest to the missions is stored, such as the field borders, the units' features, the treatment types or the data generated during the execution of the mission.

Sections 3 and 4 describe the mission controllers and the dispatcher, respectively. While section 5 gives some general details of the development of the Mission Manager for RHEA, in particular, about the planning, supervising and data processing systems.

3 The Mission Controllers

The proposed mission controllers automate the execution of missions through a high-level layer built based on the basic operations supported by the robotic units. In other words, it allows saving the gap between planning and supervision, automating the cycle planning-execution-supervision. Specifically, the controller is responsible of decomposing the mission plan in as many sequences as units are involved in the mission. The sequences, also called sub-plans, contain simpler and more understandable commands. A sub-plan example is: 1) connect to the unit, 2) initialize it to execute the mission, for instance, setting the origin of the coordinates, the Base Station position, etc., 3) send the sub-plan, 4) verify that it is successfully received 5) wait until the mission is accomplished, 6) stop the unit, 7) confirm the unit is actually stopped, and 8) close the connection.

Since the automation sequences of mission controllers depend on events caused by many systems, such as requests from the GUIs, communication timeouts, confirmations from the units, connection errors, etc., as well as by previous events, such as if it has completed a similar request, if it is already connected, if a response was received, etc., we can conclude that the mission controllers are reactive systems (Harel & Pnueli, 1985). Therefore, their behaviours are difficult to be predicted because, at every moment, they respond to multiple asynchronous events based on their current state obtained from the previously received stimuli. The behaviour of reactive systems is complex to analyze what makes them very prone to failure. Thus, it is essential to make a careful design, especially when they interact with potentially dangerous elements, as in this case where the tractors, including tools, can weigh a ton.

The main problem in the design of reactive systems lies in the difficulty of specifying the reactive behaviour in a formal and rigorous manner. One solution is to use state diagrams to design and develop these kind of systems, such as those based on the *statechart* model (Harel, 1987), since the semantic richness of this model allows getting understandable visual representations. Therefore, assuming a set of basic operations common in drones and ground robots, as shown in Table 1, the state diagram for a generic mission controller, as the proposed, is presented in Figure 2.

Table 1. Basic operations considered for the units.

Operation	Description
Initialization	Set the initial configuration of the unit
Actuation	Actions on the unit (displacements, speed changes, tool activations, sub-plan executions...)
Pause	Interruption of the current operation, keeping the same state until it arrives a resume command
Resume	Resume the unit activity and the operation left paused
Stop	Stop the unit movement and any of their devices
Disconnect	Close the connection from which the request has been made

The high-level commands, in red in Figure 2, are the following:

- Launch a mission: The controller establishes communication with the units and sends the corresponding sub-plan to each one. When a unit starts executing the assigned sub-plan, the controller emits the *launched* signal and changes its state to *running* state. If no unit starts, the controller emits the signal *not launched* and returns to the initial state.
- Pause a mission: The controller send a *pause* command to all units and change its state to *paused* state after checking that all vehicles have fulfilled the order. Otherwise, the controller outputs the signal *not paused* and remains in the *running* state.
- Resume a mission: The controller instructs all units to continue the execution paused. The controller returns to the *running* state when at least one unit resumes the execution.
- Stop a mission: The controller sends a stop command to all units. When all units perform this command, the mission ends, the connections are closed and the controller returns to the initial state.
- Close connections: This command is responsible for closing all open connections when the units are already stopped.
- Take control of a unit (for remote operation): This command lets the operator takes the control of a unit of the fleet that is involved in the mission. The controller stores the remaining sub-plan before stopping the unit. The unit is no longer considered part of the fleet.
- Release a unit: This command returns the unit to the fleet. The unit resumes the sub-plan stored by the controller when the unit was taken for remote operation.
- Run Command (for remote operation): This command allows an operator to directly send commands (displacement, devices setting, etc.) to a unit that is no longer part of the fleet and, therefore, is not involved in the mission.

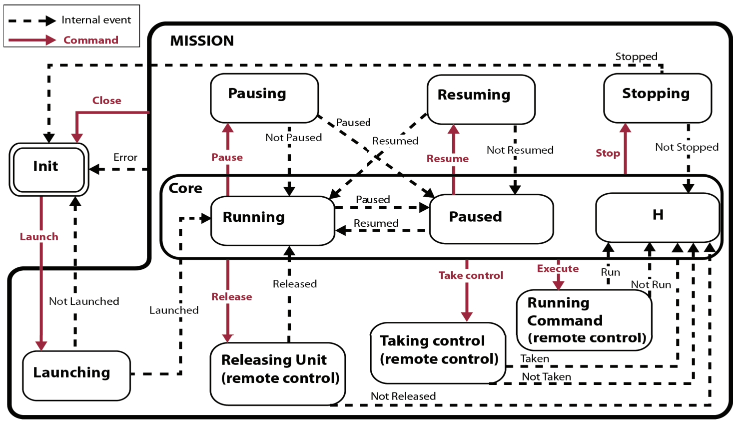

Figure 2. State diagram of a mission controller

Also, since many of the commands act on the entire fleet (launch, pause, resume, stop and close), the controller must keep a track of each unit state, to determine when the internal signals or events that change the state of the mission are occurring, dashed lines in Figure 2. Some of the proposed controller commands must be broken down into a sequence of several commands. This is the case of operations, such as the launch of a mission and the release of a unit, resulting in two requests; first the initialization of the unit and second the sending of the mission sub-plan. It is therefore necessary to create a lower-level layer formed by three controllers, one per unit, called unit controllers for a mission. These controllers are responsible for interpreting the orders of the mission controller and recode them based on the command repertoire of the unit. Figure 3 shows the state diagram of one of these controllers that is very similar to that presented in Figure 2. The main difference is that internal signals, in dashed line, now are independent on the fleet and depend on the unit. In addition, operations *launch* and *release* are separated into several steps to express in terms of low-level operations that can be run in the units.

Finally, it is needed to create a final layer to provide a confirmation service of the order executions, because units, in general, are only able to confirm command receipt without guaranteeing their execution. This new controller (see Figure 4) implements the confirmation service based on two facts: 1) the units are able to report the command receipt by an ACK and 2) the units periodically produce certain status information that is used in the fleet supervision.

Through this layering of different complexity is possible to build a generic high-level controller for missions, able to govern a fleet of several units with ease and precision in the response, the latter thanks to the confirmation service included in the proposal.

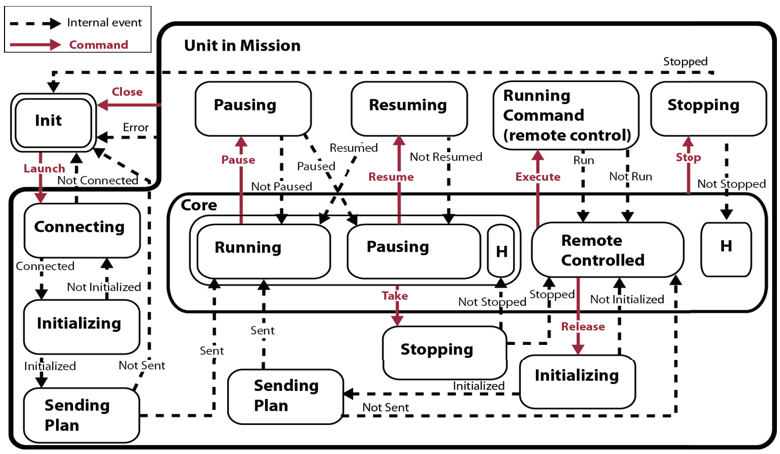

Figure 3. The state diagram of a unit controller for a mission

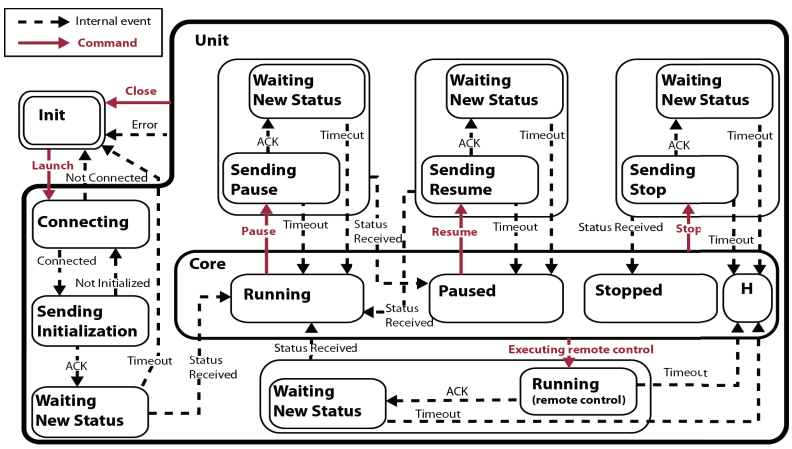

Figure 4. State diagram of the basic controller of a unit.

4 The dispatcher

The dispatcher is the distributor module of the Mission Manager. It contains the logic needed to redirect requests coming from the GUI or the portable device, creating the communication channel with the target module. It concentrates all communications with the internal systems of the Mission Manager by building a layer of abstraction that can replace any of the systems without having to make changes in the interfaces. The proposed dispatcher's workflow can be expressed by the state diagram shown in Figure 5.

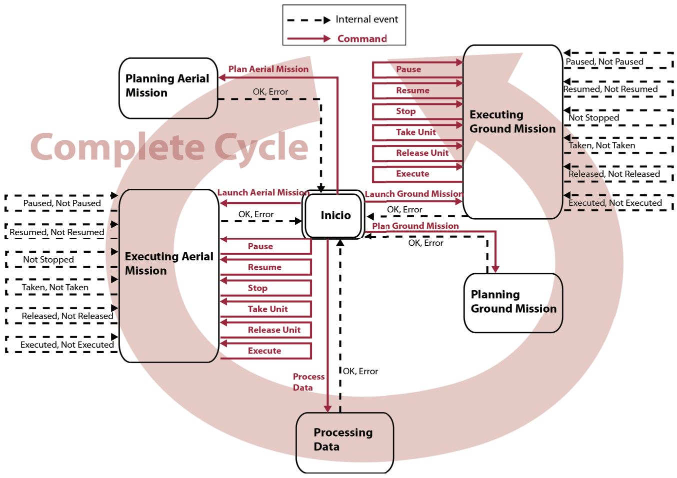

Figure 5. State diagram for the dispatcher.

Among the states associated to the planners (aerial and ground) and data processing, only it is needed to call the relevant systems and wait for the response. On the contrary, within the states associated to the missions, both the mission controllers and mission supervisors are employed. All information provided by controllers is redirected to the supervisors for being analyzed and detect any anomalies. Note that if the full cycle is executed, the aerial and ground missions are properly combined.

5 Implementation for RHEA

The Mission Manager developed for the RHEA fleet is based on the generic model outlined in the previous section. The aerial planner (Valente, Del Cerro, Barrientos, & Sanz, 2013) and the aerial mission controller and the aerial supervisor (Del Cerro, Sanz, Valente Rossi, Cancar, & Barrientos, 2014) were integrated in the Mission Manager architecture. These modules were able to handle the RHEA aerial fleet that consisted of two drones equipped with two cameras, visible and near infrared. The drones received the flight sub-plans, a list of waypoints, and they provided, during the flight, the telemetry information needed for the supervision, as well as location and the battery level.

For the ground missions or treatment missions, three modules were integrated in the Mission Manager architecture: a ground planner (Conesa-Muñoz et al. 2015a), a ground supervisor (Conesa-Muñoz et al. 2015b) and a ground fleet controller implemented from the concepts outlined in section 3 and by using the state machine environment provided by the Qt libraries (Qt Libraries, 2015). The three modules were generic and were adjusted to work with the ground fleet of RHEA formed by the three robots described in (Emmi, Gonzalez de Soto Pajares, & Gonzalez-de-Santos, 2014)

In addition, the overall system was tested by spraying weed in wheat, for which it was needed integrating the data processing module, i.e. 1) the mosaicing system (Rabatel & Labbé, 2015) in charge of the composition and the orthorectification of the photos taken during the aerial mission, and 2) the mapping system that detects and geo-references the weed patches (Peña-Barragan Torres-Sanchez, Castro, Kelly, & López-Granados, 2013). Finally, the dispatcher module has been also implemented using the Qt state machine environment and the proposal presented in section 4.

6 Conclusions

In light of the results obtained (see the numerous publications generated and the videos of the demo days in http://www.rhea-project.eu/), it can be concluded that the Mission Manager proposed, and implemented for the RHEA fleet, effectively integrates inspection tasks carried out by a fleet of unmanned aerial vehicles with the intervention tasks made by a fleet of unmanned ground vehicles. The Mission Manager also provides the means to allow single operator monitoring, in an effective way, all the elements of a fleet of robots that work together in a crop.

Acknowledgements

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CHAPTER 8

THE UC3M CONTRIBUTION TO "STAMAS. SMART TECHNOLOGY FOR ARTIFICIAL MUSCLE APPLICATIONS IN SPACE."

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The aim of the STAMAS FP7 project is to create an innovative exoskeleton for astronauts to improve exercising activities inside the spacecraft and to assist the astronauts during Extra-Vehicular Activities (EVA). The device will be formed by different actuating systems based on smart materials working as artificial muscles. Shape Memory Alloys (SMA) and Electro-Active Polymers (EAP) are the technologies that are being explored for the development of actuating systems. The actuating systems will be controlled according to the biological parameters measured from the user and the information provided by sensors placed in the space suit.

This project is funded by the EU 7th Framework Program. The STAMAS consortium is formed by 6 partners from four different countries leaded by "Arquimea Ingenieria, S.L.". Some of the most excellent research centers in Europe participate in the project: DLR (Aerospace Research Center from the German Space Agency), ETH Zürich, Interdepartmental Research Center "E. Piaggio" of the University of Pisa, and RoboticsLab of the Carlos III University of Madrid. Sensodrive GmbH. is a German private company that is also involved in this project.

1 Introduction

When astronauts return to Earth after a long period in space, their organism shows several signs after living in microgravity, such as loss of muscles mass and bones density, increase of body length, blood distribution problems, heart dysfunction and orthostatic intolerance. Other functions such as proprioception or the capability to react quickly to recover body stability are also degraded by the effect of microgravity.

Currently, on the International Space Station (ISS), countermeasures are taken in the form of exercise plans to prevent the severity of the symptoms. These plans include three phases comprising pre-flight, in-flight and post-flight exercise programs in order to prepare, maintain and adapt the astronaut's physical condition during the whole length of the mission. A leg exoskeleton has been developed in this project for the exercising during in-flight phase.

A further problem encountered by astronauts on the ISS occurs during EVA. EVA performed by astronauts are limited by several factors. One of these limitations is the duration of the space walks due to the hand fatigue that astronauts suffer when performing manual tasks. This fatigue is mainly caused by the stiffness of the spacesuit gloves. The gloves are internally pressurized, as the rest of the spacesuit, to protect the astronaut from the vacuum of Space. The pressure inside the gloves increases the stiffness of each joint of the glove, making the astronaut to exert great forces to overcome this stiffness and mobilize the fingers.

In addition, the astronaut has to operate tools or other installations which have to be carefully designed to be gripped or handled in special ways. The resistance force of the glove due to air pressure and stiff materials and the additional space and distance between the fingers and the grasped object translates in loss of touch feeling and dexterity. Thus, the astronaut has to fight against high forces when performing manipulation tasks during spacewalks. These forces disturb the intended tasks thus reducing efficiency, and causing dramatic fatigue of the astronauts' hands and fingers. A hand exo-muscular system demonstrator has been developed with the aim of assisting the astronauts in these manual tasks, reducing the extra amount of force required to move their hands.

STAMAS is an European Project developed by Arquimea Ingeniería, DLR, ETH Zürich, Sensodrive, Carlos III University of Madrid and University of Pisa. The main contributions of the UC3M to the STAMAS project are detailed in the rest of this document. Some recent advances have been published in (Villoslada et al., 2014), (Villoslada et al., 2015).

2 STAMAS project objectives

The overall objective of the project is to analyze the suitability and bring experience on the SMA and EAP based actuation technologies addressing terrestrial applications to research in new concepts of artificial muscles for biofeedback suits for astronauts, as an alternative to currently used technologies. To this end, the project team proposes to focus on designing, developing and testing both a lower and an upper limb biofeedback suit demonstrator. Such demonstrators will incorporate two different types of artificial muscles subsystems in complementary configuration in order to attack the different pathologies originated due to microgravity (muscle atrophy, bone loss, and shifting of blood from the limbs to the chest and head). In practical terms, a biofeedback leg and hand will be developed. These parts of the human body have been selected for being the most critical and representative – in terms of engineering complexity. In other words, a successful demonstrator of those devices will for sure represent an important achievement for the design and development of the whole intelligent suit.

2.1 Specific STAMAS objectives

The specific objectives of the STAMAS project are listed below:

- To generate the scientific basis to provide a smart suit for on-board spacecraft use which is able to control, mitigate and even treat the health problems that could arise owed to microgravity and lack of mobility, as well as to the stiffness of the space suit during EVAs.
- To bring experience on SMA/EAP technologies in the space domain, adapting the existing terrestrial technologies to space domain contributing to the substitution of conventional actuators.
- To adapt and develop sensors to be embedded in the suit for the control of the mechanical behavior of the suit and its actuators.

- To develop a control architecture able to process and interpret the information of the biological parameters of the astronaut, his/her movement intentions and the status of the suit and the actuators in order to provide the corresponding orders to the suit subsystems and feedback to the user.
- To develop a functional prototype of biofeedback leg and hand which can be set over the astronaut's space suit, and react to his/her actions.
- To create a demonstration prototype of a light weight, flexible exoskeleton robotic system based on SMA and EAP actuating technologies, to be test on human beings.

2.2 Progress beyond the state of the art

The main challenge of this project is therefore the adaptation of mature SMA and EAP based technologies addressing terrestrial applications to develop new concepts of feasible artificial muscles integrated in biofeedback suits for astronauts, as an alternative to currently used technologies.

At the beginning of this project, there was no research related to the development of active biofeedback suits for space applications based on SMA/EAP technologies but there is recognized interest in obtaining a qualitative improvement in comparison with current technology in space suits. This space suit is critical for assuring success of space missions. In this sense, the European Space Agency (ESA) was involved in a project aiming at improving suit space technology a few years ago, but this project called "Safe&Cool" focused on developing a special protective material with a built-in cooling system based on the technology developed for the space suits used by astronauts on the ISS to prevent them from overheating when exposed to direct sunlight during space walks. Currently, ESA is working in a new space suit equipped with devices capable of interacting with human body, but the technology ESA is employing is not based on SMA/EAP.

For all the above mentioned reasons, the STAMAS project targets the adaptation of the well-established at ground level SMA and EAP based actuation technologies for developing new concepts of artificial muscles for biofeedback suits for astronauts. The objectives of the project answers to detected needs that currently are not satisfied.

2.3 The UC3M role into the STAMAS project

The STAMAS project is divided into nine Work Packages (WP). A general overview is presented in Figure 3. Although the RoboticsLab of the UC3M participates in most of these packages, its work is mainly related to those work packages that it leads, named WP5 and WP6.

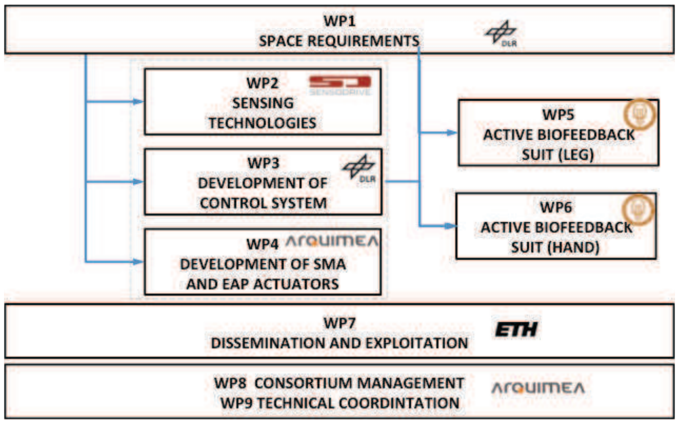


Figure 3 - STAMAS work packages with leader partner

The aim of WP5 is to develop a functional prototype to show the suitability of the selected technologies to be used in artificial muscles in space environment. The selected prototype demonstrator is an actuated biofeedback leg, as a part of an active biofeedback suit.

The leg will be actuated by means of a set of SMA or EAP artificial muscles. A set of sensors will be used for obtaining information from the leg movement and registering biological data from the suit user and provide data for the control unit to control the actuation of each muscle.

The purpose of WP6 is to develop a functional prototype to show the suitability of the selected technologies to be used in artificial muscles in space environment. The selected prototype demonstrator is an actuated biofeedback hand, as a part of an active biofeedback suit.

The following partial objectives have been identified for WP5 and WP6:

- To define a set of specifications and requirements.
- To define architecture for the actuated systems.
- To solve the potential problems during the integration.
- To test control strategies for this kind of devices.

- To test actuator designs to be used in long-stroke, medium force artificial muscles.
- To test sensors to be integrated in the device.

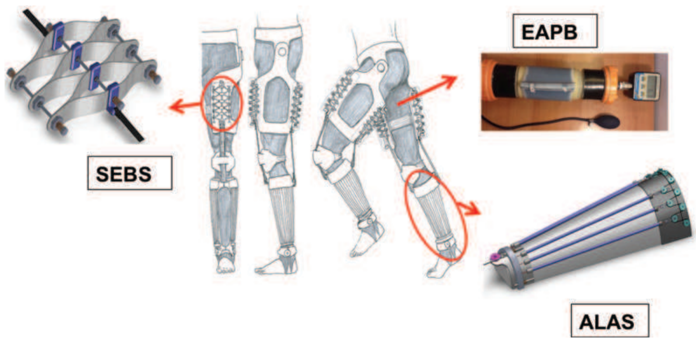
Figure 4 - Actuating system of the leg demonstrator

3 Leg exo-skeleton prototype demonstrator

One of the main objectives of the STAMAS project is to design an actuated device for the lower limb – the leg demonstrator – to be used for exercising inside the ISS, to address the problem of weightlessness that results in a loss of bone density and of muscular mass. The objectives of these measurements are to improve the exercising in orbit, to explore new countermeasures and to develop exercising devices that can be worn for long periods of time in order to exercise the legs during normal life in the ISS as well as provide a complement to current exercising devices.

The leg device will impose several difficulties to the astronaut's movement and will perform oppression and release forces over the user's thigh in order to modify the blood distribution. The leg demonstrator is divided into three different actuating subsystems, each one designed to tackle different problems associated with prolonged stays in a microgravity environment.
Five main systems form the demonstrator: Central Control Unit (CCU), Body Sensors (BS) and the actuated systems, named Ankle Lateral Actuating System (ALAS), Smart Elastic Bands System (SEBS) and Electro-Active Polymer Bands (EAPB). The CCU contains the high level controllers. It sends commands to the actuating systems controller. It receives information about the user from the BS. The BS are responsible of monitoring the user parameters required to determine the intensity and quality of the astronaut's exercising.

The leg system will consist of three different actuating systems (**¡Error! No se encuentra el origen de la referencia.**) which can be used simultaneously or individually, and can be used during the exercise time or for long periods during their daily work. These systems are:



- ALAS (Figure 5): It will exert lateral forces over the ankle, in order to generate deviations on the ankle load. The user has to use his proprioceptive abilities to keep his/her own balance. This will help to maintain the good state of all the secondary muscles which usually support the main muscles. An ALAS device fit in the internal part of the leg will produce inversion loads to the ankle, while an ALAS device and a second one externally fixed to the leg will generate eversion loads. The lateral forces generated by this system are created by a set of actuated SMA wires. When heated, the SMA wires contract. Upon cooling, the wires return to their initial length.

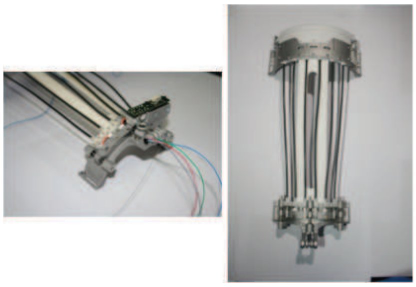


Figure 5 - ALAS actuating device

- SEBS (Figure 6): It is intended for generating a resistance to the knee movement. This device can vary the degree of resistance and the point of the leg that has to perform a greater effort on the flexion-extension movement. The resistance force is generated by a device formed by thermal-controlled SMA bands. Two SEBS devices will be implemented for this purpose: one located in the front of the leg, providing an opposition force to the flexion of the knee; the other fixed at the back of the leg, opposing its extension.

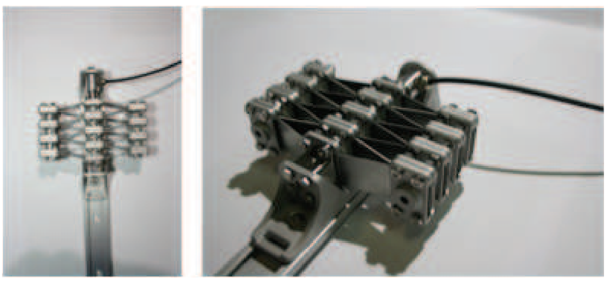


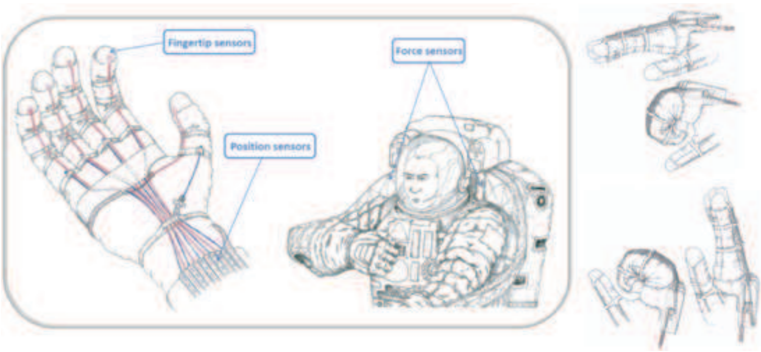
Figure 6 – SEBS actuating device

- EAPB (Figure 7): It will be placed surrounding the lower limbs. Their function is to generate alternative compressions, thus improving the blood flow in the lower limbs, replying the effect of pumping muscles.

Figure 7 - EAPB actuating device

4 Hand exo-skeleton prototype demonstrator

A hand exo-skeleton for assisting astronauts during EVA has been developed during the STAMAS project. The hand demonstrator is an actuated device used to compensate the stiffness of the space suit by counteracting the force exerted by the pressurized glove, in such way that the astronaut only exerts a normal force. These forces will be generated by aims of several SMA linear actuators, which are connected to the gloves by some elements located along the hand. The actuated system will be called Hand Exo-Muscular System (HEMS). The device will predict the user's movement intention and will act over the glove so its stiffness is reduced and the astronaut's dexterity is improved. A general sketch can be viewed in **¡Error! No se encuentra el origen de la referencia.**.



An important fact to be taken into account is that the demonstrator is intended to be integrated within an EVA glove. The device is light and low volume. The SMA wires are the basis of the actuating system, thanks to their high force to volume rate characteristics and thus, providing a biomimetic design.

The mechanical structure consists of a glove with a series of tendons attached to the fingertips, mimicking the tendon system of a human had. The tendons transmit the linear motion of the actuator to the fingertips of the glove, thus helping the user to flex his fingers. Six degrees of freedom are actuated: one for the index, middle, ring and little fingers (flexion movement) and two for the thumb (flexion and abduction). The device is integrated in a non-pressurized glove that does not apply the opposition forces of an EVA glove.

Three main systems form the demonstrator: Central Control Unit (CCU), Finger Sensors (FS) and Hand Exo-Muscular System (HEMS). The CCU contains the high level controllers. It sends commands to the actuating systems controller. It receives information about the finger forces from the FS. The FS measure interaction forces between the astronaut's hand and the glove will by means of six pressure sensors placed inside the glove on the fingertips. The HEMS actuating system is based on SMA wires. SMA have several features that make them a suitable choice taking into account the constraints imposed by the use of the device in space. They also have some limiting factors that must be solved in order to use them in the HEMS actuating system. When heated, the SMA wires contract, thus causing the flexion of the fingers. Upon cooling, the wires return to their initial length thanks to the bias force exerted by the springs that simulate the stiffness of a real EVA glove.

Figure 9 - HEMS actuating system

The hand system will include an actuating system named HEMS (**¡Error! No se encuentra el origen de la referencia.**), which will be used for assisting the astronauts during EVA, reducing the amount of force required to move the hand.

5 Conclusions

The main contributions of the UC3M to the STAMAS European project are reviewed in this document. The work is focused in the development of hand and leg demonstrators to develop smart suits for astronauts. Different actuating systems have been designed based on SMA/EAP technologies.

Acknowledgements

The research leading to these results has received funding from the STAMAS (Smart technology for artificial muscle applications in space) project funded by the European Union's Seventh Framework Program for Research (FP7) (grant number 312815). FP7 was the European Union's Research and Innovation funding program for 2007-2013. Also from the RoboCity2030-III-CM project (Robótica aplicada a la mejora de la calidad de vida de los ciudadanos. fase III; S2013/MIT-2748), funded by "Programas de Actividades I+D en la Comunidad de Madrid" and co-funded by Structural Funds of the EU.

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CHAPTER 9

TIRAMISU EUROPEAN PROJECT: DESIGN AND IMPLEMENTATION OF TOOLS FOR HUMANITARIAN DEMINING

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This paper presents the most relevant results of the work done within the framework of TIRAMISU European project (Toolbox Implementation for Removal of Anti-personnel Mines, Submunitions and UXO), by the Centre for Automation and Robotics CAR (CSIC-UPM). This project has been funded by European Union within the Seventh Framework Programme of R&D. In general, the works carried out during this project, currently in effect, have been the design and development of tools for training in search of landmines and other for locating anti-personnel landmines, such as: design and validation of e-tutors for land impact and non-Technical Survey tools, and landmines identification for training of trainee, who will collaborate in humanitarian demining tasks; design and implementation of a training tool to be used with compact metal detectors; design, implementation and evaluation of an intelligent prodder training tool for close-in detection of buried landmines; development of a semi-autonomous and teleoperated system for search and detection of anti-personnel mines, which consists of a hexapod robot and a scanning manipulator arm, that carries a metal detector at its end-effector.

1 Introduction

According to the Geneva International Centre for Humanitarian Demining (GICHD): “In a study of over 15 different programmes in 2004 it was found that of 292 km^2 of land that had physically been cleared, less than 2.5% of the area proved to be actually contaminated with landmines." These statistics underscore known inefficiencies within the mine action sector in the targeting of clearance resources, where too much land remains subject to full clearance (GICHD, 2009). In order to deal with this problem, land release of landmines has evolved over the years. However, still much work to do to contribute in solving this problem.

As every situation is different, it is impossible to provide one solution that fits all needs. Therefore, the TIRAMISU Project[3] will concentrate on developing components or building blocks, which can be directly used by the demining managers when planning Mine Actions, from area reduction to effective mine clearance. For this reason the main objective of TIRAMISU is to provide tools that for the following actions:

- Improve the overall efficiency and cost-effectiveness of humanitarian clearing of anti-personnel (AP) landmines and cluster munitions from large civilian areas
- Be integrated into a coherent and adaptable toolbox of mine-clearing activities
- Be validated by users in the landmine field
- Be backed by appropriate training and support

In general the TIRAMISU Project has been divided in ten different modules for addressing with the objectives proposed. In this case, the Centre for Automation and Robotics CAR (CSIC-UPM) has been involved within two modules, which are: Module 4, Ground-based Close-in Detection; and Module 8, Training of End-Users, Mine Action Centres (MAC), R&D community and Key Staff.

This chapter presents the main works carried out by the CAR team, specifically the Field and Service Robotics Group, within the framework of the TIRAMISU European Project funded by European Union within the Seventh Framework Programme of R&D. This manuscript has been divided in six different sections, the first is a briefly introduction about the call of the GICHD in order to work in counter the landmines and the main objectives of the TIRAMISU project. Section 2 describes the design and implementation of a training tool to improve the use with compact metal detectors in order to increase the efficiency during the searching o landmines. Afterwards, Section 3 presents the design, implementation and evaluation of an intelligent prodder for training about close-in detection tasks. For training in Humanitarian Demining (HUDEM), two e-Tutors have been

[3] http://www.fp7-tiramisu.eu/

designed by the CAR and validated by means of experts; a summary of this is presented in Section 4. The development of a semi-autonomous and tele-operated system for search and detection of anti-personnel landmines is shown in Section 5. Finally, in Section 6 a short conclusion of this work has been written.

2 Design and implementation of a training tool to be use with compact metal detectors

One of the first works developed within the framework of the TIRAMISU project has been the design and implementation of a training tool to improve the use of handheld metal detectors (HHD) for applications in HUDEM. The main idea is based in provide a best training to the apprentices, who start in the humanitarian demining cooperation. This training tool consists of two parts, which are: (*i*) a graphical user interface (GUI), and (*ii*) a sensory tracking system installed on the HHD (Fernández et al., 2012; Fernández et al., 2013; Fernández et al., 2014a).

The HHD used for this training tool has been the compact detector for special tasks VMC1 Mine Detector manufactured by Vallon (Vallon, 2012). However, this tool can be installed in any other metal detector, due its modularity and flexibility of use.

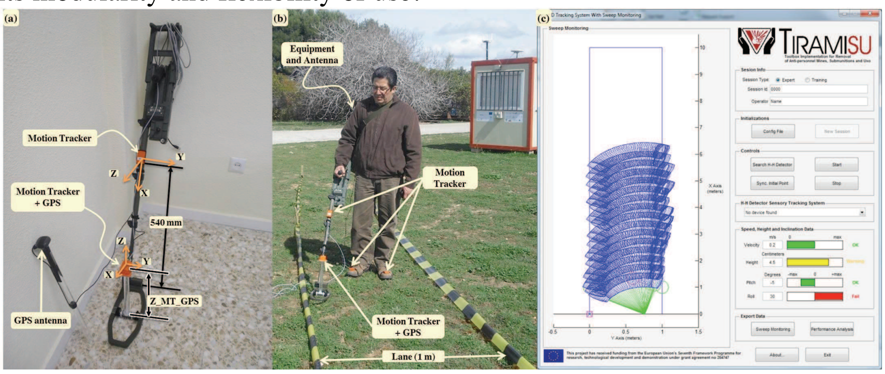

Fig. 1. (a) Compact metal detector with sensory system. (b) Apprentice with HHD training tool during an experimental test at CSIC premises. (c) GUI implemented in Matlab.

Fig. 1(a-b) shows the compact metal detector (VMC1 by Vallon), instrumented with two motion trackers (inertial measurement units) and an operator carrying out an experimental test in outdoor at the Centre for Automation and Robotics (CSIC-UPM), Arganda del Rey, Madrid.

Fig. 1(c) shows the Graphical User Interface implemented in Matlab®, which performs monitoring of the activities carried out by the apprentices using the HHD during the training process. As may be seen in Fig. 1(c), the GUI is divided into six sections, which are: (1) Session info, (2) Initializations, (3) Controls, (4) Sweep Monitoring, (5) Speed, Height and Inclination Data, and (6) Export Data.

3 Design, implementation and evaluation of an intelligent prodder for training

Other works carried out in this European Project by the CAR group has been the design, implementation and evaluation, in lab conditions, of an intelligent feedback prodder (IFP) for training tasks for close-in detection of buried AP landmines. The objective of this training tool is to provide information about the amount of force exerted and the insertion tilt in the soil of the prodder when the trainees carry out tests of searching of buried landmines. Some visual alarms are established when the force and inclination variables reach certain limits predetermined during the training process. In (Fernández et al, 2014b; Fernández et al, 2015a) the design and implementation of this training tool are shown, besides of some experimental results. Fig. 2(a-b) shows a block diagram which illustrates the concept of use of the instrumented prodder, and one current picture of the intelligent prodder designed and manufactured by CAR.

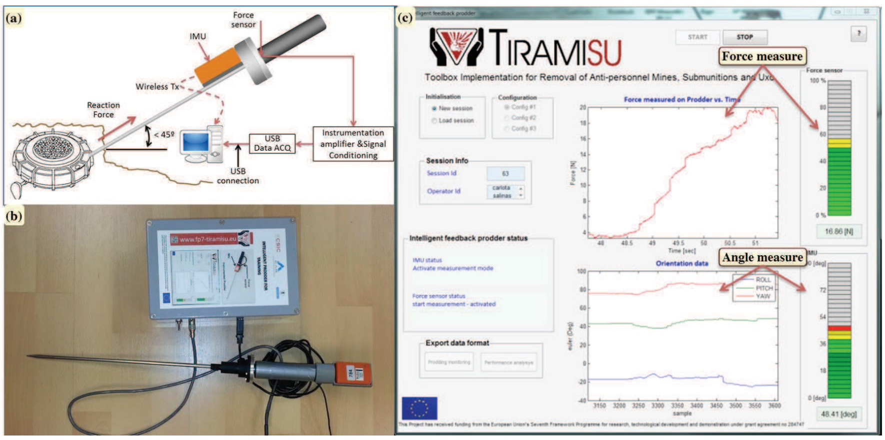

Fig. 2. (a) Block diagram of the intelligent prodder showing the different modules that compose it. (b) Intelligent feedback prodder (IFP). (c) GUI for the IFP.

This IFP consists of a NoN-Magnetic Prodder (Vallon, 2012), an inertial measurement unit (IMU), and a force sensor. The characteristics of the non-magnetic prodder device considers the technical requirements specified by GICHD in terms of size, mass, non-magnetic features, conforming to STANAG 2897 standard, and other. The IMU is used to measure the pitch, roll and yaw of the insertion of the prodder in the soil. The force sensor is able to provide force signal in only the direction of the prodder needle, which is enough in this case.

On the other hand, a GUI has been designed to be used with the IFP, in order to show to the trainee and the supervisor the results of the training in real time. In addition, this GUI is in charge of collecting the data acquired by the sensors installed on the IFP, processing, analysing and monitoring the measured performance variables, and presenting the essential information required during the training sessions, as has been mentioned above, including activation of relevant alarms when at least one of the following conditions is achieved: (i) the operator exceeds a pre-set maximum force, and (ii) the angle of insertion of the prodder exceeds 45º. In Fig. 2(c) the GUI for the instrument prodder is shown.

4 Design and validation of e-Tutors for training in HUDEM

In the present, the modern education is also based in electronic learning, known as e-learning. This is due to the progress in the information and communications technology (Mellar et al, 2007; Wu et al, 2006). Consequently, this project uses this concept in order to teach several important concepts to the learners in HUDEM courses, by means of e-tutors.

Fig. 3. Main page and other pages of the AGS and NTS e-Tutor.

The CAR team has designed two different e-tutors to teach, support, manage, and assess to the apprentices in some areas about HUDEM programme, established in MACs of some countries affected with landmine fields after the armed conflicts. The first e-tutor that has been designed and validated is titled "e-Tutor for Advanced General Survey and Non-Technical Survey", and the second e-tutor developed is titled "e-Tutor for Antipersonnel Landmines Identification" (Montes et al, 2015). Both e-tutors consist of several sections (sub-e-Tutors), which are considered great help for the basic learning in the areas for they were designed.

The teaching programme of the first e-tutor has been developed to support capacity building and on the job training at MACs in order to improve the required knowledge to manage in a proficient and effective manner all the different tools generated by the TIRAMISU project for Advanced General Survey (AGS) and Non-Technical Survey (NTS) tasks. Therefore, this e-tutor is aimed at all those that are part of the Mine Action Community and the operational personnel that would like to be introduced in the use of the new AGS and NTS tools generated within the framework of the TIRAMISU project. Fig. 3 shows the some pages of this e-tutor.

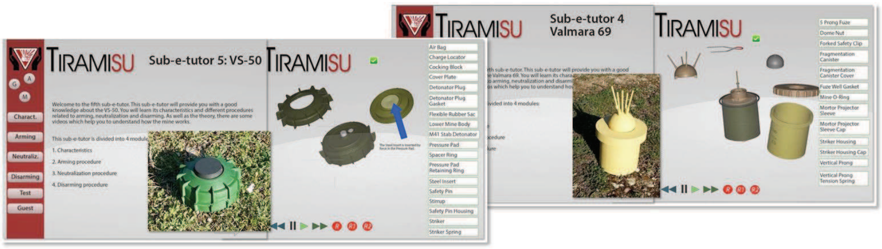

Fig. 4. Main page of two sub-e-Tutors and video slides of two landmines.

The second e-tutor has been developed in order to provide an initial training for civilian people that need to learn about of the identification in AP landmines, and that require preparing to work in this activity (see Fig. 4). The training can be realized in any time and in any place, because the base of the information is through of the electronic learning. This e-tutor consists of sub-e-tutors, which describe the functioning of several AP landmines.

5 Development of a semi-autonomous and tele-operated system for search and detection of AP landmines

The semi-autonomous and tele-operated system developed by the CAR CSIC-UPM has been a hexapod legged robot with a scanning manipulator arm, which is used for search and detection AP landmines. The idea of using legged robots for humanitarian demining has been developed about the last 20 years, and several prototypes of these robots have been tested experimentally, under environments controlled. Some examples of these robotic platforms are TITAN VIII (Hirose & Kato, 1998), AMRU-2 (Habumuremyi et al, 1998), RIMHO2 (Gonzalez de Santos & Jimenez, 1995), COMET series (Nonami et al, 2003), SILO6 (Gonzalez de Santos et al, 2002; Gonzalez de Santos et al, 2007), and other.

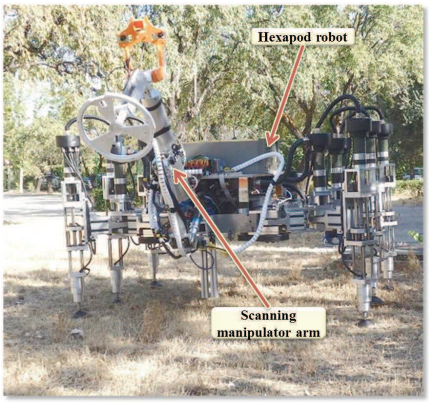

Fig. 5. Hexapod walking robot and scanning manipulator arm.

This robot has a control architecture that consists of an on-board computer, control cards, data acquisition boards, power cards, signals conditioning cards, positioning sensors, DC motors, Wi-Fi communication system, DGPS, batteries, and other devices and accessories. The algorithms have been developed in C/C++ and run in QNX RTOS. With this, several control strategies has been performed in order to carry out HUDEM tasks (Montes et al, 2015a; Montes et al, 2015b; Mena et al., 2015).

The objective is carry out stable trajectories in order that scanning manipulator arm can perform suitable motions of its end-effector, where is mounted the metal detector head. Fig. 5 shows the hexapod robot with the manipulator arm installed in front of its body.

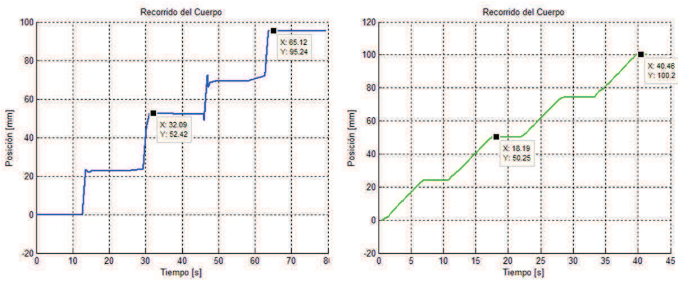

Fig. 6. Comparison between the motion of the robot during a discontinuous gait (to left) and continuous gait (to right).

Fig. 6 shows the comparison between the discontinuous gait and the continuous gait with length steps about 50 mm during a gait cycle of two steps and a support factor of ½. In continuous gait, it is possible to see some discontinuities; this is because the contacts of the feet with the soil have a delay related with the constructions of them. The feet have springs in order to the inductive proximity sensors detect the contact with the soil, in this moment, each axis of the foot is displaced inside of foot chamber, up to be near to the sensor.

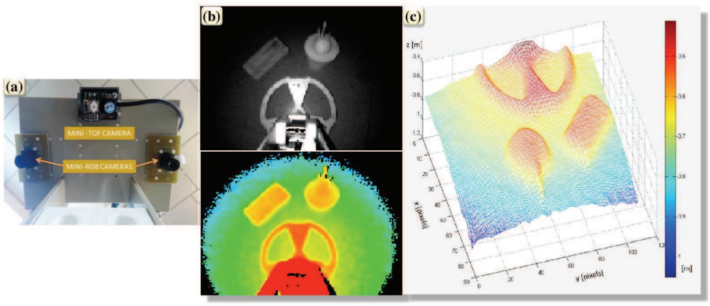

Fig. 7. (a) Set the cameras installed on the manipulator, mini-ToF and mini-RGB cameras. (b) Image of amplitude, and depth range of the mini-ToF. (c) Terrain surface mapping.

On the other hand, the manipulator arm has 5 dof and has been installed on its tool centre point a metal detector head, in order to search landmines. Additionally, in the scanning manipulator arm are been installed two different cameras, a mini ToF camera and a VRMagic multi sensor camera. The first camera has resolution of 120 x 160 pixels used to acquire a depth map and amplitude image, as well as a cloud of points that contain the Cartesian coordinates of the target. The second camera is equipped with two pixel-synchronous CMOS sensors, which acquire RGB images with resolution of 754 x 480 pixels. The sensor fusion between the ToF data with the RGB images provides the necessary information to know the area that the manipulator arm explores (Fernández et al., 2015b; Gavilanes et al., 2015). Fig. 7 shows the different images of the sensory system installed on the manipulator arm, in order to observe the zone scanned by the manipulator.

6 Conclusions

In this paper has been summarized the main works and general results from TIRAMISU European Project carried out by the Centre for Automation and Robotics CSIC-UPM. The works performed by CAR team (Field and Service Robotics Group) has been related with the design, implementation and validation of several tools, which have been proposed to be used in humanitarian demining tasks. For further information provided in this chapter, the interested reader could search the references related with the works carried out by the CAR group, which are cited in Reference section.

Acknowledgements

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CHAPTER 10

THE ROBO-SPECT EU PROJECT: AUTONOMOUS ROBOTIC TUNNEL INSPECTION

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ROBO-SPECT is a European 7th Framework project funded under the ICT programme on Robotics Use Cases (contract No. 611145), implemented by 10 partners from 6 European countries. Driven by the tunnel inspection industry, its main objective is to adapt and integrate recent research results in intelligent control in robotics, computer vision tailored with semisupervised and active continuous learning and sensing, in an innovative, integrated, robotic system that automatically scans tunnel intrados for potential defects on the surface and detects and measures radial deformation in the cross-section, distance between parallel cracks, cracks and open joints that impact tunnel stability.

1 Introduction

One of the greatest challenges engineers face is the inspection, assessment, maintenance and safe operation of the existing civil infrastructure. This includes large-scale constructs such as tunnels, bridges, roads and pipelines. In the case of tunnels (water supply, metro, railway, road, etc.), they have increased in both total length and number, and will continue to do so. Furthermore, some tunnels still in service were completed over 50 years ago, with the existing construction and materials technology.

Only in Japan in 2006, the number of active tunnels was up to 9000 (Mashimo, 2006), with tunnels such as the Seikan Tunnel, which is 54 km long and partially below the seabed (Ikuma, 2005). Figure 1 depicts the evolution of Japanese tunnels in terms of number and length until 2006.

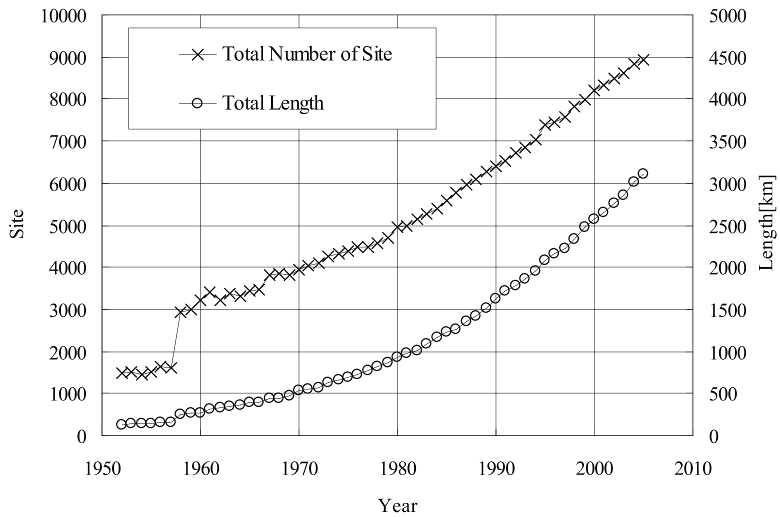

Fig. 1. Changes in the number and total length of road tunnels in Japan (Mashimo, 2006)

Tunnel environments are characterized by dust, humidity, and absence of natural light. Artificial and natural impacts, change in load criteria, or the simple effect of ageing, make tunnels require inspection and maintenance. These operations are commonly performed by human operators, taking time and expertise, without guarantee quality control. The previous examples highlight the need of automated, cost-effective and exhaustive inspection of tunnels that prevents such disasters (Balaguer, 2014). In this chapter, we present the current works and future objectives of the ROBO-SPECT EU research Project within this area.

2 The ROBO-SPECT EU Project

ROBO-SPECT is a project co-funded by the European Commission under FP7-ICT (Robotics topic), that started in October 2013 and will finish in October 2016, and is coordinated by the Institute of Communication and Computer Systems (Athens, Greece). The objective of ROBO-SPECT is to provide an automated, faster and reliable tunnel inspection and assessment solution that can combine in one pass both inspection and detailed structural assessment that does not interfere with tunnel traffic (Montero, 2015). The robotic system will be evaluated at the research infrastructure of VSH in Switzerland, at London Underground and at the tunnels of Egnatia Motorway in Greece and the system is expected to:

- Increase the speed and reliability of tunnel inspections.
- Provide assessment in addition to inspection.
- Minimize use of scarce tunnel inspectors, while improving the working conditions of such inspectors.
- Decrease inspection and assessment costs.
- Increase the safety of passengers.
- Decrease the time tunnels are closed for inspection.

In summary, the needs to which ROBO-SPECT will be replying are the following (Loupos, 2014):

- High cost of new tunnel constructions (need for inspection, assessment and repair of existing).
- Transport demand is highly increasing and cannot cope with the rate of transport infrastructure and high tunnels uptime.
- Inspection and assessment should be speedy in order to minimize tunnel closures or partial closures.
- Engineering hours for tunnel inspection and assessment are severely limited.
- Currently tunnel inspections are predominantly performed through scheduled, periodic, tunnel-wide visual observations by inspectors who identify structural defects and categorize them manually (manual, slow and labor expensive process).
- Un-reliable classification of the liner conditions and lack of engineering analysis.

3 The ROBO-SPECT architecture and design

The ROBOS-SPECT system is composed of three different components that will allow the complete inspection and assessment of the tunnel and will provide all the functionalities to the final users. The first component is the robotic system. The robotic system will perform the inspection inside the tunnel and incorporates all the different sensors that will be used during the inspection. The second component is the Ground Control Station (GCS) that will work as a central unit to monitor the robot mission and communicate with the platform. The GCS works also as a link between the robot and the third component, the Control Room (CR). The CR will be equipped with the PCs that contains the Structural Assessment Tool. This software will use the inspection results to generate a complete assessment report about the tunnel state.

3.1 Robotic system

The ROBO-SPECT robotic system design is based on an industrial wheeled robotic system able to extend an automated crane to the dimensions of the metro and motorway tunnels. It is equipped with a robotic arm to place with high accuracy a specifically designed ultrasonic sensors to measure width and depth of detected cracks inside the tunnel lining. The defects inside the tunnel are detected using a series of cameras and a 3D laser profiler to detect deformations on the tunnel lining. Figure 2 presents the actual design of the robot and the different components that will be described. The mechanical design of the robot is inspired by the robot used on the Tunconstruct EU project (Victores, 2011), that uses a similar vehicle, crane and robotic arm configuration.

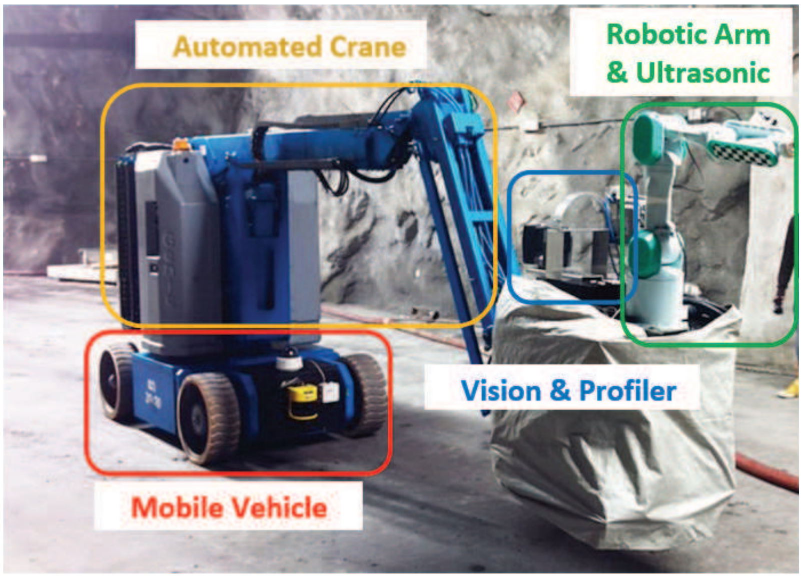

Fig. 2. ROBO-SPECT robotic system

3.1.1 Mobile vehicle

The robotic platform will be able to move on road and rail to cover the applicability of the robotic system in the two use cases chosen for the project:

motorway and metro tunnels. This mobile vehicle is able to navigate autonomously and perform collision avoidance through the tunnel using a pair of 2D range laser sensors, one in the front and one on the back of the vehicle. The navigation is performed using SLAM by placing a series of reflective beacons in known positions inside the tunnel. These beacons are detected by the laser sensors and used to update the localization of the robot in the tunnel. A real 2D map of the navigated tunnel section is created at the end of the inspection, and can be used to improve navigation on subsequent inspections.

3.1.2 Automated crane

The crane of the vehicle has been automated using encoders inside the joints in order to control the crane tip position and orientation. The joints of the system are equipped with special brakes to minimize the oscillation and vibration of the parts. The crane tip is designed to carry a platform with a robotic arm equipped with ultrasonic sensors and a series of cameras and a 3D laser profiler. The behavior of these components is described below. The crane can position the mentioned platform at maximum 10 meters height from the ground, which is enough for the vast majority of tunnel geometries.

3.1.3 Robotic arm

The robotic arm placed on the crane platform is the Mitsubishi PA-10, a 7 Degrees Of Freedom (DOF) industrial manipulator. The 6DOF provides the arm with full position and orientation capabilities, and the additional degree of freedom produces redundancy to provide the robotic arm with collision avoidance capabilities. The workspace of the robot cover from a few centimeters to 1 meter approximately from the base of the arm to the end-effector. A special set of ultrasonic sensors will be placed at the tip of the robot. The mission of the robot is to place the ultrasonic sensors on a crack inside the tunnel to perform width and depth measurements. In order to calculate a safe trajectory to the final point, a 2D range laser sensor is attached to a link of the arm to scan the surroundings of the crack position and create a 3D point cloud of the wall before moving the system.

3.1.4 Vision system

The ROBO-SPECT system is equipped with two pair of 9.1MP cameras to detect different defects inside the tunnel walls during the inspection. This cameras are placed on the crane platform to be able to be positioned at a controlled distance to the wall. The first pair of cameras are designed to be able to identify a set of different defects commonly found on tunnels such as spalling, staining, exposition of reinforcement, water leakage, white deposits, etc… These defects are detected using machine learning techniques like Convolutional Neural Networks (CNN) trained with real images of tunnel defects. The other pair of cameras are designed specifically to detect cracks in real time, and they will be able to detect and estimate the 3D position and orientation of the crack inside the tunnel. This information is then passed to the robot to move the crane to the crack surroundings first, and move the robotic arm to place the ultrasonic sensors later. The cameras will be capable of taking a stereo image of the crack to be used later on the structural assessment tool for characterization purposes.

3.1.5 Laser profiler

Furthermore, a 3D laser profiler is placed on the crane platform to extract a 3D section of the tunnel. The 3D laser profiler used in ROBO-SPECT is the Faro Focus3D X 130. This profiler will be used to detect tunnel structural deformation with an accuracy of ±2 mm. The laser scanner is able to produce a 360 degree point cloud of one million points/second scanning rate.

3.1.6 Ultrasonic sensors

At the end of the robotic arm a set of ultrasonic sensors will be attached. These sensors are designed specifically for the ROBO-SPECT project to measure the width and depth of the crack while in contact with the tunnel wall. The depth of the crack is measured using two piezo-electric ceramic transducers. To perform the depth measurement, the transducers will be positioned on each side of the crack by the robotic arm. Regarding the width measurement, a newly created fiber-optic sensor will be used. The sensor will be positioned using a special XY positioning stage attached to the robotic arm. When all the measurements are made, the robotic arm remove the sensors from the wall and the inspection continues.

3.1.7 Global controller

In order to control all the different subsystems of the robot, a general controller will be developed to manage the communications between parts. All the different components (mobile vehicle, crane, cameras, etc…) will be connected to a common network inside the robot to receive the commands and provide the measurements and state of the systems. This general controller will receive a mission from the Ground Control Station and provide the protocol to command the robot to perform the requested inspection mission autonomously. It will be able to navigate the robot through the tunnel, detect when a crack has been spotted and perform the necessary joint movements to place the ultrasonic sensors on the crack and perform all the required measurements. The controller will update the GCS with the state of the mission and the inspection data gathered.

3.2 Ground Control Station

The Ground Control Station will be a computer component outside the robot that will be in contact with it. The GCS will provide a graphical user interface and it will work as a human-machine interface (HMI). From the GCS the user can provide a mission to the robot and retrieve the state of the mission while the robot is inside the tunnel. The communication between the robot and the GCS will be based on a wireless connection.

The GCS will be in contact with the Control Room as well, and depending on the tunnel and the final user, the connection with the CR could be wireless, access to the nearest access point of the infrastructure network or internet, or a direct connection if the end-user will process the data once back in the company HQ. This communication provides the CR with all the inspection data gathered by the robot to process later using the structural assessment tool.

3.3 Control Room

The Control Room is the last component of the ROBO-SPECT tunnel inspection system. The CR represents the site where all the data gathered by the robot will be processed. This processing will be made by the Structural Assessment Tool (SAT), a software created inside the project scope to store, graphically represent and process all the inspection data. The SAT will allow the end user to see the generated maps of the tunnel, the 3D slices computed by the laser profiler, information about the different defects detected and their position inside the tunnel. It will use all the mentioned data to produce a complete assessment report of the structural state of the system that will be presented to the end-users. The SAT will be able to use also information from multiple inspections of the same tunnel separated in time to study the rate of deformation of the lining or the evolution of the cracks and other defects.

4 Future developments

At this stage of the project, the current developments taking place right now are focused on:

- Finalizing the global controller design and test all the communication between components to perform field tests and evaluate the overall system behavior. This will allow to define process accuracies on navigation and positioning of the different robotic parts, as well as precisions on the final data gathered by the sensors.

- Performing simulations of the complete system to explore different inspection procedures. The simulation of the system is being developed using Gazebo robotic simulator under ROS environment. Figure 3 shows the simulated system inside a Gazebo tunnel environment.

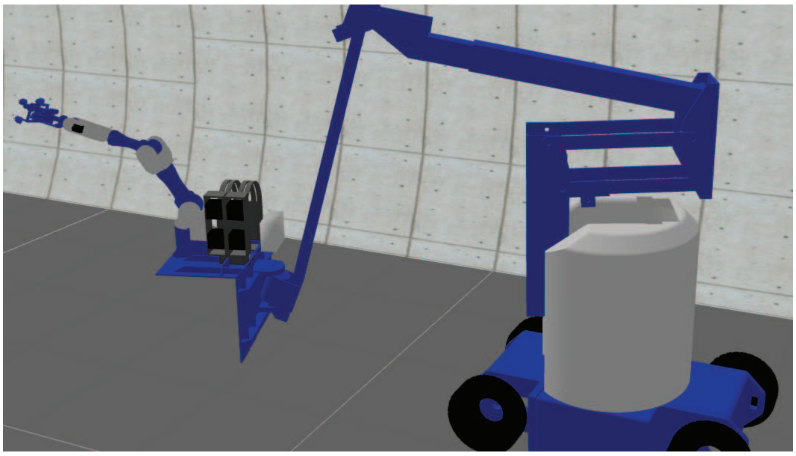

Fig. 3. Gazebo simulation of the ROBO-SPECT system

- The placement of contact sensors at the end of the ultrasonic sensor frame is being developed. There will be four contact sensors on the rigid piece attached to the robotic arm where the ultrasonic sensors are placed. These sensors will allow the robotic arm controller to know when the mechanical piece is touching the wall and detect if the four sensing points are in contact with the wall. This information will be used to control the orientation of the robotic arm end-effector to achieve a good positioning of the sensors that provides the best scenario for the measurements.

Apart from the specific points described before, the project partners are working continuously on different parts of the robot to improve the control and the autonomous behavior. The robotic drivers and the navigation software are being in constant development to provide better control of the different parts and better navigation autonomy of the mobile vehicle.

Acknowledgements

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CHAPTER 11

ROBOTICS FLOODED MINES INSPECTION AND MONITORING

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The main objective of the EU project STAMS (Long-term Stability Assessment and Monitoring of Flooded Shafts) is the development of robotics tools for long term monitoring of deep abandoned coal flooded shaft over 2km deep. The challenge is to use underwater robotic devices to position several type of sensors in the shafts walls and register their locations. However, the devices used in other industries for underwater inspections are not suitable for the conditions of deep-flooded mine shafts. This is why radically new solutions need to be developed. The sensor´s power supply and underwater communication are other important issues of the project. In this way, the closing of the mines in European countries such as Spain, Poland, and UK will be guaranteed in sense of safety of mines itself but also of the surrounding environment.

1 Introduction

The STAMS project, under RFCS-2014 call, try to solve important environmental problem of the maintenance of abandoned European flooded shafts. Most of them, especially in Spain in the area of Asturias, are very close to the cities with the potential dangerous of flooding and buildings collapse. The long term multi-features monitoring is essential in order to close these old coal mains under recent EU regulation and guarantee the safe environment.

The project consortium is a multidisciplinary team leading by French National Institute for Industrial Environment and Safety (INERIS) and with several type of partners such as two end-users (HUNOSA (E) and KWSA (P), the largest mining companies in EU), shaft maintenance companies, coal authorities, several mining expert institutions and UC3M as a robotic partner. In total there are 10 partners from France, Germany, Poland, Spain and UK. UC3M is in charge of the underwater robotics device, sensors fixing in the shaft and their data transmission with to the ground monitoring system.

This papers deals with the first results of the robotics tasks of the project. As a first step, the overall system architecture had been defined, being the main activities: a) robotic system conceptual definition for sensors positioning in the shafts, b) sensors selection attending power supply and underwater communications and c) sensors' fixation mechanism in the deep flooded shafts.

2 Robotic system for sensor positioning

For continuous shaft monitoring robotic system for sensors positioning must be developed. This system will need to be adapted for different devices and sensors, and work in underwater conditions of flooded shafts (Fig. 1). Some of this sensors will be attached to the shaft`s wall and others will be free floating inside the shaft. It means that robotic device need to have the following abilities: a) prices underwater navigation, b) carry attachment device for sensors positioning (manipulation), and c) precise knowledge of sensors positioning.

It this way the main robot features are navigation, manipulation and positioning. For navigation the robot need to be compact and robust, without protruding parts, and also need to be equipped with depth controller as well with horizontal plane controller. For sensors manipulation the robot need the attachment device that will be based on some kind of existing technologies (drilling, gluing, etc.). Finally, the exact positioning of the attached sensors (and the robot) will be calculated through natural and artificial landmarks placed inside the shaft.

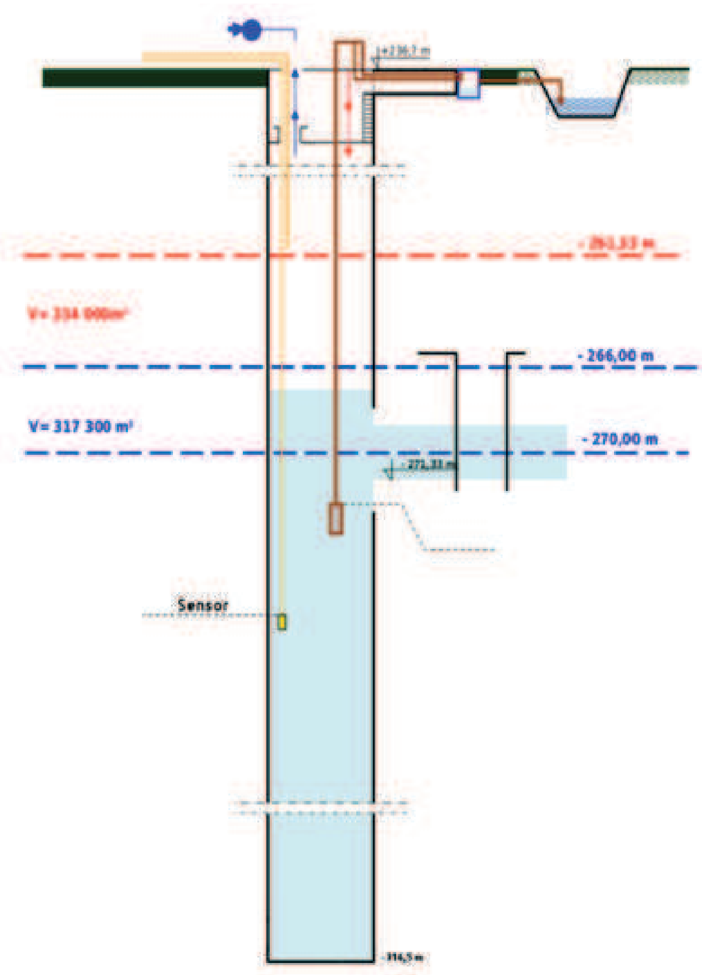

Figure 1. Typical flooded shaft with sensors

For robot navigation and shaft assessment sensors positioning several sensors will integrated in the robot: cameras with different focal distances able to detect landmarks and ultrasound scanners. Both of them, together with the depth control through umbilical cable will provide exact horizontal position of the robot as well the horizontal orientation. In this way the will be attached to shaft´s wall with high precision. This positioning and orientation control is similar to the odometry ones of mobile or underwater robots.

The shaft´s water condition is commonly very bad with poor visibility. Figure 2 shows the ground base image acquisition system and real image of the shafts wall at the depth of about 175 m. In the image it is possible to identify shaft´s transversal beams for structural stability of mine corridors and vertical columns for lift guidance. The image shows the difficulty of its processing and the difficulty of determine the exact robot position. The images will be filtered using particles filters which also will help to the segmentation and shaft´s features extraction.

Another important issue is related to umbilical connection of the robot to the ground station. Despite of several advantages of the fee diving robot in shafts of about 3-4 m diameter, the taken solution will be base in the umbilical connection. Nevertheless, this connection need to be controlled due the fact that it is very easy to twist the cable around shaft´s rubbles (iron and wood pillars, etc.). On the other hand, free diving the narrow space with the depth of 2km is extremely dangerous.

The preliminary design of the robotic system is presented in Fig. 3. It is based on the lightweight structure incorporating a commercial hammer drill for different kinds of surfaces, a camera and a LED lightning system to allow direct supervision of the process from the surface. For counteracting the recoil of the percussion drill, passive plates will be used. In the first phase the robot will be commanded in teleoperated mode with operator-in-the-loop philosophy. It means that operator will be command the robot through image and ultrasound sensors data but with strong aid of image data processing. The virtual images will be superpose with the real one and ultrasound data. In the second phase the robot will work in autonomous mode searching and selecting their best position.

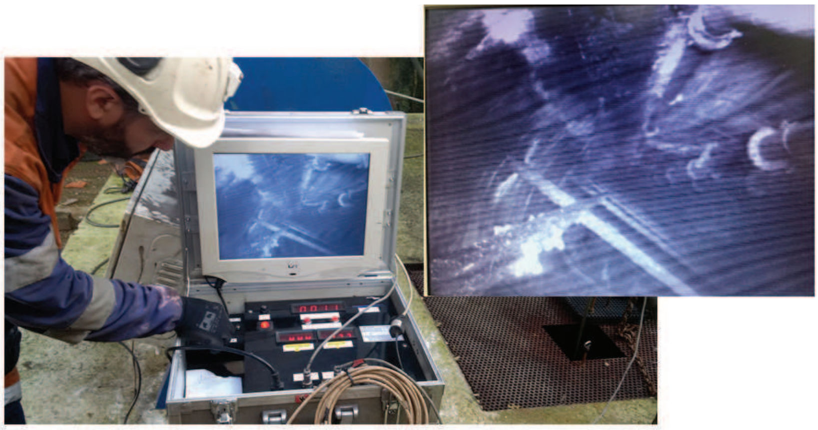

Figure 2. Ground monitoring system of the camera data in the Pozo Fondon (Asturias) flooded shaft

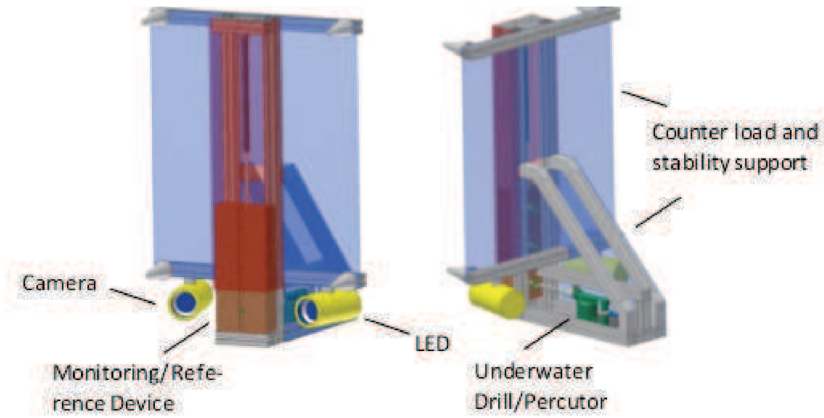

Fig. 3. Preliminary robotic system for sensors attachment

An ultrasonic sensors for robot navigation will be also used. Nevertheless, the same system can be used for inspection of the surface of the shaft's lining. The accuracy of these measurements will depends of the ultrasound transducer and is expected to be in order of several mm.

3 Sensors selection

The shaft's assessment sensors must be designed for long-term use of period of several years or decades and submerged in potentially aggressive water, and at high pressures (up to 200 bar). The main data to sense are: a) shaft structural stability, b) water level and conditions, c) gas dynamics by chemical analysis and d) thermal sensing. These will measure the evolution of acidic pollutants and vertical and horizontal stresses.

Several factors related to relevant physical phenomena, types of transducers, precision, measurement drifts, lifetime and cost, among others, have to be studied. As known by previous research, shaft risk assessment is sensitive to changes in pH, temperature, water inflows, flooding, and presence of specific chemical agents (RFCS, 2013). For the monitoring and assessment of flooded shafts is necessary to define the minimal and optimal range of measurements needed for shaft evaluation and, based on that, calculate the mechanical needs for each device and their functional requirements (Deutsche, 2007), (Lacomte and Muños, 2013).

Another crucial issue is sensors power supply, especially if they will use for long term monitoring. In the power supply side, the battery power supply probably is not the best solution due its limited life time. The umbilical connection or/and passive sensors exited by external source will be the best solutions. On the communication side, the ultrasonic modems is the best possible solution.

In this project innovative solution will be explored for simultaneous ultrasonic power supply and communication. To face this, inductive or broadband acoustic techniques for power supply and communication will be used (Liu et al., 2008). Those schemes (Fig. 4) employs a high frequency charging and signaling line with contactless couples through each unit. Once reliable and longtime data is obtained a numerical model will be developed then to improve the efficiency of these tools as well as the interpretation of new collected data (Fraden, 2004).

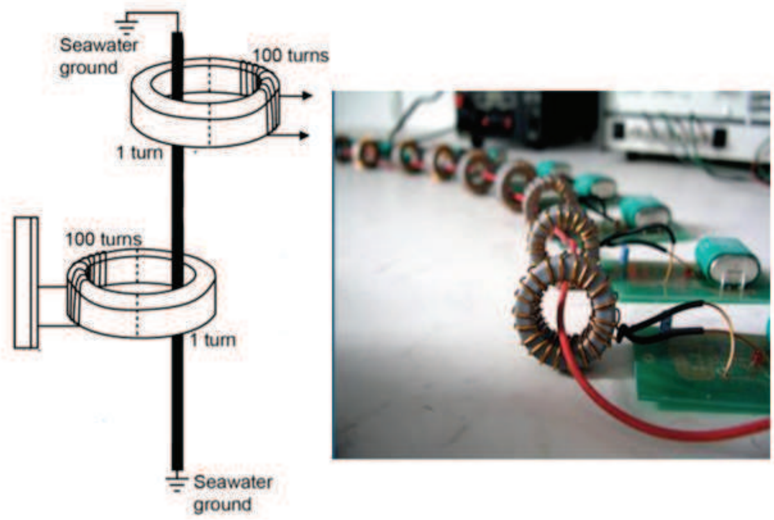

Fig. 4. Sensors with simultaneous power supply and communication

The sensors accuracy is another important issue. It is expected that fixed (to the wall or other shaft´s part) sensors have better accuracy comparing with free floating ones. Nevertheless, the underwater communications of these sensors, if using ultrasound signals, will be limited by the environment, distance and possible obstacles (Law et al., 2002). Abandoned deep shafts are complex environment that don´t help to rapid and accurate sensors and communication. This is why, one of the expected projects output will be the development of a new methodology for sensor selection and positioning.

4 Conclusions

The continuous monitoring of the flooded shafts is an important environment problem in Europe. Moreover, in the places where coal industry had been stopped there are some kind of dangerous of flooding and shafts collapsing. This is why European Union will introduce new regulation in this issue. Robotics solution for exploring these deep shafts will be very helpful and will try to adapt them to this regulation. STAMS project will develop, in close coordination with end-users and authorities, new underwater robotics devices as well new sensors networks.

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