Intelligent Systems, Control and Automation: Science and Engineering

Ignacio González Alonso *Editor*

International Technology Robotics Applications

Proceedings of the 2nd INTERA Conference, held in Oviedo, Spain, March 2013

Springer

Intelligent Systems, Control and Automation: Science and Engineering

Volume 70

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ISSN 2213-8986 ISSN 2213-8994 (electronic)
ISBN 978-3-319-02331-1 ISBN 978-3-319-02332-8 (eBook)
DOI 10.1007/978-3-319-02332-8
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013951127

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To my parents and my brother, they gave me much more than life…

Prologue

Robotics technology will become pervasive in the coming decade. It will influence every aspect of work and home. Robotics has the potential to positively transform lives and work practices, raise efficiency and safety levels and provide better levels of service. Its impact will grow over time as will the interaction between robots and people. What is more, it is set to become the driving technology behind a whole new generation of autonomous devices and cognitive artefacts that, through their learning capabilities, interact seamlessly with the world around them, providing a necessary link between the digital and physical world.

Robotics is one of the pivotal technologies that will strengthen the competitiveness of industries, the provision of solutions for current societal challenges and excellence in science. Robots have proved to save costs, improving the quality of work conditions, as well as reducing resource waste. Robots are at the dawn of a new era, safer collaboration with humans, seamless cooperation with other machines and sensors, as well as increased flexibility and ease of use will transform them into ubiquitous helpers able to improve our quality of life by providing efficient services in our homes, offices, factories and public spaces. From today's €22 billion worldwide revenues, robotics industries are set to achieve annual sales of between €50 billion and €62 billion by 2020.

Further to these competitiveness advantages, robotics has a key role to play in addressing some of the most pressing societal challenges facing our society in the near future in areas as diverse as demographic change, health and well-being, food production, transport and security.

Robotics will be essential to meeting these challenges sustainably and cost-effectively. Robots are already serving as life-saving tools for surgery, smart rehabilitation trainers for the convalescent, attentive guards and rescuers to protect environments and safeguard human lives, as well as reliable movers in all kinds of logistics scenarios; their role, impact and interaction with people will only grow.

On its second year running, INTERA 2013, has been a repeated success, not only creating new links and bringing together Spanish research groups working in robotics, but also in consolidating cooperation between academia and the private sector. A research and networking exercise essential to advance in this field.

The 10 peer-reviewed papers you are about to read touch highly relevant issues contributing to the key issues described such as Biomedicine, Energy Efficiency, Digital Home and Domotics. They show work related to teleassitance for elderly people, service robots of different kinds, robots to assist the health system and new technologies for robot integration.

The opportunities for robotics in the next decade are manifold. They emerge from the spread of robotic technologies into other products and industries, turning robotics into a global mainstream technology. The challenges facing our societies present yet another significant set of opportunities for robotics, as it is difficult to see how many of these challenges will be met without a significant robotic component as part of the solution. INTERA 2013 and, hopefully, subsequent editions, will continue to help identify these opportunities and bringing together academia and industry to harness the power of multi party collaboration and increase the chances for innovation in this field.

Irene Lopez de Vallejo, Ph.D., is Strategic Partnerships Director at IK4-TEKNIKER and Representative to the Robotics PPP for IK4 Research Alliance www.ik4.es/en*, being a Member of the Board of Directors of euRobotics AISBL, the private side of the PPP* http://uk.linkedin.com/in/irenelopezdevallejo.

Technical Committee

To achieve this volume, a lot of researchers and professors have been involved. Infobotica Research Group is very grateful to the Technical Committee for their helpful and constructive work.

Prof. Huosheng Hu received an M.Sc. degree in Industrial Automation from the Central South University, China and a Ph.D. degree in Robotics from the University of Oxford. He leads the Human Centered Robotics (HCR) Group at Essex and has successfully leaded a number of research projects funded by the EU, EPSRC and The Royal Society and Industry, among others. His research interests include autonomous mobile robots, human-robot interaction, multi-robot collaboration, embedded systems, pervasive computing, sensor integration, evolutionary robotics, intelligent control and networked robotics. He has published over 300 papers in journals, books and conferences, and received several best paper awards. He is an Editor-in-Chief of the International Journal of Automation and Computing. He is also a registered Engineer, a Fellow of IET and a senior member of IEEE and ACM.

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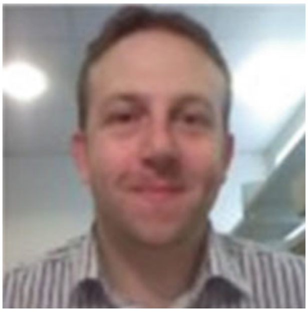

Dr. Ignacio González Alonso Ph.D. in Computer Science in 2009 with the Thesis called "CGM: Code Generation Method" and Associate Professor at the University of Oviedo since 2005. He also takes part in Infobotica Research Group linked to the University of Oviedo, developing projects in computer and robotics fields. He is collaborating in some national funded projects: Robocone (2012–2014), Smart Home Energy (2011–2013) Digital Home Compliant II (2011–2013), DHCompliant (2009–2011) and TIC4Bot (2007–2009). He is also the Co-author of nineteen international contributions and he also had a publication "Robots in the Smart Home: A Project Towards Interoperability" International Journal of Ad Hoc and Ubiquitous Computing (IJAHUC). He is also Co-author of "Service Robotics Within the Digital Home: Applications and Future Prospects", published by Springer-Verlang.

Dr. Arturo de la Escalera Associate Professor of the Universidad Carlos III of Madrid, Spain and Head of the Intelligent Systems Group. His current research interests include Advanced Robotics and Intelligent Transportation Systems with special emphasis on vision sensor systems, image data processing methods for environment perception and real-time pattern recognition. He is member of the Editorial Board of the International Journal of Information and Communication Technology and The Open Transportation Journal.

Dr. José María Armingol Moreno Associate Professor in the Department of Systems Engineering and Automation, Universidad Carlos III of Madrid. His research career has been focused on the development of sensory perception systems based on computer vision, laser technology, etc., in order to design systems for driving assistance and guidance of robotic platforms. Throughout his nearly 18 years of teaching experience and research, he has published over 60 articles in JCR journals and international conferences as well as participated in 17 research projects.

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Acknowledgments

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We must acknowledge the continuous support given by the Fundación Universidad de Oviedo to make this workshop possible. We would also like to thank the Oviedo City Council and the Príncipe Felipe Congress Hall-Auditorium for the assistance provided. Finally, we greatly appreciate the support of Dra. Miriam Cueto Pérez, Universities and Research General Manager on behalf of the Regional Government of Asturias.

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Introduction

INTERA 2013
International Technology Robotics Applications
Oviedo (Spain), 11 March 2013

A Low Cost, High Excellence International Conference

Let me introduce you the INTERA 2013 Proceedings. This is a compilation of high quality conference contributions on service robotics and energy efficiency. It is the product of the efforts from Infobotica Research Group and the Fundación Universidad de Oviedo (Spain) to organize the second International Technology Robotics Applications Workshop last March 2013, in the Príncipe Felipe Congress Hall-Auditorium in Oviedo. This was the workshop second edition and the first one with a “Low Cost, High Excellence International Conference” profile adapted to today economic situation. Its aim was to gather a high level scientific committee with very low access prices. And the results were more than satisfactory as we expect you to share while reading following chapters and contributions.

The conference combined service robotics and energy efficiency experts from the academia as well as from different industries in order to achieve a unique knowledge exchange over the current state of those topics. The workshop gave the opportunity to researchers from national and international organizations to showcase their advances in applications and technologies such as home automation, service robotics, energy efficiency and e-health. But not only, much work was really interdisciplinary.

Therefore, this proceedings book is the tangible outcome of that process and it attempts to present the latest and higher quality scientific research. Only the half of the contributions were accepted by the workshop reviewers, so it was a tough competition to be there, and we hope that helped to improve the quality of the contributions you will find here.

Finally, I would like to acknowledge to the organization committee that made possible the workshop and this book. They had promoted the involvement of researchers in the compilation of the manuscripts far over their own duties. Then, I am sure the reader will share my opinion about their excellent work.

Dr. Eng. Ignacio González Alonso

Part I
Biomedicine

Augmented Reality in Robotic Assistance for the Elderly

Francisco J. Lera, Víctor Rodríguez, Carlos Rodríguez and Vicente Matellán

Abstract The basis of this research was to create a platform for social interaction based on augmented reality, ready to be deployed in the homes of elderly people. Two main components are presented: the first one is an affordable robot platform built from TurtleBot robot. The second one is the underlying software system built on top of ROS, in charge of the interaction interface and the user tasks, called MYRA. The purpose of this study is to test the platform and the augmented reality in real environments and how it can be used effectively and without complications by elderly people. With this goal in mind we prepared our platform to be able to do two different tasks: a generic assistance system, and a drug dose control system. Both were tested in a real environment.

1 Introduction

Social robotics have been growing up during the last years, in particular in the field of assistance to the elderly in everyday environments. The Ambient Assisted Living (AAL) association was founded in September 2007 and stablished a new European funding programme for research and technological development. Not all projects applied to this programme, but it has served as an inspiration to explore

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_1, © Springer International Publishing Switzerland 2014

new ways to improve the quality of life of the elderly, or the technology that is related to them.

Our proposal, a prototype that could help elderly in daily tasks, is not a novel solution like the one that we can see in [1]. In this work, the authors made a categorization of assistive robots for elderly in two groups: rehabilitation robots and assistive social robots. In the second group we can find the service-oriented robotic platforms as the robot Flo [2], the nursebot Pearl [3], RIBA robot [4] or Hector [5]. Other new plataforms as Florence [6] or Giraff [7] were introduced during last years under the AAL projects and have been tested in some elderly homes during last year around europe. The category of companion robots is included in assistive robots, there we can find AIBO robot from SONY, the more recent Paro [8], the Huggable [9] or the Homie [10]. In our case, the robot has been designed to assist caregivers in the control of medication of elderly people using augmented reality.

The Augmented Reality [11] (AR from now on) is a live view of a real-world scenario whose elements are augmented by computer-generated information such as sound, video, graphics, etc. In this article, we suggest that the use of AR applied in a robotic platform can improve the lives of elderly people, and we try to demonstrate it. For our proposal we developed an assistance system and a drug dose control with AR. In the prototype described in this paper we used ArUco [12], a free software library designed at the University of Cordoba, to implement our AR sub-system.

As a robotic platform, we started our experiments with the TurtleBot robot built by Willow Garage [13], an open platform which is one of the cheapest and most expandable robotic platform at present time. Later, we use a modified version adapted to elderly needs as we can see in Sect. 4. New open robotics platforms (ROP [14]) intended for assistance are being introduced constantly, like AMIGO [15] or like NimbRo-OP [16] that will be introduced in the future as companion robot.

The rest of the paper is organized as follows: in Sect. 2, the general prototype and the software architecture design are presented. In Sect. Sect. 3, we present the prototype built for the tests, Sect. 4 showcases the preliminary tests made to validate our development, its usability and the possibility of implementation in real environments. Finally, Sect. 5 presents conclusions and further work, highlighting the main outlines of our work and its future development.

2 Prototype Description

We present a software and hardware prototype intended to make the usage of a medical drug dispenser (pillbox) easier for elderly people. Its main component is a multi-platform software application based on ROS, OpenGL, and ArUco, running on a hardware platform consisting in a computer on-board a mobile robotic platform.

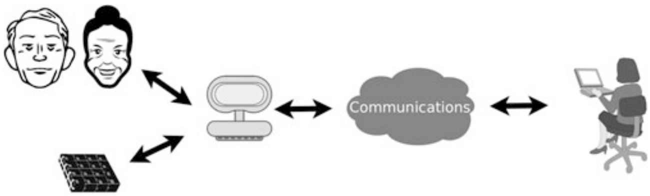

Fig. 1 General approach

Figure 1 shows the general concept of our proposal. In left side the elderly has the interaction with the robot and the pillbox. With the use of AR, the task could be improved. To the right, somebody can control the robot and offer real-time assistance to the elderly, using the camera speakers and phone mounted onboard.

2.1 Software Description

This section presents the software developed for the system, which is based on two main modules: ROS (Robot Operating System) and MYRA. ROS [17] is a popular and widespread set of libraries and tools used to build any kind of control software for robots, developed by Willow Garage.

MYRA is our interaction architecture, short for "Elderly and Augmented Reality" (in Spanish *Mayores Y Realidad Aumentada*), and it has been created at the *Cátedra Telefónica—Universidad de León* to help and improve the daily lives of elderly people through the use of AR using only a computer and a camera.

The MYRA architecture is a hierarchical architecture with three main levels. The *Model* level encompasses the software needed to connect to other libraries that MYRA needs, as for instance: OpenCV, ArUco, pjproject libraries or ROS ecosystem. These libraries provide image recognition, augmented reality and VoIP services respectively. ROS provides support for getting images from a Kinect sensor, and sending commands to the hardware platform to control the robot movement. The *Controller* level consists of different subsystems that process the received data, and generate the information that will be fed to higher levels of the application, that is, to the View component. The *View* level builds the interface that interacts with the users, that will be shown in the robot's display.

Figure 2 portrays the implementation of the MYRA architecture for building a robotic assistant for medication control presented using SysML modeling language. The hardware part, roomba block diagram, is adapted from [18] (we are not showing the roomba blocks concerned to sensors that we are not using in the MYRABot platform).

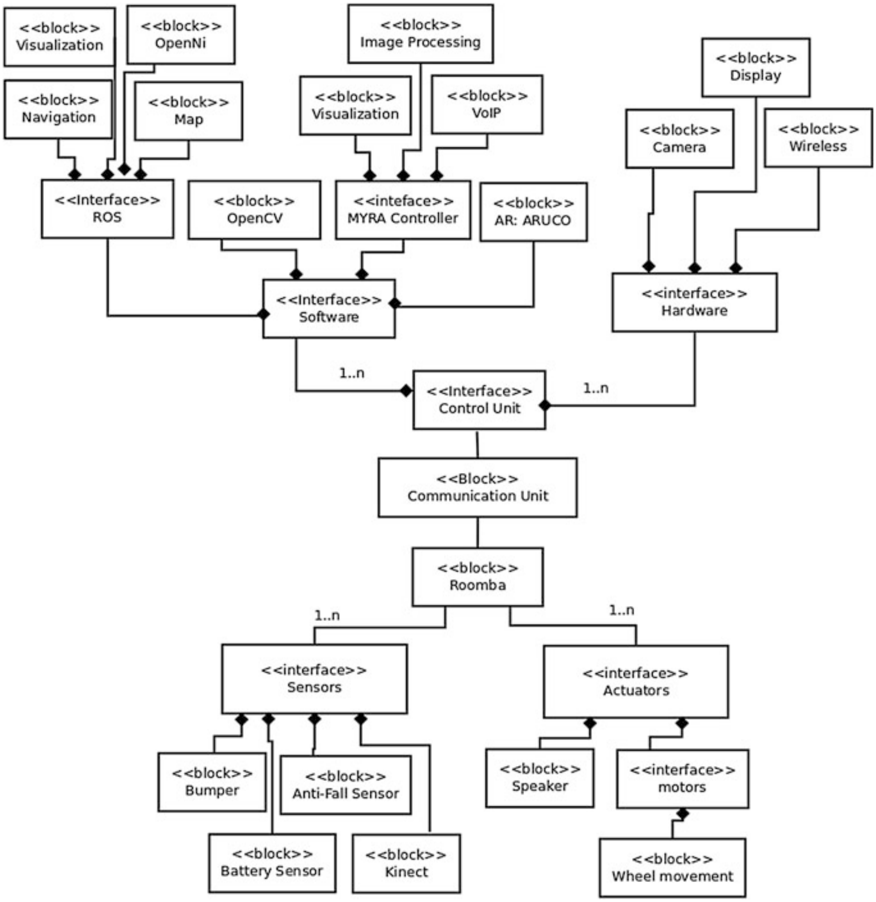

Fig. 2 High level SysML diagram

3 Prototype

In this section we present the first prototype developed using the software architecture described above.

The interface built for the prototype (MYRA display) is shown in the left picture of Fig. 3 made up by three different modules. The *Presentation* module is in charge of showing information to the user. This information is based on the images captured by the system, augmented with information added by the Controller component. The *Telepresence* module is in charge of managing the communications. In the preliminary prototype we are providing just voice calls, using the VoIP stack, which means that the remote user can be on a computer or on a phone. The *AR* module manages the information included in the Presentation interface.

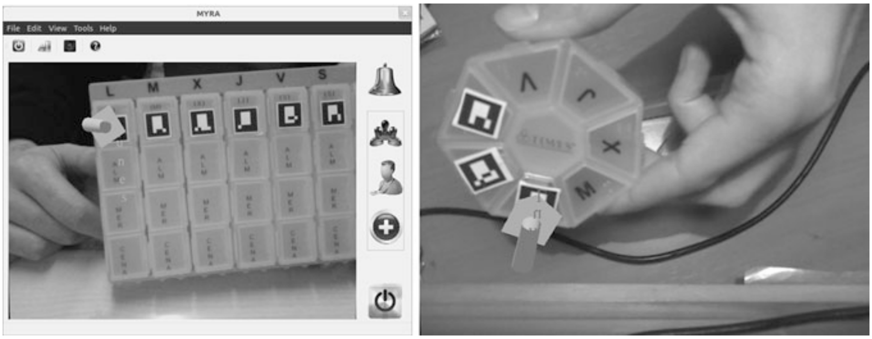

Fig. 3 Interface screenshot and simple AR pillbox example

4 Evaluation

In this section we describe the preliminary tests we made to validate the prototype. The purpose was to obtain real user feedback for our prototype, and we tried to adapt the tasks to our final architecture. The tests were made with a limited population of five people aged 59, 64, 84, 86, and 90. A brief explanation about the platform and the experiment was given to them. The tests took place in an environment well known to them: their own homes, where close relatives were present to supervise and make them feel more comfortable. The duration of each test was about 1 h.

4.1 Test 1

Our first test was developed with the Turtlebot robot, and the main goal was defined as: "are the elderly people ready to interact with robotics and Augmented Reality?" We divided the test in two parts. The first one was an acceptance oriented test. We wanted to evaluate if seniors would accept the robot, and in particular if they would feel comfortable with a non-anthropomorphic robot. The second one was an interaction test where we wanted to evaluate the interaction interface, in particular the AR interface. In this part we simulated a medication event, and asked every individual to use the AR pillbox for drug dose control (Fig. 4).

4.2 Test 2

We used a modified version of the Turtlebot robot to make this test, as we can see in the left picture of Fig. 5. We wanted to establish whether or not the robot experience could be improved with a hardware modification, and if the medication

Fig. 4 First HRI test

Fig. 5 AR elderly interaction

task could really be improved with the use of augmented reality. This modification was prompted by the first experience, where the users asked for a taller platform to interact with. We named this robot "MYRAbot" because of the relationship with our software architecture.

A perfect example is presented in Fig. 5, the individual is able to see an arrow being overlaid on the pillbox, and he is pointing to the right medication for that moment.

5 Discussion

An objective evaluation was made. After each experience, we asked the elderly about the quality of the interaction. With these results we retrieved some relevant information about the users' experience. Table 1 shows the assessment of each subject based in the Likert scale [19], where the value 1 means "totally disagree" and 5 is "totally agree" for a given sentence. The final results are presented in Table 1.

Figure 6 shows the interaction time of the subjects. We can observe that the interaction average in the first test (31.8 min) is below the 38.8 min average of time spent in the second test. The two main reasons for this improvement are that (1) in the second experiment the robotic platform was modified because it was adapted in height and (2) also, the graphics used in the AR interface were improved. We allowed to increase or decrease the size of the rendered graphics, per user request.

Analyzing the data fetched with the polls, we concluded that the use of AR had indeed positive effects in the users. Anyway, we see in Table 1 that the subjects were not comfortable with part of the solution. The reason was that they needed an extra graphical solution to get the correct drug; for instance, when the elder person needs a dose and he or she shows the pillbox to the robot, a video showing a hand or maybe a person manipulating the pillbox could be an extra help to be more precise with the correct dose.

Table 1 User valoration table

Evaluation\Age	59	63	85	86	90	Evaluation \ Age	59	63	85	86	90
Enjoyment	5	5	4	5	4	AR usefulness	5	5	4	5	3
Robotic platform	5	5	5	5	5	AR friendliness	5	5	3	4	2
HCI friendliness	4	4	5	5	5	AR functionality	5	5	2	2	2

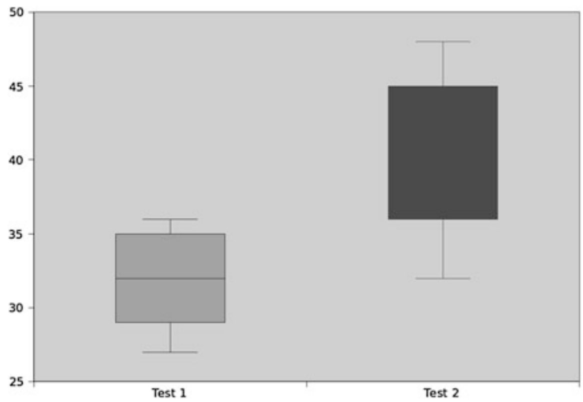

Fig. 6 Analysis of interaction time

6 Conclusion and Further Work

This paper describes the development of a robotic tele-presence system equipped with an augmented reality system for interaction. The main contribution of our research is a human robot interaction architecture named MYRA, used to build a system for elderly assistance and medical dose control that includes augmented reality to improve the interaction with the robot.

MYRA has been built using open source libraries. This was a design decision that speeded up the development, but it also has its drawbacks: we are stuck to particular versions of the libraries. The MYRA architecture developed for this project is available for downloading and testing.

As we explained throughout the paper, using our prototype it is possible to follow a simple medical guidelines to take the daily pill dose, thanks to the help given by the augmented reality, with just presenting the pillbox to our robot or to a camera if we use the MYRA computer solution. Also, the telepresence system using VoIP appears as a cheap way to communicate with family, friends or, with a many improvements, as a possible emergency service.

Future improvements could consist for example of a remote drug dose control, where the patient's doctor could change the prescription in real time. Another possibility would be to manage syrup medicine, for instance showing a video of somebody taking a spoon or a cap. In the hardware field, we are studying the installation of a low cost arm to be able to do new tasks and improve the interaction with the elder.

Hardware designs are made available by the ROS community. Our hardware improvements are also available in our project web [20].

Acknowledgments This work has been partially funded by Cátedra Telefónica-Universidad de León (grant CTULE11-2).

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HENUFOOD: Development of New Methodologies and Emergent Technologies for Showing Food with Health Claims on Chronic Diseases Risk Reduction in the Middle Age of Life

G. Anzaldi, X. Domingo, A. Moreno and P. De La Peña

Abstract HENUFOOD looks forward reduce chronic disease pathologies risk factor and, in this way, improve adult population health, between the range of 45 and 65 years. However, the benefits of this project, based on healthy ingredients and foods development, try to reach the rest of the population from the beginning up to the seniors. The main objective of HENUFOOD is discovering the healthy benefits from aliments using innovative methodologies, and scientifically demonstrate it. That will permit develop value products at nutritional level and demonstrate their health effects. These foods must keep on being foods, and must demonstrate their effects in quantities which are usually consumed in a diet. The project is looking forward determining in a clear way which foods or ingredients are absorbed by the organism and produce the beneficial effect that they are supposed to. This paper will focus on describing the ICT platform developed to support the scientists reach that purpose.

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I. González Alonso (ed.), *International Technology Robotics Applications*, Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_2, © Springer International Publishing Switzerland 2014

1 Introduction

Health is one of the main concerns of developed societies. However, the pace of modern life has come to people leaving the healthy eating habits which are a key factor to prevent the incidence of chronic diseases. As said by the WHO [1], chronic diseases are increasing and in 2020 will be responsible of 75 % of total world deaths. However, fighting against the risk of having non transmittable chronic diseases is on our hand. The experts agree that when people follow a balanced diet in a continued period, the organism acquires a greater response capacity in front of possible health incidences. With this aim, food industries have started to offer products with nutrition or health claims which, in addition, will help them to improve their competitiveness in the market.

Moreover in accordance with Regulation (EC) 1924/2006 of the European Council and Parliament [2] of 20 December 2006 of nutrition and health properties of food, economic operators can only use nutrition or health claims on their products if and only if, such declaration is based on scientific evidence and, in addition, it is understandable to the average consumer.

The 15th article of Regulation (EC) 1924/2006 of the European Council and Parliament, states which should be the studies to be submitted to applications: the studies and other material mentioned in the 15th article, 3rd paragraph, 'c' and 'e' points. The studies will mainly consist of human studies and, in the case of statements regarding the development and health of children, children studies. These studies will be presented based on a hierarchy depending on the study design. This hierarchy will reflect the relative weights of the evidence that may be obtained. The outcomes of that studies should be clearly explained to target markets, and for this reason, some of the information to be clearly explained includes: (a) the target population for the intended health claim, (b) the amount of the nutrient or other substance, or food or food category, and pattern of consumption required to obtain the claimed beneficial effect, (c) where appropriate, a statement addressed to persons who should avoid using the nutrient or other substance, or the food or food category, which is the subject of the health claim, (d) a warning for the nutrient or other substance, or the food or food category, which may pose a health risk if consumed to excess, and (e) any other restrictions of use and preparation or use instructions.

Thus, with the current European legislation on the hand, all the foods with healthy or functional properties must scientifically demonstrate that they result in a beneficial effect in one or more organism functions, apart from the intrinsic nutritive effects, in a way that they result to improve the health and wellness, decrease disease risk, or the two things together. These foods must keep on being foods, and must demonstrate their effects in quantities which are usually consumed in a diet. So, they cannot be capsules but foods that are part of our daily diet. The project is looking forward determining in a clear way which foods or ingredients are absorbed by the organism and produce the beneficial effect that they are supposed to. Concretely, HENUFOOD will research on fiber, fatty acids and phytosterols, probiotics, active peptides, photochemical and calcium, in order to detect the beneficial effects that they have in some health areas: cardiovascular protection, digestive and cholesterol metabolism, antioxidant action, immune homeostasis, comfort and intestinal health, glucose homeostasis and weight control, osseous and articular system.

To evidence this health benefits and scientifically demonstrate them, controlled clinical trials will be used. Controlled clinical trials are studies done by scientists on a concrete domain with the objective of execute a prospective analysis that attempts to compare the effect and value of one or more interventions in humans under specific conditions. To support these activities, a specific platform will be built. This platform will support scientists on their everyday tasks including researching the state of the art of their concrete study, advising and supervising the correct clinical trial execution, helping in the interpretation of the results, running analytical processes, semantically understanding the necessities by a user friendly interface based on query answering techniques, and acting as a decision support system. This paper will focus on that ICT platform intended for support the general objectives of HENUFOOD project.

2 Objectives

Taking in consideration the previously mentioned regulation context and industries necessities, HENUFOOD aims to discover and scientifically support the healthy benefits from aliments using innovative methodologies. These innovative methodologies include "omics" (transcriptomics, proteomics, metabolomics…) and the image diagnose (Functional Nuclear Magnetic Resonance-FNMR), which will let studying new biomarkers and analyze the changes that the organism suffers after the ingestion of some foods or ingredients. In this way, it is expected to guide the food development and production to an optimal nutrition, understood as the consumption of foods that provide clear and proven benefits for the risk of chronic diseases prevention.

From our concrete point of interest, our technical objective is to develop a general computational platform which will support evidence, outcomes validation, and decision support applied to procedures and scientific trials which are related to the research of beneficial food properties and their impact on health. The required functionalities to be covered by HENUFOOD technological objectives are:

- Integrate data from different biological models and generate conclusions.
- Optimize the design of nutritional intervention studies in humans.
- Procedures and automatisms helping in understanding the action mechanism. based on the various results in the test samples.
- Build a health risk prevention system.

- Application of computational methods to predict, using computer simulation, healthy effects of nutrients, as well as obtaining statistical justifications for such actions.

The activities need to build a unified platform which meets these functionalities and, in addition, offers management support and scientific trials conclusion guidance, validation and outcome management. Three separated but intrinsically related stages are considered:

1. Obtaining, pre-processing and treatment of data.
2. Automatic models validation, intelligent decision support and scientific support of the validated models.
3. Intelligent and intuitive data interpretation.

3 Impact and Benefit

The biomarkers that will be studied are focused on people health problems that are in the middle age of life: digestive and sensory changes associated with age, osteoarthritis, neurobiological changes associated with aging, circulatory disorders peripheral arterial hypertension, metabolic syndrome…

The selection of this group of people is because, at present, various WHO [1] studies have confirmed that in the coming decades, both health related no transmittable food chronic diseases (obesity, diabetes and cardiovascular) derived from the current way of life, and the increase of health costs to be supported by the developed and developing countries to address these diseases, are expected to increase worldwide. In this context, it should be noted that food and eating habits are the main non-genetic aspects related to health, which have an important role in the prevention of these facts and resources saving.

HENUFOOD looks forward reduce chronic disease pathologies risk factor between the range of 45 and 65 years. However, the benefits of this project, based on healthy ingredients and foods development, try to reach the rest of the population from the beginning up to the seniors.

4 HENUFOOD Platform

HENUFOOD solution is based on a central knowledge base which contains all the information needed for all the implied processes in the platform. This information includes domain ontology with medical and nutritional related terms, state of the art of the corresponding research groups and their publications, new knowledge acquired during the usage of the tools, and the relevant results of running analytical and data mining processes over the data. This ontology is the base of four differentiated modules:

- The bibliographic and state of the art research module: This module is responsible of collect information from different data sources. Natural language processing techniques [3, 4] are used together with content indexing. Then Knowledge Discovery in Databases [5–7] processes are applied and relevant data is added to the ontology. More information about this can be found at [8].
- The clinical trial management tool: This module is responsible of allowing scientists introduce different data from different controlled clinical trials and their later information treatment. It is also able to show alerts when necessary, in example, when CONSORT [9] recommendations are not accomplished, or when the concrete sample which is being introduced shows notorious differences in its characteristics than the other. The latter fact that could suggest an error in the sample collection or manipulation.
- The analytical wizard: This module is responsible of analyzing the information and running the corresponding statistical or data mining processes to the data. The interactions are done using a wizard based application which guides the user throughout the process. When new relevant knowledge is discovered, it is added to the central ontology. Examples of used algorithms are FP-Growth [10], A-priori [11], and other association, classification, correlation, prediction or segmentation algorithms.
- The avatar graphical user interface: This module is responsible of interact with scientists as if it was a personal assistant. The basic idea under this development is to allow scientists to ask for concrete analysis or questions over the state of the art in natural language. The system is able to answer to these questions in natural language too, or even run some processes or take some actions, depending on the context.

5 Work Done

This paper will explain the advances achieved related to the objectives of the platform. This section will be divided in different parts according to the stages described on the previous section.

5.1 Obtaining, Pre-processing and Treatment of Data

The comprehensive platform, which aims to solve the problems associated with intelligent information management, is focusing in two aspects regarding the research on methods of obtaining information: the indicator results obtained by biomarkers on the one hand, and on the other hand, the integration of unstructured data from external data sources (intranet, extranet, specialized databases and images).

In terms of the compilation of active substances, natural ingredients and its relationship with health, the medicine based on evidence paradigm has been taken as the basis. With that premises, relevant and innovative knowledge has been acquired by accessing semantically to the Linked Data cloud. In addition, multiple connectors to data sources related to the bio-nutritional state of the art have been developed. A bibliographic aggregation platform over the annotations base in natural language and the information extraction based on the platform ontology has been built.

Together with the previous functionality, an automatic extraction system has been developed to obtain relevant knowledge according to the data provided by the trial samples set, so that, depending on targets, decide which models to be applied (statistical models and data mining), and which are the main and multivariable attributes to feed that models. This automatic extraction system is based on a wizard guidance, which automates the more complex processes within CRISP-DM [12] methodology for managing the data mining information stream. These previously functionalities can be checked in a summarized schema in Fig. 1.

On the other side, focusing on the automatic evaluation of medical images, taking as a reference the automatic extraction of interest zones, graphical targets have been defined over the generality of the image. To accomplish that, data mining algorithms have been used, especially SVM and neuronal networks. However, traditional artificial vision matching techniques have been also applied. To improve the user interaction with these applications, a unified visual analysis solution with both technologies embedded has been designed.

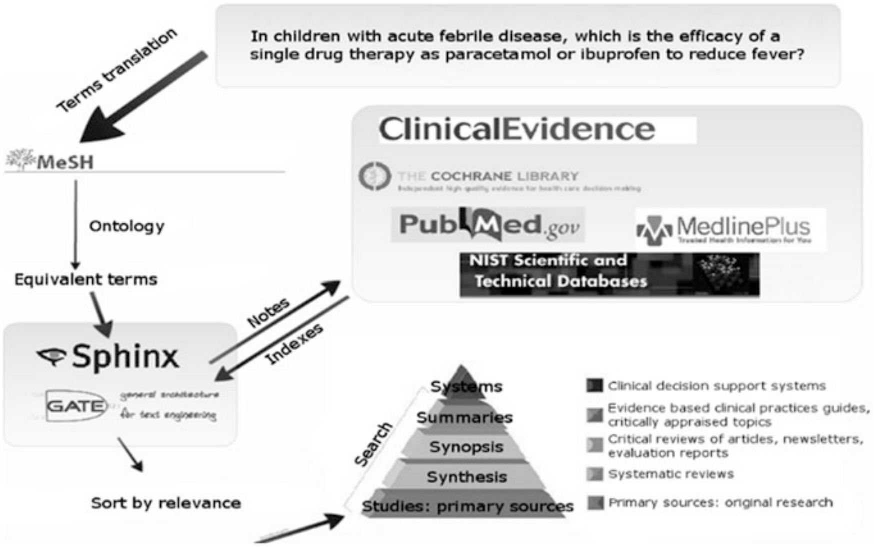

Fig. 1 Obtaining, pre-processing and treatment of data

5.2 *Automatic Models Validation, Intelligent Decision Support and Scientific Support of the Validated Models*

In parallel to the functionalities previously described, a modelling system has been developed. This system is using different state of the art techniques, such as profile and modelling comparison (multivariate analysis): ANOVA, PCA, PLSDA, and others, together with an association rules extraction system and a semantic inference engine (SWRL) over that information. This system, taking in consideration the study results, is able to determine the model convergence, the confidence level based on the original premises (analysis of the null hypothesis) and also to explain in a contextual way the outcomes. The system is also able to predict and respond how the system would respond towards concrete changes in input indicators.

This modelling system offers an intelligent support for clinical trials modelling and their simulation. It is empowered with a rule based expert system which will be responsible of checking in real time the rules and knowledge obtained in the previous subsection, together with the manual introduced ones. Some of the introduced rules are the ones coming from the CONSORT statements or the good clinical practices. Simplified architecture of these systems can be seen in Fig. 2.

To semantically support the entire platform, a central ontology is used. This ontology is the main kernel of the decision and control system and, in addition, it allows using a common vocabulary, integrate internal information, disseminate the trials outcomes, control the trial lifecycle, and validate, taking in consideration predefined quality rules, the outcomes, the samples and their priori defined objectives.

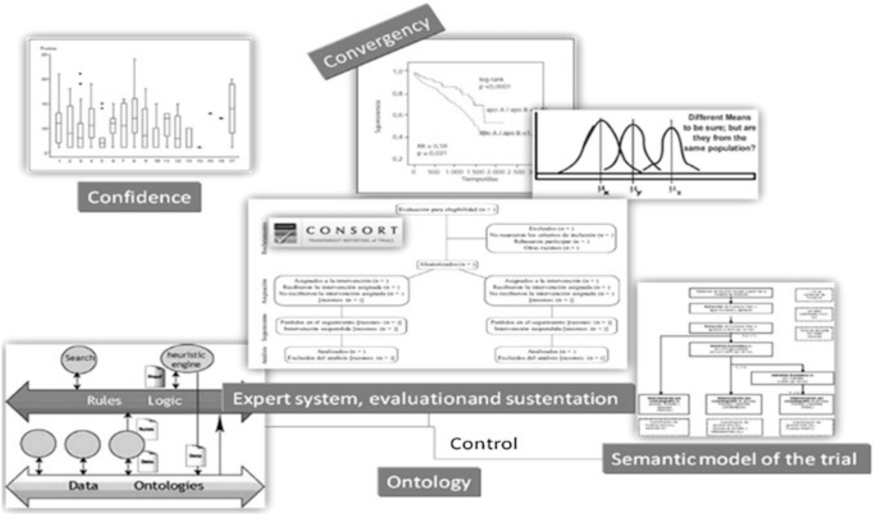

Fig. 2 Automatic models validation, intelligent decision support and scientific support of the validated models

This ontology includes and is based on other taxonomies as SNOMED [13], and pretends to match all the natural language described information with UMLS codification to later populate it. It also includes all the necessary terminology to successfully represent the concepts involved in the support and validation control of the target models. Additionally, the outcomes obtained using data mining processes are also included when relevant.

5.3 Intelligent and Intuitive Data Interpretation

The data accessing and interpretation, has to be done in an intuitive way. In this way, the interaction with the decision support system is done using questions in natural language. The first steps of this functionality include an interaction with the data mining and expert systems using direct questions over the object of study. Examples are "which are the independent variables?", "which are the relevant attributes?", "which are the recommended methods to apply?" or "which are the restrictive conditions in the models?". In fact, it is a controlled language which is abstracted from data base and the data mining terminology to allow high level interaction.

To make this interaction more accessible, an avatar, with which the interaction is actually done, has been designed. Thanks to that, scientist can ask questions or ask for some processes to be run and the avatar responds according to the context using natural language, running some statistical or data mining processes or similar as required.

Thus, the complete process of information compilation and manipulation, the knowledge extraction, the trial execution support and control, the analytical processes parameterization and execution, and finally, the results interpretation are executed in a transparent way to the scientists, as seen in Fig. 3. A general example of use of the platform will comprise the following steps:

- Scientist has an initial hypothesis and research the state of the art for similar studies and outcomes. The system answers with related literature and previous outcomes obtained. In case outcomes are significantly negatives, the system suggests trying another method or study. The avatar is the primary interface used with that aim.
- During trial execution, the system checks whether the partial results are aligned with the initial hypothesis, showing alarms when necessary. It also checks the accomplishment of regulations and good practices.
- After trial execution, the system runs analytical processes to check whether the hypothesis has been confirmed on the one hand, and on the other hand, discover new relevant non-obvious knowledge. The results are also introduced on the knowledge base.
- During all process, the system checks automatically the data sources for new relevant information to annotate it in the knowledge base.

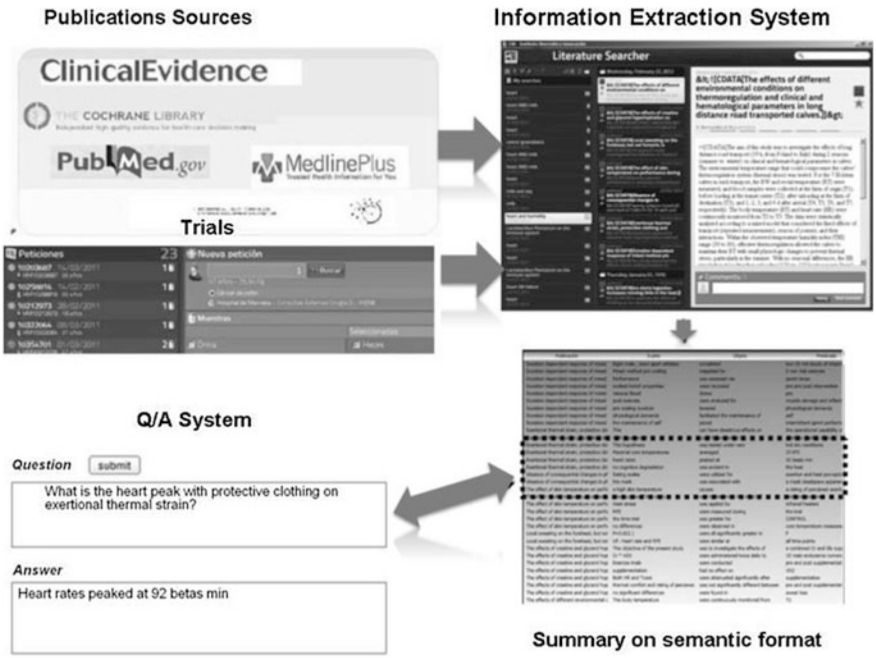

Fig. 3 Information retrieval system process (screen captures of the HENUFOOD developed platform)

6 Future Work

HENUFOOD is starting its last year of research and this is why although most of the procedures and functionalities previously described are fully functional prototypes, the intention is to use this year to increase the stability, performance and maturity of the whole system.

Another key point to improve is the better integration of all of its components and the integration of more external data sources in order to improve the central ontology. Furthermore, this ontology is continuously fed with new knowledge from the execution of clinical trials.

Finally, as the intention is let scientists use all the resources and take benefit of the knowledge base with questioning answering techniques using natural language processing with the avatar, empowering it with more flexibility and actions to take would be a good direction to follow.

Acknowledgments The present study is supported by the company Ibermática through HENUFOOD Project (CEN-20101016), part of the CENIT program from Spanish Minister of Economy and Competitiveness.

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Part II
Energy Efficiency

Big Data Technology to Exploit Climate Information/Consumption Models and to Predict Future Behaviours

A. Cortés, A. E. Téllez, M. Gallardo and J. J. Peralta

Abstract This study presents a work in progress of the Smart Home Energy project (SHE), in which tests and simulations have generated a large set of energy consumption data that has been evaluated analytically to define a prediction model for energy consumption, based on automatic machine learning. The SuperDoop Lambda Arquitecture developed by Ingenia for Big Data implementation used in the SHE project allows implementing a service to do predictions massively, developing a personalized home energy knowledge model for each home. These methods and related technology can be used also for other energy consumers, like shops, offices, buildings, industries, electrical vehicles, etc.

Keywords Big data · Lambda architecture · Hadoop · Storm · Data mining · Data science · Neural networks · Energy consumption predictive model · Energy efficiency · Energy home knowledge

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_3, © Springer International Publishing Switzerland 2014

1 Introduction

Nowadays, the awareness of reducing CO_2 emissions is increasing all over the world and many studies are focused to propose solutions to reduce energy consumption regarding our lifestyle, especially in residential sector: energy consumption prediction, energy efficiency, energy bill managing, etc. The Smart Home Energy Project (SHE) [1], supported by the Spanish Ministry for Economy and Competitiveness, proposes a full solution to manage, control and improve home energy bills through a tool based on DH Compliant devices [2]. In order to achieve this objective, several approaches have been evaluated from different points of view, considering the aspects of many stakeholders like energy suppliers, energy consumers, energy corporations, industrial sector, among others. One of the proposals that satisfy most of mentioned groups is the use of a two-step procedure composed of energy simulations on the first step and learning process based on artificial intelligence, e.g. machine learning algorithms.

Through simulations a large set of energy consumption data has been acquired and evaluated analytically in order to define a prediction model of home energy consumption based on automatic machine learning, which is a subset of algorithms related to artificial intelligence that make it possible automatic learning of the system performance. These algorithms have been studied in order to forecast energy consumption, what furthermore would allow classifying and making energy efficiency recommendations. In addition, SuperDoop Lambda Architecture has been used to implement a service that can make energy consumption predictions for a massive set of homes with a massive set of data for each one. This will allow us to build a characterized model of prediction for each controlled home. This methods and technology can be used also for other stakeholder solutions.

2 Weather Data and Modelling

As mentioned above, data required for current assessment has been obtained thanks to SHE project, which aims at obtaining energy savings in residential and tertiary buildings. In this section, the main components involved will be shown in order to clarify the different steps of the investigation.

The energy consumption in residential buildings can be divided in the following components: lightning, heating and cooling, and finally other equipments like appliances, office equipment and electric machinery. The main energy sources used in this kind of buildings are electricity, natural gas, butane and diesel, but a decomposition based on energy sources cannot be generalized, due to there are a high number of variables that are involved in energy consumption, like the city meteorology, house geometry, thermal envelope, purchasing power residents to buy facilities of different energy performance, number of residents, occupancy changes along the day, user behaviour, thermal perception, and finally the level of awareness about the use of energy related to environmental impacts.

Thus, the weather zone has a significant impact on heating and cooling energy consumption because buildings placed on soft climate zones do not require as amount of energy to reach the thermal comfort as others with harsh winters or summers. For instance, natural ventilation through fenestration usually is enough most of the year in warm climates.

On the other hand, thermal envelope is considered the main passive element a building has to isolate the indoor thermal conditions from the outdoor environment, since thermal isolation, solar protections and the infiltration level are usually positive factors to keep comfort conditions, minimizing the amount of necessary energy. In addition, the thermal storage capacity of envelope and indoor elements, e.g. walls and furniture, creates a thermal inertia that cushion variations of indoor thermal conditions against the outdoor environment fluctuations. For this reason, a proper evaluation of thermal inertia, opaque enclosures (walls, roofs, ceilings and floors) and glazing helps energy auditors to reduce the number of hours HVAC system is working for keeping comfort conditions.

Focusing the study on residential buildings and taking into account conclusions of SPAHOUSEC project [3], the first necessary classification in order to model the thermal behaviour of building was isolated houses and apartment blocks. This classification is mandatory because boundary conditions depend on geometry and the different zones a partition separates. For example, a house that belongs to an apartment block with a ceiling instead of roof will have better thermal conditions than other with the entire envelope in contact with the environment. The final report of SPAHOUSEC defines the average Spanish residential building regarding facilities, occupancy and appliances.

2.1 Weather Data

Heating and cooling demand are directly related to weather fluctuations, since HVAC systems try to keep the home temperature within comfort conditions. Therefore, the analysis of weather data is mandatory on current assessment. In Spain, Código Técnico para la Edificación (CTE) [4] set every capital cities in 12 climate zones. To force a new building complies with the energy demand limit, CTE establish a minimum transmittance value (W/m^2) for the walls and fenestration depending on the orientation and the kind of construction (floor, wall, roof and ceiling). In this way, combinations of different construction materials regarding thermal conductivity, density and thickness is limited to every climate zone.

In order to simulate environmental conditions, the weather data published by EnergyPlus [5] has been used since its database includes hourly data for all the Spanish capital cities. The indoor conditions have been established according to set points limits recommended by IDEA (www.idae.es), i.e. 21 °C in winter and 26 °C in summer.)

2.2 Modelling

When the simulation building model was defined, different possible envelope configurations, which could be found in Spain, had been considered. For example, it could be found buildings with only outdoor walls or others with up to three walls in contact with other buildings, i.e. a townhouse or apartment blocks. This fact makes unable to consider all possible cases regarding orientations and weather zones, as mentioned above. Therefore, it has been necessary to simplify the building model with the following characteristics: 100 m^2 floor area, 34 % glazing and 3.5 m height, including different partitions to simulate the indoor inertia, for instance kitchen, living room and bedrooms. For every room hourly profiles have been defined based on occupancy, facilities, internal gains, lighting and other devices according to [3] conclusions.

Therefore, four configurations have been defined according to boundary conditions in outdoor walls, what allows evaluating between different kinds of residential buildings that could be found actually (see Fig. 1). Every outdoor wall has its own fenestration surface.

Simulations aim at obtaining the heating and cooling energy demand for each type of residential building and combination according to orientations in every defined weather zones. The use of passive elements like blinds on fenestration has been considered, since actually has an important effect in energy demand, blocking the solar radiation but, in some cases, increasing lightning consumption in some hours.

The building model has been implemented in EnergyPlus [6], programming the different combinations for each Spanish weather zone, where envelope characteristics have been defined to comply with CTE restrictions. The implementation of the building models has considered the following parameters:

- Weather zone: the 12 zones described by CTE.
- Orientation: four orientations rotated 90° on each case.
- Number of outdoor wall: from 1 to 4 outdoor walls.
- Open-close blinds: two options (fully open, fully closed).

The electric consumption has been modeled using the *ElectricEquipment and Lights' EnergyPlus* modules. In both, following parameters have been defined, among others, in order to control the performance:

- The rated power of each zone is based on conclusions in [3] and average electric power of the most widespread appliances in Spain.
- Behaviour profiles: in order to simulate switching on/off of home electric facilities, hourly profiles have been defined according to the human behaviour described in [3] and other assumptions based on typical appliances used in Spain. Since this element can change drastically from one household to another, a simple approach has been considered to define the learning process that SHE prototype will have implemented.

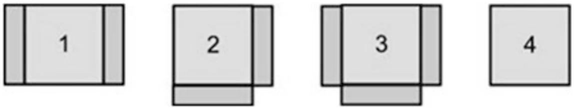


Fig. 1 Possible configurations according boundary conditions. *1* (2 orientations); *2* (4); *3* (4); and *4* (1). Adiabatic walls in *grey* (assumption)

- Thermal loads: radiant, latent and lost energy fractions have been implemented according to [7] suggestions.

Three different zones, which are typical in Spanish houses, have been defined: bedrooms, kitchen and living room. Each zone has got assigned different values for mentioned user-profile parameters; for instance, kitchens usually have higher energy consumption than living rooms, whereas bedrooms have the minimum one. A similar approach has been considered for lightning and occupancy, with different energy factors depending on the zone.

However, EnergyPlus allows only defining and simulating a building with fixed parameters so it has been necessary to use additional software called JEPLUS [8], which allows parametric simulations. As result, 1440 simulations have been performed, which is a representative sample of the behavior of such housing in the different climatic zones.

In order to find a simple prediction procedure, several regression models have been evaluated, being multivariate linear regression model which has shown the best results. The input variables that have demonstrated a better correlation in order to predict the building energy demand were the following: hour (1–24), dry-bulb temperature, relative humidity and global radiation. The multivariate correlation coefficient obtained in different tests was about 0.80, what indicates there could be correlation. Though this is not the best method compared with others like neural networks, it allows a simple and manageable calculation way for most of cases. Regression adjustments have been validated yearly, for each season and monthly, verifying the latter the best.

The Fig. 2 shows the comparison of the heat demand for the winter season in one of the climatic zones obtained by multivariate linear regression method and compared with data from EnergyPlus simulation. It must be mentioned a regular pattern can be observed and this phenomena has motivated this study partially.

In addition, Fig. 3 shows a comparison between the cooling and heating energy demand for a typical summer and winter day respectively, obtained by a multivariate linear regression model and EnergyPlus.

The accuracy of this multivariate linear model could be questioned by two mean reasons: the peak loads do not match with the linear approximation and the error level that can be observed for cooling conditions is too high in order to implement the model in an expert system. However, the prediction performance of linear regression for heating conditions shows a better result and could be useful for design criteria.

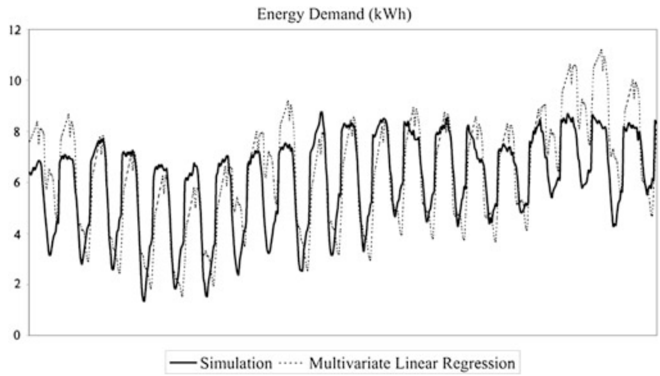


Fig. 2 Comparison linear regression estimation versus EnergyPlus simulation

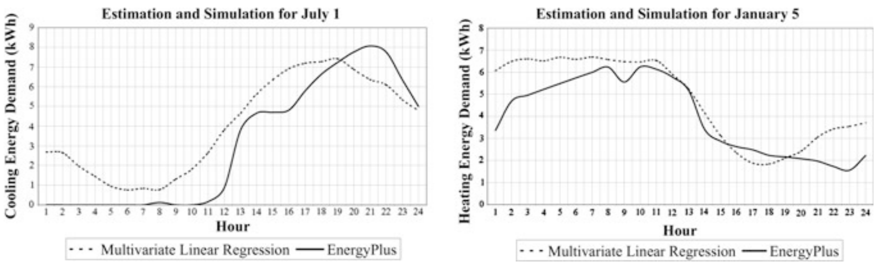


Fig. 3 Comparison of heating and cooling energy demand in two days (linear regression vs. EnergyPlus simulation)

3 Big Data Description

Energy consumption metering generates large data sets. In order to acquire, store and process this amount of data sets it is needed a system that scales horizontally with the number of houses that will send measurements, providing the needed services within a tolerable elapsed time.

Smart Home Energy project uses SuperDoop and allows making massively predictions and develop a customized "consumer energy knowledge" for every home, working on massive data set for each one, through heavily process machine learning algorithms.

SuperDoop is a Hadoop [9] and Storm [10] based Open Source stack integration made by Ingenia that scales horizontally in order to solve challenges that include acquisition, curation, storage, searching, sharing, analysis, and visualization of large data on a tolerable elapsed time. This can be used in general purpose applications, e.g. communications, banking, security, smart cities, energy efficiency, emergencies, social networks… and many others specific areas.

SuperDoop was first presented at ICSEA2012 “The Seventh International Conference on Software Engineering Advances” as technology support into a work in progress [2], and fits into the Lambda Architecture concepts published by Nathan Marz in fall 2012 [11]. The designed architecture also identifies an additional layer to solve the data acquisition, in order to solve the challenge related to bring the data to the speed and batch layers, following the Lambda Architecture nomenclature we named it as Acquisition Layer.

Several solutions can be applied to for the Acquisition Layer challenges, requisites and problems that are very different to other layers ones, and there could be as many as systems where or trough we acquire data. The Acquisition Layer must be an isolated layer, solving problem separately most as possible from speed, batch, and service layers.

Focusing the Smart Home Energy project, weather data needed to make the consumption predictions, in a worldwide approach, is highly varied because of different sources (meteorological services and institutions), formats, and protocols. Short time meteorological predictions also changes frequently, where an hourly interval is usual to get new predictions for the next 72 h, this also mean that predictions done also could be changing hourly.

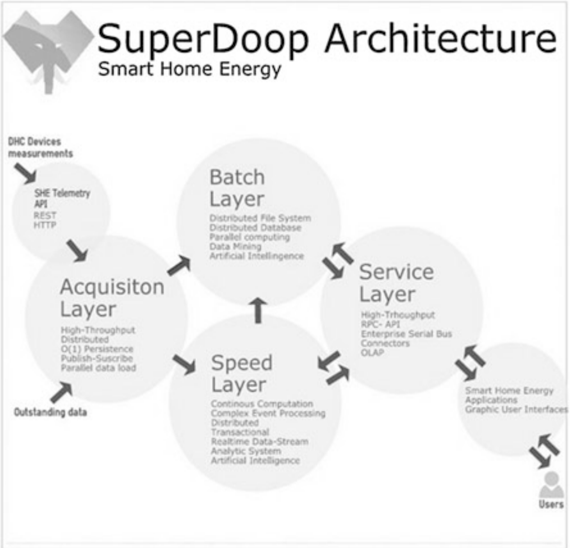
Smart meters in the Smart Home Energy project send measurements under the designed protocol and telemetry API for SHE. There is no variety of data formats, because a common protocol is used, but there are many data sources (meters), and a high amount of data that increases linearly with the number of devices.

The SuperDoop architecture Acquisition Layer solves the data acquisition problem to the speed and batch layers. This concept has been implemented as a prototype in a flexible way for SHE using the http protocol REST and JSON API, a temporal storage or cache using MongoDB, and a Redis based system for the speed data layer data insertion [2].

The Speed Layer for the Smart Home Energy project was needed to provide a close to real time monitoring and control capabilities for users through a Graphical User Interface. This layer needs to make some calculation and aggregation with the data, as typical functions as average and summarization, for each user, group of devices, and time intervals in a continuous computing close real time [11]. Finally this layer provides this information to the service layer in order to make this data available for the GUI application.

The Batch Layer for the Smart Home Energy project includes several components to store and process the data, using data mining and machine learning algorithms to acquire a customized knowledge for home energy consumption. These algorithms can be executed massively for each home, each user, many times at day to learn and predict the consumption using a large set of data for each execution.

Fig. 4 SuperDoop architecture



The Service Layer for the Smart Home Energy project includes data publishing for both, the batch layer and the speed layer, through a REST API, that allows the GUI application to query and receive data and to stream data to the GUI (Fig. 4).

4 Advance Predictions and ANN

After different attempts performed to match energy demand simulated with multivariate regression models, next step was to prove implementation of artificial neural network models (ANN) as [7] suggested in the review of energy prediction models for buildings. Several studies can be found in bibliography about prediction of building energy consumption and temperature forecaster based on ANNs like [12, 13, 14]. ANNs have well-demonstrated high accuracy predicting energy demand and consumption in buildings but with the main drawback this method need a learning process for identifying the particular patterns that define the system performance or behaviour. In this case, a simply ANN (3 hidden layers, using a symmetrical sigmoid as activation function and a 0.1 of learning ratio) has been tested with the back-propagation algorithm [15], using as input parameters outside temperature, outside humidity ratio, previous hourly energy demand, among others.

The obtained results have satisfied survey expectation since using short-term ANN for energy demand prediction has shown an average error of 3 % during a complete year simulation (see Fig. 5) what constitutes negligible deviation compared with typical estimations that usually energy experts make in energy audits (more than 20 %).

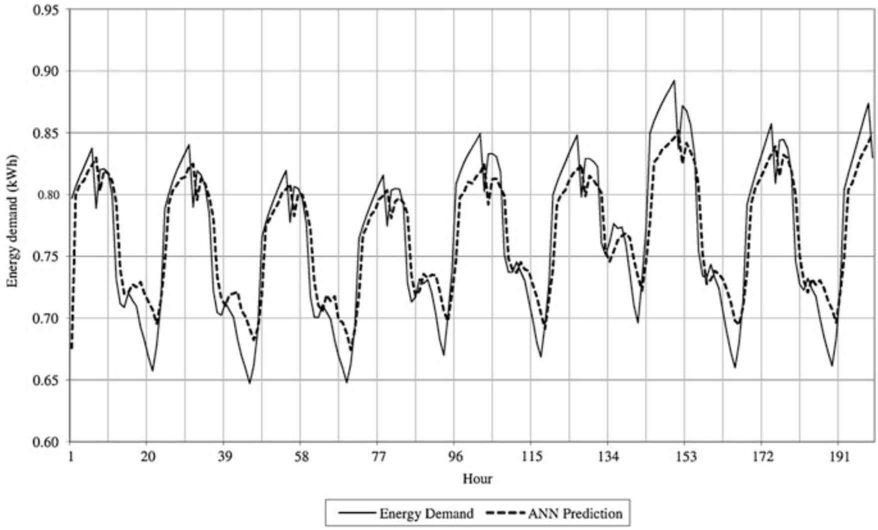


Fig. 5 Comparison of building energy demand and ANN prediction

The mentioned accuracy has been achieved even with simple ANN composed by 5-neuron layers designed for estimating the thermal energy demand of a house as output, paving the way to design a robust energy forecaster. In order to include the data in the forecaster, the value of input parameters have to be established between 0 and 1. For instance, in this study outside temperature T_{out}, humidity ratio ϕ and previous energy demand d_{k-1} have been transformed according with following equations (1), (2) and (3):

$$T^*_{out} = \frac{T_{out} - T_{\min}}{T_{\max} - T_{\min}} \tag{1}$$

$$\varphi^* = \frac{\varphi}{100} \tag{2}$$

$$d^*_{k-1} = \frac{d_{k-1} - d_{\min}}{d_{\max} - d_{\min}}, \tag{3}$$

where min and max subscripts are related to the minimum and maximum historical temperature and potential demand respectively. Once the ANN calculate the current energy demand d^*_k, inverse transformation is easy to understand according to (3).

As mentioned above, ANNs need a learning process in order to modify the synaptic weights that allow the network to integrate the performance of a complex system. In this study, an example has been tested to show actually the potential of this method. In Fig. 6 can be observed the ANN prediction for a winter day after 100 epochs with 8760 samples, improving the average error less than half.

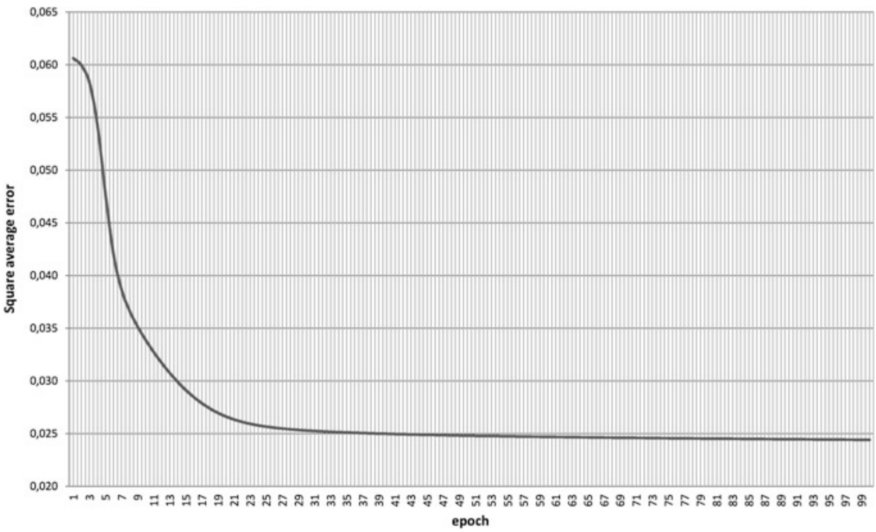


Fig. 6 Evolution of square average error in the learning process (100 epochs)

Current assessment was focused without considering set of seasons, different months, bank holidays… in order to obtain a better accuracy since another more sophisticated algorithm exists, called support vector machines (SVM), which has into account the identification of behaviour patterns related to the probability an event occurs based on input parameters [16]. This mixture of artificial intelligent and statistical approach, e.g. regression models, confers a highly effectiveness in solving non-linear problems with reduced training data, as our current project, what shows this model as the ideal candidate for energy consumption prediction in buildings. In addition, due to the robustness of this prediction method, potential perturbations, which could appear by adapting the smart home system to new buildings, will be mitigated as it is mentioned in [17].

5 Proposed Solution

Using SuperDoop allows receiving metering and does both a batch and a continuous close to real-time processing of the measurements, working with a large set of measurements taken along the time from a large set of homes and historical data. It allows applying ANNs and machine learning algorithms for each home using stored and real-time data, thus can be used to acquire personalized consumption knowledge for each home. The system will start from the initial information obtained from simulated data, so that could be trained in a continuous learning process using actual data from the house measurements and weather conditions.

6 Discussion About the Proposal and Working Lines

Applying SuperDoop in the SHE project will make possible to receive metering and do both a batch and a continuous real-time processing of the measurements, processing a large set of measurements acquired along the time from a large set of homes and historical database. It allows applying ANNs and machine learning algorithms using stored and current data, thus can be used to learn the consumption behaviour of each home. The simulated data generated from climate historical data and simulated buildings outfit the forecast system with previous knowledge that can use to predict energy consumption in homes with similar characteristics, what can be evaluating after a logical classification of evaluated homes. After all, real measurements of each home, and meteorological conditions, could develop a customized knowledge that progressively will replace the previous knowledge. This allows the system to acquire the ability of predicting consumption for each home through the customized home energy knowledge.

Acknowledgments This project is funded by the Ministry of Economy and Competitiveness of Spain (IPT-2011-1237-920000). We are also very grateful to all the members of the consortium (Ingenia, Satec, Ingho, Tecopysa, Cotesa, IAT, University of Oviedo).

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Identification of Electrical Devices Applying Big Data and Machine Learning Techniques to Power Consumption Data

M. Rodriguez, I. González and E. Zalama

Abstract The efficient use of resources is a matter of great concern in today's society. Specifically, power consumption has led to small networks that incorporate management systems, which are also being integrated in other networks that increasingly cover larger installations (homes and offices, buildings, districts, cities, etc.). From the natural evolution of the common services management, the concepts of Smart Grid and even Smart Cities have arisen strongly, pursuing the efficient management of resources, which is the strategic investment of these complex and smart systems. One of the biggest restrictions on setting up an intelligent environment is the lack of interoperability between different devices. In this context, the need to be able to identify the devices connected to the network will allow to automatically execute a software adapter that makes the device interact with the whole system in a standard way. Achieving that objective could also bring other positive consequences, such as being able to anticipate energy demand. Based on the idea that the amount of consumption data is large and is increasing, the suitability of using big data techniques to handle this information, combined with automatic machine learning techniques to extract value from such a large amount of data, is proposed in this work in progress.

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_4, © Springer International Publishing Switzerland 2014

1 Introduction

Ideally, a Digital Home is an intelligent environment that learns and adapts to the needs of its occupants. For this purpose, its components, such as domotic systems and service robots, must be able to communicate with each other and also with the user. However, there is a lack of interoperability between systems of different manufacturers, solved partially thanks to DH Compliant (DHC) [1] technology.

In particular, DHC2.0 is the second version of a standard communication protocol at the TCP/IP stack application level that includes the corresponding adapter for each device. This protocol allows the intercommunication between devices that comply with a label like the one shown in Fig. 1, which ensures the suitability of their adapters.

The next step in the integration of DHC devices in the Digital Home would be to identify them when they are connected to the grid. Thus the corresponding adapter could be deployed automatically and from that moment the device could interact with the environment.

Among other modules, DHC contains a block dedicated to improve energy efficiency called DHC Energy, and this specific part is integrated in the Smart Home Energy (SHE) project [2]. The SHE project arises from that need by establishing the concept of energy and smart grids in the DHC communication protocol. A set of concepts and energy management savings are defined to allow the user to know in detail the energy consumption data in the Digital Home environment.

Given that consumption data is already obtained, uploaded and stored in a cloud by the SHE adapters, the initial idea is to use said data for device identification, as can be seen in Fig. 2.

The document is organized as follows: firstly, an overview of the researches related to the identification of electrical devices is exposed in the State of the Art section. Then the design of the experiment is described, followed by the way in which data is collected and the proposal for its processing using machine learning techniques. Finally, the document closes with some conclusions and all references used.

Fig. 1 DH2 Compliant label

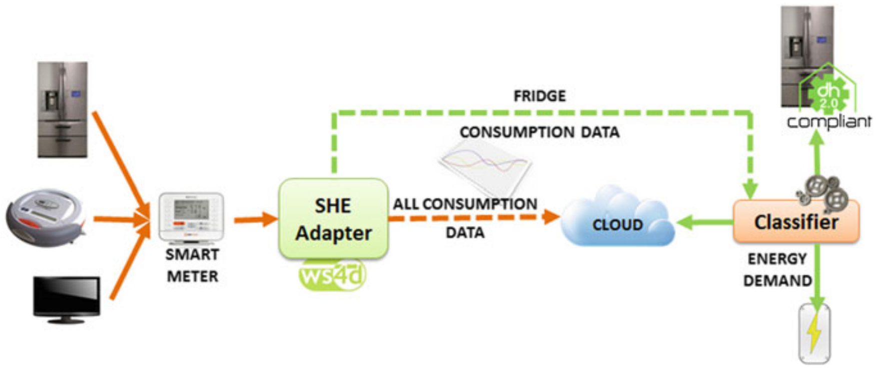

Fig. 2 General overview of the proposed system

2 State of the Art

The topic of the automatic identification of electrical devices was proposed for more than a decade in several studies [3, 4]. At that time, Smart Meters were a very expensive technology, effectively limiting its use to a single device, located at the point of entry/exit of the house, and it had to be able to identify the power consumption of each appliance separately. In particular, a non-intrusive method was presented in [5] based on the algorithm of George Hart [3], to recognize a representation of a finite state machine consumption of an appliance over time, given the consumption changes (up and down).

After years of relatively little research in the field, it seems that new ideas have emerged more strongly, perhaps driven by the new possibilities that have arisen around the concept of Smart Grid and new technological opportunities. Thereby two problems are exposed in [6]. Firstly, decomposing the signal into a set of signals (one from each device), and secondly, identifying which device corresponds to each of those signals. The proposed method needs to have a database of different electrical signals appliances. Building it manually is not feasible, hence they suggest the use of statistical methods.

As for the data used as input for the research, the approaches which focus on using consumption data are relevant to this study. In general, two main approaches are followed. On the one hand, obtaining very accurate data, but using a lower rate. This data is processed by simple software that analyzes it [7, 8]. This option requires special hardware so it does not fit with the initial idea as stated before. On the other hand, there are studies based on measuring a lot of data but not very accurately, therefore necessary software for analysis becomes more complex. Specifically, most studies are based on machine learning techniques, considering the use of different algorithms such as Hidden Markov model [9], Nearest Neighbor, Gaussian Naïve Bayes, Decision Trees (DT) and MultiBoost [10], Neural Networks [11], Radial Basis Function [12], Support Vector Machine [13] or Genetic Algorithms [14].

Although a great deal of progress has been made, the problem of identification has not been resolved with guarantees. Firstly, the methods are not yet fully automated. Furthermore, they do not take into account the possibility that more than one device may change its state at a time or may have similar consumption values. In addition, many of them fail to recognize low consumption devices which are not considered if the total consumption is large.

3 Data Collection

As already mentioned, data required for the experiment is obtained thanks to the SHE project. In this section the main components involved in that operation are included.

3.1 *Smart Meters*

With regard to the hardware requirements, it is necessary to have an intelligent measuring device (Smart Meter) which will report information in real time about the power consumption. It has to be pointed out that the SHE project aims to be independent of the measuring device. Specifically, the Smart Meters [6] and its plug devices for connection shown in Fig. 3 are the devices that have been used. The data, collected by a software adapter based on in Devices Profile for Web Services (DPWS) technology, will be sent to the cloud after a process of extraction and filtration of useful data.

3.2 *Cloud*

The consumption data collected from the digital home is centrally stored thanks to cloud technology, which moreover does not require high-capacity storage in

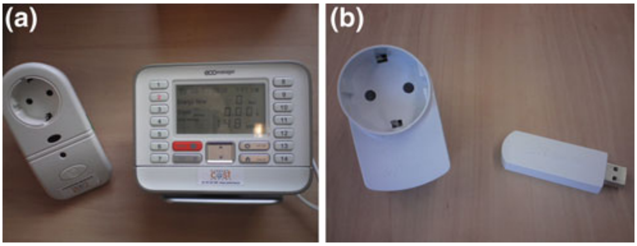

Fig. 3 **a** EcoManager smart meter (current cost), **b** Plugwise smart meter

homes. It also gives facilities to manage and maintain the integrity, security and availability of data, storing replicated data to ensure recovery in case of a loss of information.

3.3 Smart Home Energy Production Environment

In order to work with data as real as possible, a production environment has been created. Consumption data is obtained every minute through two Smart Meters of different manufacturers, which are connected to three and five appliances respectively. The specific appliances that have been used in the experiments can be checked in Fig. 6. The DPWS software adapter uploads the information to the cloud, where it will be stored.

The consumption data for each Smart Meter can be seen as plotted in Fig. 4. In this case, 3 h consumption data through EDF Eco Manager Smart Meter is represented.

Once the consumption data obtained is analyzed, it can be deduced that the loading phase pattern remains constant for all of them. Figure 5 shows consumption in watts for the fridge during the first 5 h, and then, how the patterns are repeated in the next 24 h.

3.4 Big Data

The experiment is proposed for eight appliances, but it must be considered that the number of devices will grow exponentially. Therefore, the amount of consumption data will increase. In the gap between the very expensive solutions of specific hardware supercomputers and enterprise servers, Big Data technology can solve the problem for storage, growth, and process large data amounts from greater user amounts. Furthermore, Big Data provides other useful characteristics, such as facilities to use machine learning algorithms, visual mining tools, mixing heterogeneous data, etc. Finally, another advantage of using Big Data is that the infrastructure does not require a high initial investment.

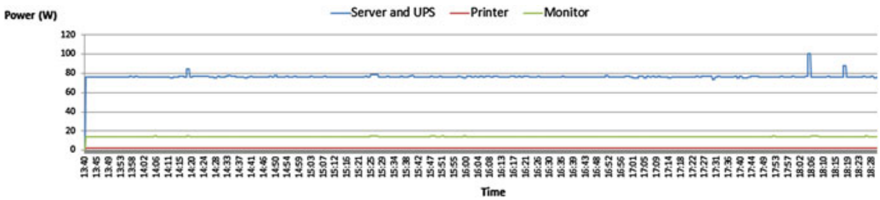

Fig. 4 Three hour consumption data obtained through EDF eco manager smart meter (power values refers to server, 3D printer and Monitor)

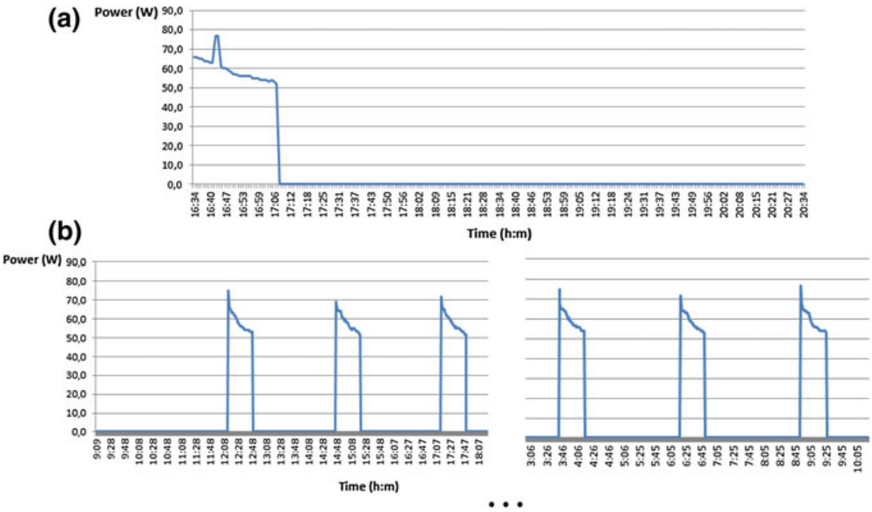

Fig. 5 **a** Power consumption of the fridge during 5 h, **b** Power consumption of the fridge during 24 h

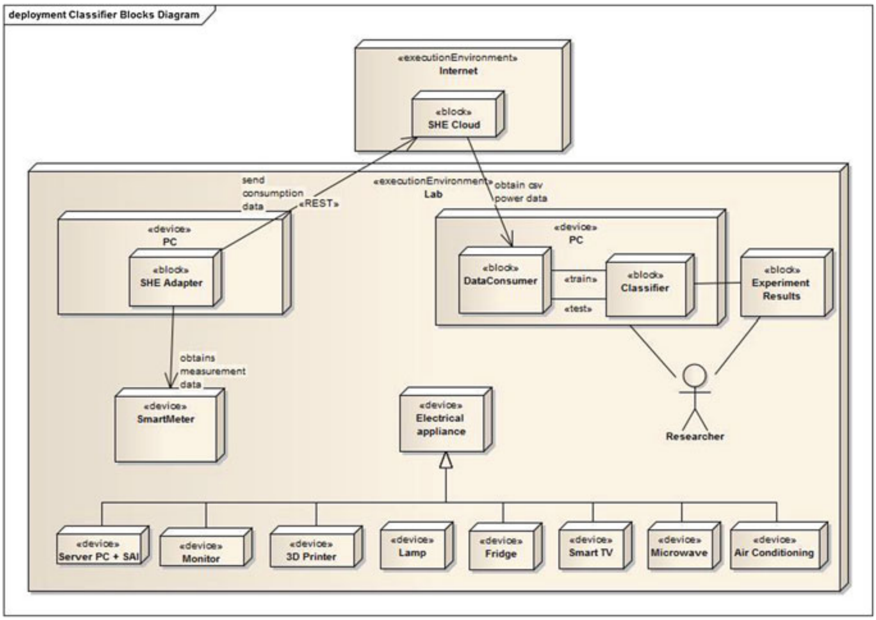

Fig. 6 SysML blocks diagram of the experiment

4 Proposed Solution

4.1 Machine Learning with Mahout

Mahout [15] is an Apache project that aims to produce a free implementation of a package that includes the main Machine Learning algorithms. The project is very active, but there are still algorithms to be incorporated. Its main advantage over other implementations of automatic learning is scalability offered by being able to run on Hadoop [16].

The algorithms offered by Mahout can be classified into:

- *Recommendations or collaborative filtering*: enables users to create profiles in order to predict the ranking that a user would give to a particular item, based on the ranking given by other users of the same profile.
- *Clustering*: unsupervised learning that allows to group objects with some similarity previously unknown.
- *Classification or categorization*: supervised learning that helps to determine whether a particular object belongs to a specific category.

In our research, the classification methods allow us to decide to which device belong some specific consumption data belongs, and a clustering algorithm can help to select the interesting input data in order to improve the results of the classification.

4.2 Power Consumption Data Classification

As mentioned before, the purpose of this study is to identify which device produces a specific consumption data series that acts as input of the system. In other words, making a classification of the power consumption input data. This classification involves three main steps when using Mahout:

- *Training the model*. Initially the target and predictor variables are defined. In this case, the target variable is the ID of the appliance. These identifiers are preset in advance. Specifically the devices found in the production environment listed by the ID are server PC, 3D printer, monitor, lamp, fridge, microwave, smart TV and portable AC.
  The next step is to define the predictors. In a first interaction, only the consumption in watts is considered.
  The implemented software will process eighty percent of the consumption data using one of the learning algorithms offered by the tool [17].
- *Evaluation and adjustment of the model*, running the remaining data (twenty percent of the original data). In this step it is possible to adjust the input variables and the learning algorithm used.

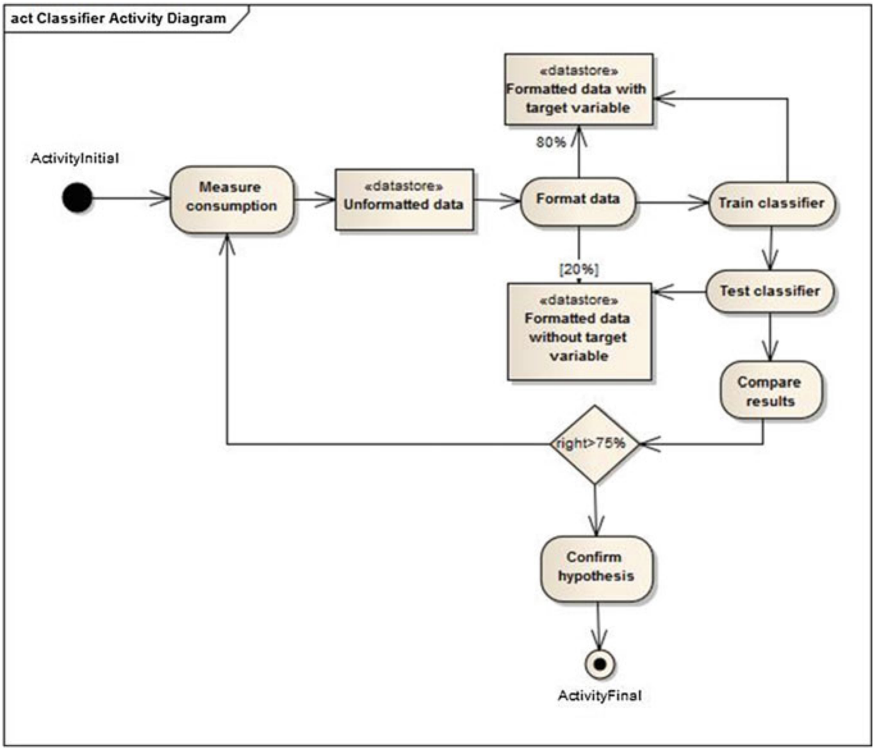

Fig. 7 SysML activity diagram of the experiment

- *Using the production model*, performing the classification with real data.

The components involved in the experiment are depicted in Fig. 6.

The process carried out in each iteration of the experiment is shown in Fig. 7.

Taking the consumption in watts as predictor variable and Stochastic Gradient Descent (SGD) as training algorithm, the number of correct classifications is reflected in an average value of 0.66 for Area under Curve (AUC) (where 0 indicates a classifier that is always wrong and 1 indicates one that is always correct) so it becomes necessary to refine the model until reaching the desired value of 0.80 for AUC. The proposals to design an improved model are outlined in the following section.

5 Conclusions and Future Work

Given the results exposed in the previous section, a refinement of the model has to be carried out. To achieve this, two main ways are proposed:

- Clustering techniques will be applied to all the consumption data obtained from Smart Meters, in order to find out other possible side variables that may be involved in distinguishing electrical loads, since the experiments carried out with the consumption in watts as predictor variable have not produced optimum results.
- The training phase will be held with different learning algorithms. From the state of the art, both Dynamic Time Warping (DTW) and Longest Common Subsequence (LCSS) can be considered as the most suitable algorithms for time series. These algorithms are flexible over time. However, neither of them have as yet been implemented in Mahout. Therefore, preliminary tests with a small amount of data could be performed with software such as Matlab.

Regarding other future improvements, the noise introduced by the electricity provider has to be taken into account as well as the consumption of the Smart Meter devices used in the experiment. Moreover, some appliances could have multiple configurations that could influence their identification.

In short, it can be concluded that this ambitious approach, which is still at an early stage, could provide more interesting results in the future. This can be achieved by enhancing the idea of developing a more ingenious and precise method by means of the techniques described above, allowing the identification of electrical appliances with more guarantees.

Acknowledgments This work is being possible thanks to the financial support of the Spanish Department of Science and Technology, the Ministry of Industry, Energy and Tourism and FEDER funds. We would like to acknowledge the continuous support given by the University of Oviedo, and their management of the DHCompliant 2 project (TSI-020100-2011-313). We are also very grateful to all the members of the DHCompliant 2 consortium, composed by Infobotica Research Group, Ingenium, Ingeniería y Domótica S.L. and Domotica DaVinci. We are also very grateful to the Ministry of Economy and Competitiveness of Spain for making possible the Smart Home Energy Project (IPT-2011-1237-920000) and to all the members of the SHE consortium (Ingenia, Satec, Ingho, Tecopysa, Cotesa, IAT, Infobotica Research Group).

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Knoholem: Knowledge-Based Energy Management for Public Buildings Through Holistic Information Modeling and 3D Visualization

G. Anzaldi, A. Corchero, H. Wicaksono, K. McGlinn, A. Gerdelan and M. J. Dibley

Abstract The mismanagement of energy in public buildings is related with the continuous growing up of energy consumption. Energy efficiency concept is one of the main awareness in the current society. The main contribution of the paper is focused on describing intelligent energy management architecture capable of intelligent generation of recommendations taking into account infrastructure behavior (building), user behavior (occupants of the building) and holistic techniques (recommendations and knowledge from other buildings). This article describes an approach developed under European Union project called KnoHolEM. Project solution is characterized by: (1) Support buildings in (near-)real-time energy monitoring through smart metering; (2) Knowledge-based development of intelligent energy management solutions, supporting interoperability between heterogeneous systems and assisted by algorithms for energy consumption,

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I. González Alonso (ed.), *International Technology Robotics Applications*, Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_5, © Springer International Publishing Switzerland 2014

optimization and rationalization. (3) Simulation and virtual-aided validation of these intelligent energy management solutions and their configurations. (4) Closed-loop building control.

1 Introduction

For the last few years, energy efficiency has been considered as one of the major issues in any sector, including building. According to the European Union (EU), the building sector is one of the main contributors to greenhouse gas emissions (GHG emissions) with 36 % of EU's total CO_2 emissions. Furthermore, public and residential buildings energy consumption is more than 40 % of whole demand in EU [1]. Aligning these aspects with the scarcity of natural resources, the growing of energy prices as well as public opinion regarding climatic changes, awareness on energy efficiency has grown up inside current society.

Nowadays, energy management concept is aligned with the achievement of maximum possible energy savings. Most of the energy saving measures that have been applied up to date in buildings, focus on the improved thermal isolation technologies, energy efficient air conditioning and devices, extended usage of energy saving light bulbs, as well as to intelligent electricity meters. Nonetheless, this mentioned activities that have overcome up to date ("classic" approach) are not sufficient. In parallel with "classic" approach have been emerging other methods based on intelligently avoiding energy wasting and optimization of energy demand and consumption. This emerging method empowers energy management in an efficient way by an intelligent solution. An intelligent solution refers to the analysis energy consumption based on correlation among building, office-specific processes and use-cases.

A project called KnoHolEM has been launched to develop a novel approach of an intelligent energy management in building. KnoHolEM is a collaborative research project co-financed by the European Commission within the scope of the 7th Framework Programme. Its international consortium consists of 13 partners (Building Research Establishment LTD; Karlsruher Institut fur Technologie; Trinity College of Dublin; Centro di Progetazzione, Design and Technologie dei Materiali; Cardiff University; Steinbeis Innovation gGmbH; Isotrol SA; Stichting Smart Homes; Woningstichting de Zaligheden; Stiching Hoger Beroepsonderwijn Haaglanden en Rinjnstreek; Fundació Privada Barcelona Digital Centre Technologic; Matrix SPA; and Tera SRL) from six different countries (United Kingdom, Germany, Ireland, Italy, Spain and Netherlands). KnoHolEM includes five demonstration object buildings in Spain (Barcelona and Seville) and the Netherlands (Eersel and The Hague) that are used by the consortium to develop, enhance and extensively test the solution. An overall knowledge-base is created through a detailed analysis of the structure of the demonstration object buildings and their energy consuming/producing devices, through the intelligent interlinking of building usage with its energy demand, as well as by various energy consumption behavior simulations.

2 Objectives

The KnoHolEM project's main aim is the engineering of an intelligent holistic energy management solution to considerably reduce energy consumption through: (1) avoidance of energy wasting (as it is caused for example by superfluous illumination, heating or cooling, or simultaneous heating and cooling); (2) intelligent coordination of building facilities (like the combination of sunblind adjustment with ventilation or air conditioning utilization); and (3) optimization of the building's total power consumption through intelligent coordination of the entirely of building activities and use cases that take place in the building's facilities.

Accordingly, the KnoHolEM solution is able to facilitate more than just intelligent minimization of energy consumption. It is capable to identify hidden energy wasting and energy saving potential or even intelligently derive complex energy savings measures.

The solution proposed is intended to be applicable and configurable in any type of public buildings in different European countries. In the same way, the solution shall be capable of be runnable on (near-) real-time hardware controllers installed in the building.

3 Architecture

The proposed KnoHolEM system architecture concept is shown in Fig. 1. It consists of four main components: (1) an ontology knowledge-base that contains a representation of the building functionalities, the building use cases and interaction of users with the building, building usage goals structures and building test cases; (2) a data mining component to automatically discover and update ontology rules on energy efficient and comfortable usage of the building; (3) a simulation and visualization component that provides a user-friendly environment to visual-interactive simulate various building configuration and use cases. Ontology information, rules and goals can also be controlled, modified and simulated by using this environment; (4) interfaces to real buildings that permits a bidirectional communication between the building and the visualization environment.

The proposed architecture is service oriented in which software components have control over individual sensors/actuators through the management of distributed control systems (hardware boxes). The hardware boxes permits group several sensors and actuators of the same domain. The project architecture uses ontology to represent the building domain. Within the scope of the latter, a building ontology is supported by data mining tools that enhance the ontology rules to find energy wasting points.

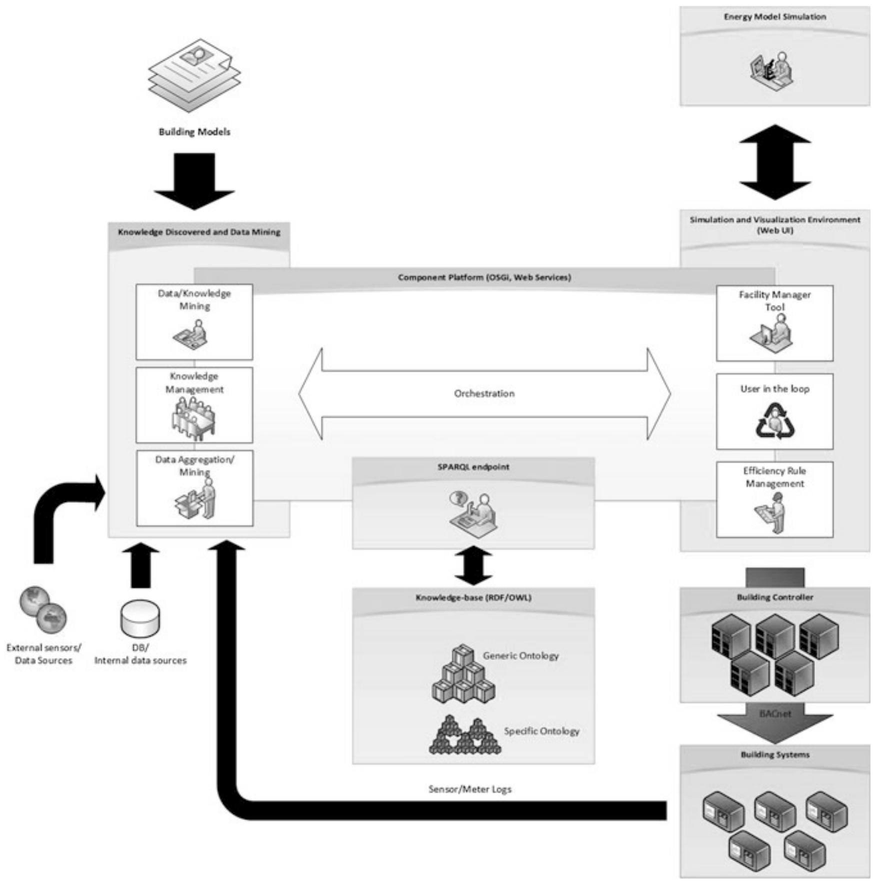

Fig. 1 KnoHolEM general architecture

3.1 Simulation and Visualization Environment

A 3D visualization tool based on building CAD geometries (architectural files) enables monitoring of the building energy consumption and occupancy patterns, configuration of building systems and enhancement of the ontology. The CAD files are converted into a 2.5D representation of the building and visualized in a web browser using WebGL. This solution (See Fig. 2) builds upon work for designing and evaluating smart buildings and smart building applications [2]. This methodology provides a real time virtual representation of the building which can exchange data with the building ontology. The web based interactive visual environment will enable users to explore the building, defining typical routes through the building and zones where activities and interactions with building devices take place. Also, information is presented to the user using visual displays

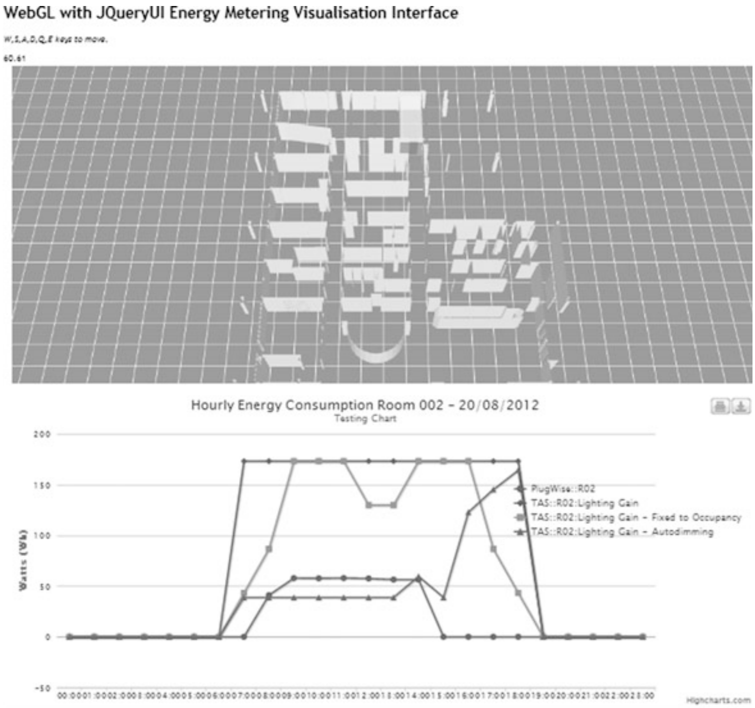

Fig. 2 Simulation and visualization environment (User in the loop concept)

which provide data in real-time about the energy behavior of zones, or devices installed in the building. User behavior and sensor data related to occupancy can be simulated based on activity models to assess energy impacts prior to implementation and, after that configure the final setup to establish security and comfort measures. Simulation procedures generate a bridge between the building ontology and the expert intuition. This process permits the creation of rules manually, the inclusion of new building elements into the building ontology and the automatic inference of ontology rules.

3.2 Ontologies

KnoHolEM ontologies represent the building construction and infrastructure, building automation devices (sensors and actuators), occupant behavior and activities, and potentially the software component's goals primarily for the support of dialog and collaboration between components. The building ontology is created taking into account building specific information from a real plot (demonstration objects). Once all information is structured semantically (with T-box and A-box), decision making on energy behavior of the building is done. T-Box contains the meta-model and semantic definitions based on current standards used generally in the building field, such as Industry Foundation Classes (IFC). IFC describes building components from lifecycle point of view. However, IFC has some weakness in the description of specific building automation devices. For this reason, specific sensor ontologies such as OntoSensor [3] have been included as a way to enhance the IFC standard. Furthermore, in the way of enhance the IFC, new relationships are defined using functional diagrams and user activity modeling. A-Box contains building specific instances that are created semi-automatically from CAD files using a drawing interpretation tool [4].

The decision making process is made by utilizing an ontology reasoning engine (Pellet or Jess) that infers new knowledge from reasoning result from system ontologies. The reasoning from the building ontology is made using the direct dependencies between building status (building representation, sensor/actuators/distributed control system state, functional ontology and user activities modeling) and the rules (SWRL) generated by data mining processes [5].

3.3 Service Oriented Architecture

The system architecture facilitates interoperation of the independent components via the mechanisms of (1) a semantic interface to discover and link components in the KnoHolEM architecture (using OWL-S or similar); (2) an adaptor that manifests the interface for the local implementation; (3) a shared and layered (core) ontology.

As a component to connect/align local ontologies (specific building ontologies) with the core shared ontology (hosted by the KnoHolEM server), a NEON's [6] mechanism are used. More specifically NEON supports 'contextualized networked' ontology development with the specification of Meta Object Facility based meta-models, covering ontologies, rules, mapping and modularization. The interface definition should define properties of the units as well as operations supported and serves the purpose of executing commands, exposing results and status via simple protocols. Retrievable via the 'units' interface is access to its 'extension' ontology that allows dynamic discovery of the previously mentioned services and operations.

The system's software components typically provide services and consume the services of others. Ultimately some components control all the actuators/sensors for all the building's zones. Other components collect information about its environment and takes decisions according to the energy efficiency objectives defined in the relevant goal ontology. External building information which could affect building performance (e.g. weather conditions influence on thermal system) is used to improve decision making and is a further example of a service. Hardware units and other units providing services such as data mining similarly use the same interfacing mechanisms.

A KnoHolEM core software component delivers the central functionality and some orchestration of system units although primarily the system employs distributed control. A broker component provides location and 'yellow pages' lookup services while other components deliver user interfaces and tool integration.

Overall the architecture provides a uniform integration of platforms, independent of (component) execution platform and implementation (language). Interconnection of nodes is via conventional Ethernet. Nodes may be merged by deploying unit components onto the host node.

4 Work Done and Future Work

The ongoing development has been focused on development of a first version of the described KnoHolEM solution [7] into some of the demonstration objects (Forum Building and MediaTIC building). First steps has been focused on developing and architecture and methodology to create each element of the architecture. All analysis process and development methodology has been done using Business Process Modeling Notation (BPMN) and UML diagraming describing use-cases, actors involved, activity diagrams and deployment architecture (See Fig. 3).

In regards with the knowledge base, efforts has been focused on developing a version of the ontology taking into account the three demonstration objects. However, more adequacy and instance of the ontology has been done in the Forum and MediaTIC building. The defined ontologies includes information about actors,

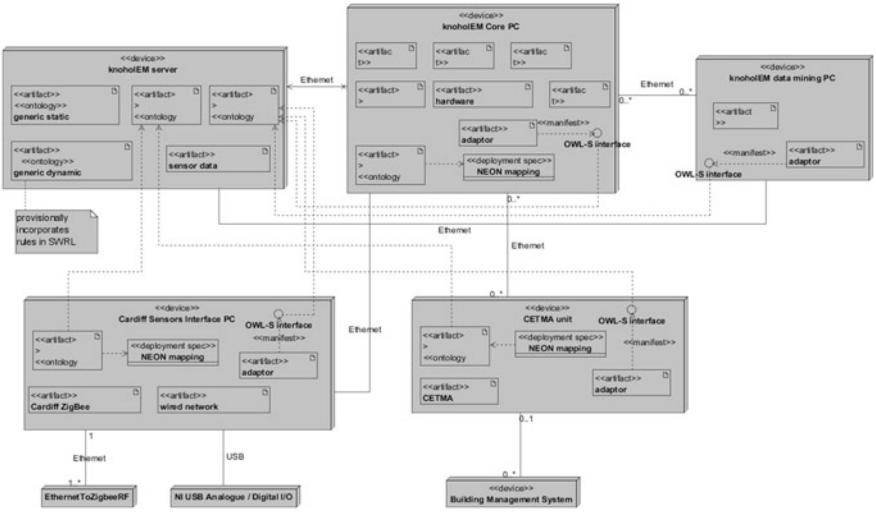

Fig. 3 KnoHolEM deployment architecture

user and system behavior, main building control information, main information about building infrastructure, first approach of building states as well as visualization information and energy goals. As described, the knowledge-base has been developed taking into account current standards used in the construction (like Industry Foundation Classes) and electrical field (like OntoSensor). The ontologies has been created in OWL format using Protégé software. In order to share ontology models and querying it using SPARQL, a Fuseki server has been installed and configured. OWL files ontologies also has been upload into Fuseki server. Ontologies must be populated to make the correct queries. In this aspect, ontologies has been populated with building infrastructure using OntoCAD tool.

In relation with data mining strategy, a Knowledge Discovery on Databases process (KDD) has been defined and designed. Currently, data mining work is focused on collecting building data to extract the knowledge, especially rules to predict the energy consumption and to identify energy wasting. The data mining results semi-automatically enhances the ontology (See Fig. 4).

The latter with the ongoing work, the visualization environment is focused on representing the demonstration objects in 3D environment using the CAD files. 3D models has been rebuilt from CAD using gbxml via Revit (ArchiCAD) software.

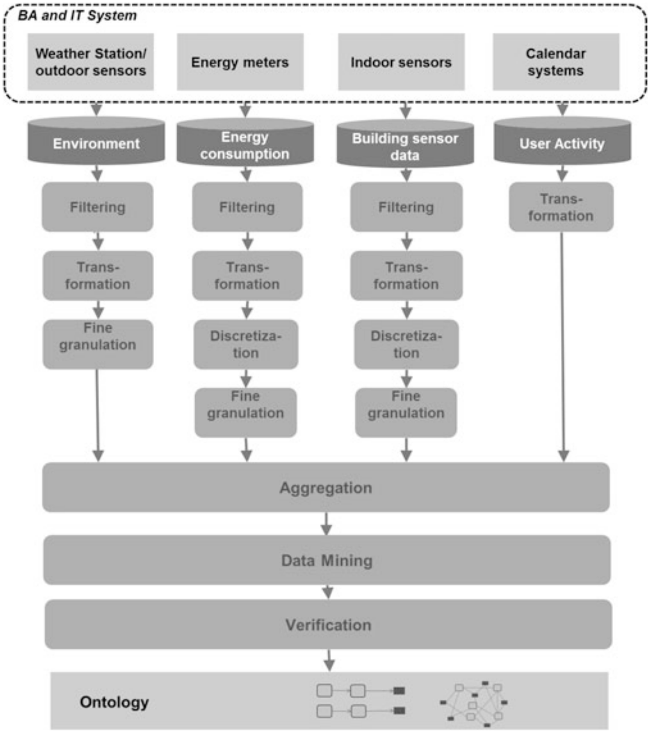

Fig. 4 KnoHolEM data mining

Also, first analysis of building information has been done using simulation engine from de tool developed. The first analysis has reveal structural gaps in building performance including (humidity anomalies, thermal anomalies about devices mal-functions, etc.).

As a future work, a specific enhancement in the KnoHolEM architecture and methodology will be done. In regards with the knowledge-base, an enhancement of the ontology that includes new specific building information, new properties, rules, data ranges and individuals will be incorporated. In relation with data mining, a generation of rule sets that could be included into the ontology will be done. The latter, the visualization environment work will be focused on describe building reality including users behavior and building infrastructure.

5 Impact and Benefit

With 450 million energy consumers, the EU is the world's second largest energy market and soundly recognizes the need of a more responsible, economical and rational use of energy.

The benefits of the proposed intelligent energy management solution are summarized on: (1) Significant reduction of energy consumption, both by intelligently identifying and avoiding energy wasting and by knowledge-based optimization of load-balancing in (near-)real time. The estimated reduction is up to 30 % of the initial consumption, depending on the initial configuration of the building and its usage; (2) Assistance of building facilities and building automation system reconfiguration through energy consumption optimization by knowledge-based simulation. (3) Considerable intelligent energy management system planning and configuration effort reduction for new buildings through usage of the knowledge of building functional model and on building ontology rule sets; (4) Increase awareness of occupant as well as building manager about energy efficient practices through intelligent identification of energy wasting and usage anomalies based on building configuration and energy usage behavior.

The possibly of uncomplicated and efficient integration of the existing building infrastructure and building facilities into the intelligent energy management solution will reduce it installation, configuration and utilization costs considerably. The required initial investment (for example, about 100€ per 100 m^2 are the estimated set-up costs for the real time hardware devices) will be amortized, depending on the building's usage, at the latest in long-term- a period of 10 years. As it is expected that energy prices will continuously grow in the near future and new taxation regulation will penalize energy efficiency and unburden efficiency, likewise, it can be expected that the investment amortizes even faster and finally helps reducing operating costs of buildings.

The most important benefit and strongest impact is given by the generality of the solution, which also justify the complexity of the creation approach of the solution, as the adaptation easiness to various types of buildings in different

European climacteric zones, to different use cases of buildings, buildings facilities and automation devices increase its flexibility and price-worthiness.

The intelligent building energy management system could become also an important component of the Building Energy Management System (BEMS) that the commission intends to create based on the results of several projects for similar thematic. The methodologies developed in this project and the adaptation of building standards permit an integrative view on the entire lifecycle of a building as possible basis for a seamless building model that operates from the building design phase to the building operational phase.

At the end, the project not only helps to save energy and reduce the costs of building operators, but will also contribute to economize natural resources and diminish greenhouse gas emission. In long term, this would be the premier benefit that can be archived through this project.

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Part III
Home Automation and Robotics

Uniovi RoboCup Team's Retractile and Compact Robot for RoboCup@Home

Jose F. Díaz, Ricardo Mayo, Yorel Moreda and Víctor San Juan

Abstract This paper is a working progress that introduces the actual state of the development of Uniovi RoboCup Team's robot for RoboCup@Home. The discussion is based on different unexplored and unprecedented ideas embodied in the terms Efficient Robotics and Green Bots. The robot design aims to find some advantages over other robots that participate in this competition, basically in the fields of safety, efficiency and compactness. We show how the concept design of the robot overcomes the limitations of other robots and some future line works are set out to determine the principal length of the jointed bars and the stroke of linear actuators needed, as well as sizing these elements to withstand stresses using recycled materials. The bases for the control system of the robot are also established to be developed in future works.

1 Introduction and Motivations of the Investigation

Uniovi RoboCup Team is a pioneer human team formed by of professors, researchers and both current and former students of the University of Oviedo. This team aims to participate in the international competition RoboCup@Home which

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_6, © Springer International Publishing Switzerland 2014

is the largest international annual competition for autonomous service robots, and is part of the RoboCup initiative.

The main goals of the team are the following:

1. Designing and building a service and assistive robot that allows Uniovi RoboCup Team to participate in the competition.
2. Analyzing, designing and implementing a software application that allows the robot to solve the challenges posed by RoboCup@Home rulebook [1].

We have been discussing some of the approaches about our participation in this competition since June 2012, when the team was formed. We reached the conclusion we could develop a fully new robot based on different unexplored and unprecedented ideas, encouraged mainly by the team member *Ignacio González Alonso*. These ideas may be embodied in the terms Efficient Robotics and Green Bots. Some of these aspects can be classified in:

- Mechanics: retractile, lighter, autonomy and recyclable materials.
- Electronics: recycled and cheaper.
- Behaviour: efficiency in trajectories and gentle robots.
- Opensource and openhardware designs.

This paper will reflect the current state of the mechanical design of the robot. This paper is also focused on how we break with the patterns established by other teams and will conclude with the future action plan for developing and manufacturing the robot.

2 State of Art

Many teams from all over the world have participated or are still participating in Robocup@Home, configuring their robots in several ways. Considering the work of the most successful teams (the first three ones in each category), we observed that most of the significant mechanical features can be discussed as it is done in this section.

To analyze the previous contestant's design, attention can be drawn to:

- The configuration of their drive system.
- The main structure of the robot.
- The devices used to behave like a human arm.

The first team we took into account is *AlemaniACs* (2006, 2007 and 2008): *Hannibal and Caesar* [2]. Both robots use a differential driving configuration with a modular and rectangular shaped supporting structure. They also use a commercial robotic arm, Katana, from *Neuronics*.

Other interesting team is *b-it-bots* (2008, 2009, 2010 and 2012): *Jenny and Johny Jackanapes* [3]. Both of them are based on previous *Fraunhofer Institute*'s designs. *Jenny* is based on the *Care-o-bot*, which uses an omnidirectional configuration with nine actuators, two each one, and a seven DOF manipulator with three-finger hand. *Johny* is based on the *Volksbot*, and uses a differential configuration with a modular rectangular structure and a five DOF *Katana* arm.

Robocare (2006): *Adi.* Uses commercial devices assembled over a Pioneer P3DX differential drive system.

UT-Austin (2007): Segway. It is built from a commercial Segway RMP base, which uses a differential drive system.

Other significant team is *eR@sers* (2008–2011): *team@Home* and *DiGORO*. They both use an omnidirectional drive system. *team@Home* uses a 6 DOF arm, and *DiGORO* uses an *Upper Body Humanoid Robot* HIRO (KAWADA Industries).

ToBI (2011): *ToBI* [4]. The robot uses several devices developed by *MobileRobots*, such as *PatrolBot*, a differential drive base with two caster wheels, and *GuiaBot*, a platform to place sensors, cameras, etc. It also uses a *Katana* arm.

Wright eagle (2012): *Kejia*. It uses a differential configuration with a robotic arm. The last update includes a manual height adaptor mechanism.

The last team we considered is *NimbRO* (2009–2012) [5]: *Dynamaid* and *Cosero*, whose appearance is totally humanoid. They use an omnidirectional base with conventional wheels and an upper body lifting mechanism using a rack-pinion system. They also include anthropomorphic arms made with *Dynamixel* actuators (Fig. 1).

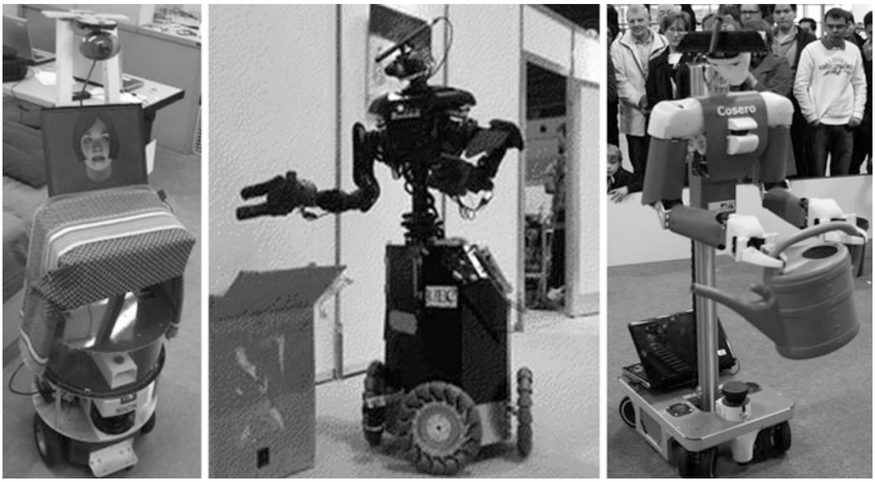

Fig. 1 From *left* to *right* Adi, DiGORO and Cosero

3 Design Alternatives

In this section, we will discuss the different design alternatives that we developed. These alternatives are going to be the object of our analysis in order to identify their advantages and disadvantages. These alternatives are developed in a way that allows us to maintain, as far as possible, the design requirements established by the competition rules [1] and all the requirements that we consider that the robot must comply (referred to in Sect. 1).

All the previous concepts led us to design alternatives that break with established patterns. As we could see in Sect. 2, all the robots participating in the RoboCup@Home are humanoid-shaped ones. Most of them are as tall as a kid or even more, and just a few of them have an adaptive body which can go up and down, so that they can operate at any height.

However, Uniovi RoboCup Team strongly believes that is not a must for the robot to carry out its tasks having a vertical fix supporting structure.

The foregoing led us to develop alternatives prone to use retractile systems and mechanisms. This would allow us to reduce the height of the robot without the need of using vertical displacement systems, which require an important amount of space.

The main advantages of these alternatives would be the following:

- Allowing the robot to be stored under a bed or similar, during standstill periods, due to its reduced height.
- The possibility of making safer displacements, as the robot could move “shrunken”, improving its stability as a result of decreasing the height of the gravity centre.
- The advantage that we previously pointed out would give us the opportunity of making faster displacements (the max speed is limited by the rules of the competition, but in general is feasible thought).
- The compactness of the robot would allow us to optimize trajectories in order to avoid obstacles and pieces of furniture. Therefore, in order to dodge obstacles that are higher than it, the robot can pass under them instead of surrounding those obstacles, with the consequent saving of both energy and manoeuvre time.

Besides, selecting a specific configuration is one of the steps needed to build a mobile robot. Once analyzed the advantages and disadvantages about every single configuration [6, 7], we decided to develop some alternatives based on a differential configuration.

The first solution we developed consists of a folding arm driven by an electric actuator attached to a “U” shaped chassis (the chassis could be designed to shelter the different devices, keeping the space saving). The robot has a unique arm to manipulate the different objects, and has a workspace range of 360°. Furthermore, it has different sensors and devices (microphones, speakers, etc.) that allow the robot to interact with its environment (Fig. 2).

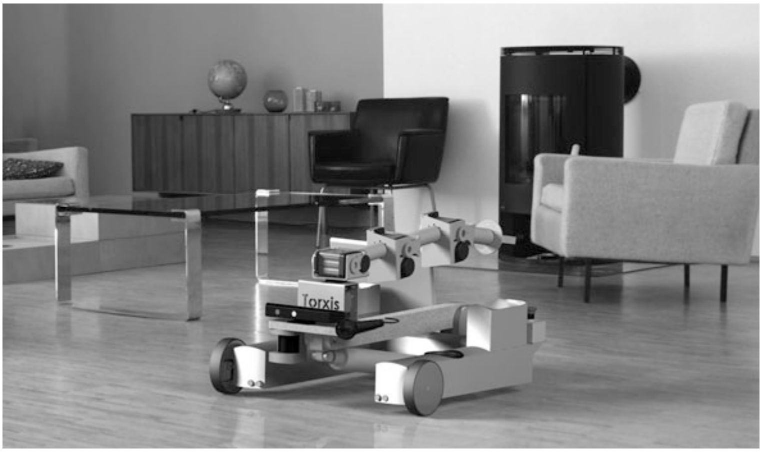

Fig. 2 Concept design of the folding arm alternative

We have developed other solutions like a scissor mechanism alternative, a SCARA robot with a retractile support alternative and a jointed bar alternative. All of them are very similar and present advantages and disadvantages. However, we observed that the jointed bar alternative is the best one for our purposes as its manufacture is simpler than the other ones. It also is very compact and it improves accessibility to the emergency stop button (mandatory by [1]), among others.

We found the solution suggested above very interesting. Nevertheless, we decided to use some existing components from the Infobotic's Laboratory of University of Oviedo due to lack of time. In particular, we will use a *Pioneer P3DX* platform of *MobileRobots* and a *Sick LMS 200 LRF* from the same brand. This is a very important constraint that will prevent the robot to be as small as we wish.

Thus, if we combine the jointed bar alternative with the previously mentioned components, we come to the solution depicted in the Fig. 3. From now onwards, we will refer to this solution by the name of *Geoffrey*, winking to the butler of the popular 1990s TV series *Fresh-Prince*.

Geoffrey consists of two jointed bars that divide the full height of the mechanism. These bars are articulated in their extremes, and can be retracted using an important variety of actuators (either linear or rotary ones).

Our former idea was to build a "humanoid" skeleton, taking advantage of this configuration, so two arms were positioned and the vision system and emergency button where placed centered at the top. Therefore both the accessibility and the ability of the vision were improved. The top bar was originally powered by a rotary actuator to reduce the geometric interference. The low bar was connected to a linear actuator, in order to give stability to the mechanism and simplify the electronic control.

After some analysis, we decided to install only one arm in a centered position, which will be enough to fulfill our aims. In addition to this, we use two linear actuators, due to some stability and feedback control troubles.

Fig. 3 On the *left* Geoffrey folded; on the *right* Geoffrey unfolded

In respect of the obstacle avoidance control system, it should be noted that is one of the most important systems of the robot. The final design has not yet been developed, but we have taken several considerations into account.

The system will be divided into two parts: one to recognize the obstacles and other to avoid them.

The system that recognizes the obstacle has two inputs: one from the laser (*LMS 200 LRF*), which maps the surface and helps to navigation, and other from the anti-collision sonar sensors which are integrated in the *Pionneer P3DX*. These devices give the robot the information about the obstacles in the environment so, when the robot is nearer than a pre-adjustable distance, called sensitivity range, it has to start the task to avoid the obstacle.

The variable of the obstacle avoidance system is the robot's velocity. Combining this velocity with the distance mentioned in the previous paragraph we obtain the remaining time to crash with the obstacle. This time, depending on the sensitivity range and the velocity of the robot, could be very close to the processing time. The processing time cannot be higher than the time described because the robot would crash. To solve this problem, when implemented the control system, we will have to calibrate the velocity and the sensitivity range to avoid crashing into the obstacles.

We should note that one of its innovative behavioral characteristics is that *Geoffrey* can operate at any height without the need of big structures that occupy a lot of vertical space, making the displacements and tasks safer and allowing it to follow efficient trajectories if possible (that is, when the obstacle's height is greater than *Geoffrey's* height).

4 Conclusions and Future Line Works

Taking into account the sections above, we may reach the conclusion that we have developed a retractile and compact robot for the RoboCup@Home which outperforms traditional robot designs. *Geoffrey's* design is simple and would be lighter than other robots that participate in the RoboCup@Home, therefore it increases its autonomy.

Geoffrey is an innovative unprecedented service and assistive robot that can be stored during standstill periods without need of great space. Its main behavioural characteristic is that he can operate at any height improving safety in tasks like displacements and object manipulation. This also allows *Geoffrey* to optimize trajectories in order to avoid obstacles and furniture. Thus, in order to dodge those objects higher than him, the robot could pass under instead of surrounding them, with the consequent energy and manoeuvre time saving.

The foregoing makes *Geoffrey* a potential energy efficient robot.

The technical development of *Geoffrey* is still an open issue. The next stage of the mechanical development is the dimensional synthesis of the mechanism. It means that we will determine the principal length of the jointed bars and the stroke of linear actuators needed using a DOE methodology based on pure geometrical criteria. Therefore, we will determine the optimal configuration of the mechanism from some indicators of goodness.

The final stage will consist of the dynamic analysis that could allow us to size the bars to withstand stresses. In this respect, we are making a research on how to use recycled materials such cardboard, plastics and wood to substitute traditional materials. In this way, *Geoffrey* would be a green robot. We also will design the control system so *Geoffrey* could make efficient trajectories while it is moving.

Once we have the full 3D model of the robot we will upload all the design to *ROP* (Robotic Open Platform), so it will be available to the whole community.

In our future work, it is still somehow unclear when we could develop a real retractile robot from scratch but it is on our list of things to do for the next year's competitions.

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Uniovi RoboCup Team Software Components for RoboCup@Home

Ignacio González, Natalia Navas, Luis F. Pérez, Juan J. Romero and Víctor Sánchez

Abstract This paper describes the Uniovi Robocup Team (URT) Software Components for their first participation at RoboCup@Home competition. URT presents Geoffrey, a robot for service applications in the home environment. This is an efficient and green robot with a friendly behaviour. It is an ultra low-cost approach, designed with free hardware and software and recyclable components.

Keywords Robocup@Home · Green robotics · Robotic smart homes · Human-robot interaction · Robot operating system (ROS)

1 Introduction and Motivation

Uniovi Robocup Team (URT) at University of Oviedo has been established in June of 2012 to build a service robot and to participate in the RoboCup@Home 2013 competition. URT is one of the first Spanish teams in the RoboCup@Home. The team consists of Bachelor, Master and PhD students, old students and university teaching staff.

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_7, © Springer International Publishing Switzerland 2014

The team main research objective is to develop intelligent and efficient mobile robots, with a friendly and green behavior and ultra low-cost interfaces approach. Moreover, as the objetive is to participate in the Robocup@Home, develop service robots which can be used in home environments. Our robot, called Geoffrey in honour of the butler of the popular 1990s TV series Fresh-Prince, tries to fulfill all this characteristics plus the requirements given by the organization of RoboCup@Home.

1.1 What is Robocup@Home

Robocup is an international competition who aims to develop solutions to problems of Artificial Intelligence (AI), Robotics and other related fields. One of the branches of this event is Robocup@Home which is the league that aims to develop service and assistive robots technology with high relevance for future personal domestic applications. Although other categories of the competition try to develop difficult tasks in simple environments (e.g. a football match), Robocup@Home follows the opposite philosophy as the goal of the robots is to do simple tasks in a more complex environment (e.g. follow a person through many obstacles).

The final goal of this competition is bringing robotics to normal life, far away from the controlled environment of a laboratory. In order to do so, robots has to pass a several tryouts that test robots in several domains as Human-Robot Interaction, Navigation, Computer Vision, etc.

1.2 Challenges of Robocup@Home

The challenges of the Robocup@Home are five, plus one open challenge that each team can develop by themselves:

- "Robot Inspection": The robot has to take an inscription formulary, recognize it, trespass a door and left the formulary into a table.
- "Follow me": After a specific command, the robot has to follow the person that has ordered it. Obstacles and other people have to be avoided by the robot in its path.
- "Who is who": A recognition problem which consists in the robot bringing drinks to people identifying them by their face and name.
- "Clean up": It consists in cleaning a room with multiple obstacles without pushing any of them.
- Technical challenge: Each year there is a different technical tryout, consisting in a group of complexes tasks (e.g. go shopping in a real supermarket) related to recent state of the art problems.
- Open challenge: If the team passes at least one of the previous challenges, they can participate with an additional one that is proposed by the team.

1.3 Contents

This paper is organized as follows: Sect. 2 will cover the state of the art of the Robocup@Home, and various technologies that are going to be used; Sect. 3 will describe the hardware infrastructure of the robot while Sect. 4 will explain the particular software solution. Finally, in Sect. 5 we will show the conclusions of the teams' actual work.

2 State of Art

2.1 Green Robotics

Green Robotics refers to environmentally sustainable robotics. The goals of green robotics [1] are similar to green chemistry; reduce the use of hazardous materials, maximize energy efficiency during the product's lifetime, and promote the recyclability or biodegradability of defunct products and factory waste.

We are researching on how to use recycle materials such cardboard, plastics and wood to substitute traditional materials. In this way, Geoffrey would be a green robot.

2.2 Robotic Smart Homes

The homes [2] themselves will become more intelligent in terms of sensor and interconnecting processing units, and they will be populated by robotic servants, Geoffrey in our case, that operate in these intelligent houses in close interaction and cooperation with the human user.

2.3 Human Robot Interaction

Human-robot interaction (HRI) [3, 4] is the interdisciplinary study of interaction dynamics between humans and robots. Mostly humans express their intentions via speech, gestures, expressions and sounds. Domestic service robots, like Geoffrey, must be aware of those intentions and also be able to understand them.

2.4 Robot Operating System

Robot Operating System [6] is an open source robot operating system, not in the traditional sense of process management and scheduling; but it provides a structured communications layer above the host operating systems of a heterogeneous compute cluster. ROS is distributed under the terms of the BSD license, which allows the development of both non-commercial and commercial projects. ROS passes data between modules using inter-process communications, and does not require that modules link together in the same executable.

ROS [7] was chosen in this project because it is a free and open-source robot operating system, modular, peer-to-peer, tools-based, multi-lingual and thin, that allows to develop the software system of Geoffrey in a simply manner.

3 The Mobile Robot Geoffrey

A mobile robot [8] is an automatic machine capable of movement in a given environment. Mobile robots [9, 10] have the capability to move around in their environment and are not fixed to one physical location.

It should be noted that most robots are very expensive and their function is very specialized. Therefore, research carried out nowadays must be focused on developing more economic and general robots, so they are accessible for all the people that want to solve problems in everyday life.

3.1 Infrastructure

The design of the Geoffrey robot can be seen on in Figs. 1 and 2. The robot is built upon a platform Pioneer 3× over the others devices are disposed. The complete list of devices and their relations with the architecture are shown in Fig. 3.

While most of the robots that participate in Robocup@Home are of human size, Geoffrey was thought with a more flexible approach. The robot has the capability to be folded with a linear actuator, work at different heights and occupy the less space possible when it has to be stored.

Fig. 1 Geoffrey folded

Fig. 2 Geoffrey unfolded

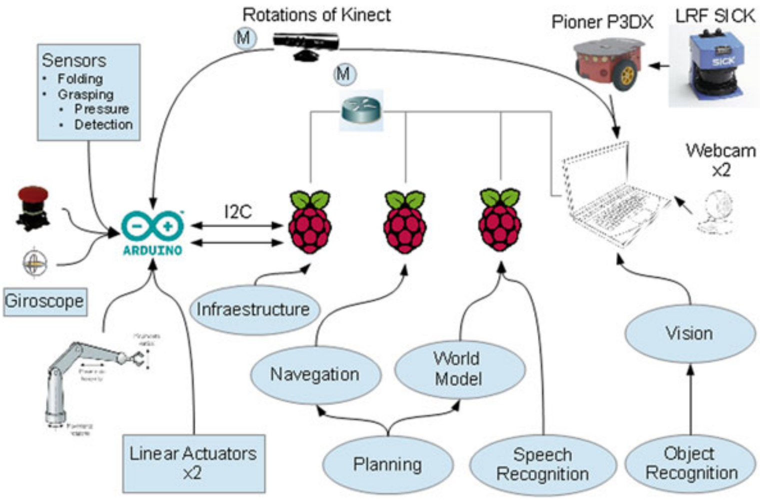

Fig. 3 Deployment diagram of the robot

3.2 Architecture

The architecture of Geoffrey, as seen in Fig. 3, can be divided in two different sections linked by a network controlled by a router.

First section is constituted by actuators and sensors whose time operation is critical (e.g. detection of the pressure in the robotic hand); the core of this section is constituted by an Arduino board which communicates with the Router with a Raspberry Pi.

Second section is constituted by a set of computers, each one of them controlling a specific area of the robot functioning. Raspberry Pi will be used in all means except in processes that need more computational cost (e.g. vision) that will be managed by a laptop with a more powerful microprocessor. Vision sensors will be attached directly to it. Some of the sections must share resources as they are much related (e.g. planification and navigation). This relationship is managed with ROS.

3.3 Description of the Open Challenge

In the Open challenge section, the team has decided to analyze how we can make a "green" robot. This main goal will be decomposed into several different tasks.

- Mechanics: As the robot will be foldable, the structure of the robot will be smaller and lighter. Also, in most cases, we will intend to use recycled materials to build it.
- Electronics: Materials will be the cheapest possible, trying to adjust in all cases to open source electronics.
- Planning and Navigation: Robot will seek for efficiency in trajectories, which would results in low energy path trajectories and a more efficient in resource planning that will save energy.

4 Proposed Solution: The Software Architecture

As we can see in Fig. 4, the Software Architecture proposed will be divided into four parts: infrastructure, vision, interaction and planning.

4.1 Infrastructure

The infrastructure of the robot is composed by all the programs that control the physical level of the information of the sensors and actuators. The core of the infrastructure of the robot is the Arduino board which controls the most critical systems like linear actuators, and motors of the robotic arms. It is necessary to put over the Arduino board, some programs that control the infrastructure over each sensor and motor.

There must be a program to extract the information from the laser, a laser rangefinder, which is used to measure the distance to an object, counting the flight time taken by the laser beam sent to and reflected by the object. This information will be passed to the vision section that will manage it properly.

The robot is mounted over a platform Pioneer 3D×. In order to control their movements the driver P2SO will be used, which is specific for ROS.

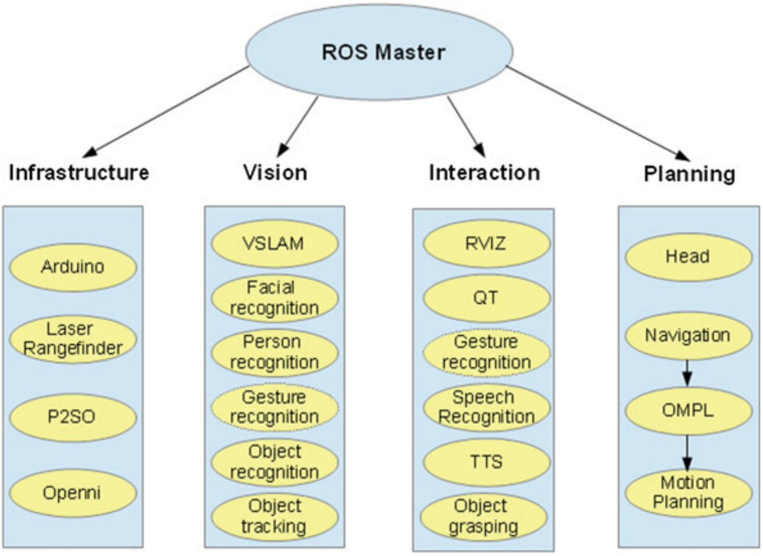

Fig. 4 Software architecture proposed as solution for geoffrey

4.2 Vision

In this project will found the typical computer vision tasks such as object recognition, pose estimation, face and person recognition or map reconstruction and different processes for these tasks will be used. To do so, we will include methods for acquiring, processing and analyzing images from the real work.

The Fig. 4 shows the process for the computer vision in this project: OpenNI (infrastructure), Visual Simultaneous Localization and Mapping (VSLAM), Facial Recognition, Person Recognition, Gesture Recognition, Object Recognition and Object Tracking.

4.2.1 OpenNI

The OpenNI framework is an open-source SDK used for "natural interaction"—using your hands and body to interact with your digital devices (cameras, Kinect, etc.).

This project will not use OpenNI directly. ROS include openni_camera package. Openni_camera already implements a fully-featured ROS camera driver on top of OpenNI. Through the Openni_camera could access to Kinect (a motion sensing input device by Microsoft) and others cameras. Using Openni_camera and Kinect the robot could recognize people for the different tasks.

4.2.2 Visual Simultaneous Localization and Mapping (VSLAM)

VSLAM [11] is a technique used by robots and autonomous vehicles to build up a map in an unknown environment or to update a map within a known environment. VSLAM will use OpenNI information to map out position of a robot in a new environment. Once the position is set the planning process will decide the next step.

4.2.3 Facial recognition and Person recognition

A facial recognition is a computer application for automatically identifying of verifying a person from a digital image or a video frame from a video source. This application will be used in tasks such as "Who is Who" or "Follow me", using OpenNI.

ROS includes packages for face recognition in video stream. The package provides an antionlib interface for performing different faces recognition functionalities such as adding training images directly from video stream, re-training, recognizing faces from video stream, etc.

4.2.4 Gesture Recognition

In some of the challenges, Gesture Recognition is involved in the process as the robot has to recognize some simple gestures from the referee. The input is given by Kinect through OpenNI information, and this information is processed by OpenCV and interpreted by an algorithm that decides whether the gesture recognized has a meaning for the robot or not.

4.2.5 Object Recognition and Object Tracking

The object recognition and tracking is the process of locating an object over time using the camera. The OpenNI information is processed by OpenCV and interpreted by an object recognition algorithm in order to find objects in an unknown environment in tasks such as "Who is Who" or "Clean up". The planning process will use this information to decide the next step into the task.

4.3 Interaction

Gesture Recognition is involved in the process of some challenges as the robot has to recognize some simple gestures from the referee. The input is given by a webcam, this information is processed by OpenCV and interpreted by an algorithm that decides whether the gesture recognized has a meaning to the robot or not.

It is important for the robot to recognize different commands and voices from different persons. For speech recognition it will be used the open source software Sphynx. However, the robot has also to communicate with the people (and robots) around them. In order to do this, a system of text to speech (*tts*) will be implemented. The robot has to be able to present himself and the team, and ask for input commands given by voice. There are a lot of solutions of this type of technologies (e.g. Loquendo or Verbio) and the use of one or another will depend in their usability and prize (as one of the goals of the team is search for the more economic option).

4.3.1 Interaction with the World

To interact with the real world, computer must interpret the information received by the sensors. In order to do so it will be used an open source ROS library called "*rviz*" that creates a 3D visualization environment to recognize exactly what the robot is seeing and thinking.

4.3.2 Interaction with People

Geoffrey is provided with a computer which displays information of the robot. Although the robot must be fully independent along all the try-outs, it is important to create an interface that informs of the state of the robot and permits a basic control for the preparation time between challenges. For this purpose, the "qt" application framework will be used to create a graphic interface. This solution is chosen because its cross-platform flexibility.

4.4 Planning

4.4.1 Head

As the robot has the capability to be folded, the management of the head (where the Kinect sensor and webcamera of the robot lies) acquires more complexity. Not only the robot has to adjust the inclination of his eyes, but also put them in the correct height at each moment.

4.4.2 Navigation

Ompl library [12] will be used in order to develop the robot navigation. This library consists in many state of the art sampling-based motion planning algorithms and uses the Ompl ROS Interface package which allows easily creating and configuring a motion planner for the robot. *Ompl* contains implementations of many sampling-based algorithms such as PRM, RRT, EST, SBL, KPIECE, SyCLOP, and several variants of these planners, but, at this moment, the team has not decided which one will be used.

5 Conclusions and Future Work

Robocup@Home is a unique opportunity to develop solutions for state of the art applications in Domestic Robotics, Artificial Intelligence, Computer Vision etc. Uniovi Robocup Team is contributing to this goal with its robot Geoffrey, a folding robotic solution that tries to give the most economic and efficient response possible to these problems.

Software solution of the robot uses a wide range of applications and techniques, given the amount of different challenges of the competition and the number of devices needed in the implementation. The communication between all the different processes is made with ROS. Hardware used tries to adjust to the most economic and opensource solution using Arduino board and several Raspberry Pi for the computation.

The first line of future work is evident; solutions described in this paper must be implemented. Several problems will appear, especially in the most complex tasks, and other alternatives must be chosen. As one of the goals of the robot is to be more energy efficient, software has to be implemented with the less computational cost possible. However, as the amount of work is huge, this goal must be covered in next year's competitions.

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Novel Method for Vehicle and Pedestrian Detection Based on Information Fusion

Fernando García, Arturo de la Escalera and José María Armingol

Abstract A novel approach for vehicle and pedestrian detection based on data fusion techniques is presented. The work fuses information from a 2D laser scanner and a computer camera, to provide detection and classification of vehicles and pedestrians in road environments. Thanks to the data fusion approach, the limitations of each sensor are overcome. Thus reliable system is provided, fulfilling the demands of road safety applications. Classification is performed using each sensor independently. Laser scanner approach is based in pattern matching and vision approach is based in the classical Histogram of Oriented Gradients features approach. A higher stage performs data fusion using Kalman Filter and Global Nearest Neighbors.

1 Introduction

Roads are the transport with more fatalities. It is estimated that more than 40,000 people die every year in Europe in traffic accidents. During the latest years, the advances in both vehicles and roads helped to reduce the numbers of deaths in roads, but there is still lot of work to be done.

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_8, © Springer International Publishing Switzerland 2014

Fig. 1 Intelligent vehicle based on visual information (IVVI) 2.0

In recent years, efforts have focused in creating applications that use the advances in information technologies to help to increase the security in roads. One example of these applications are the Advance Driver Assistant Systems (ADAS), which purpose is to help and warn the driver in case of a hazardous situations.

Among all the available sensors for road safety applications, it is difficult to find a system able to fulfill the strong requirements of these applications. In the present article an approach based in data fusion is presented. This system tries to overcome the limitations of each sensor by fusing the information provided. A classic vision based ADAS is enhanced by adding a 2D laser scanner, providing pedestrians and vehicles detection with a high positive rate. The resulting application is already available in the Platform IVVI 2.0 (Fig. 1).

2 State of the Art

Fusion approaches can be divided according to the level where fusion is performed:

In **Low Level** approaches raw data is fused, creating a new data set, which combines information from different sources. Usually these methods depend on the technology or sensor used. In computer vision, stereovision is an example of low level fusion. Images from two cameras are used to create a more complete set of information able to provide 3D information; in [1, 2] this information is used to provide pedestrian detection.

Medium Level fusion requires preprocessing stages for each sensor separately, creating a feature set, based in features form the different sensors, this set is used to perform the final classification. In [3, 4]authors present works combining the features and performing classification by different ways: Naïve Bayes, GMMC, NN, FLDA, and SVM.

High Level fusion approaches perform detection and classifications for each sensor independently and a final stage combines them [5]. Performs pedestrian detection, using visual Adaboost detection and Gaussian Mixture Model (GMM) for laser scanner, a Bayesian decisor is used to combine detections at high level. In [6] pedestrians are detected using laser scanner by multidimensional features; Histograms of Oriented Gradients (HOG) features and Support Vector Matching (SVM) for computer vision detection; finally Bayesian model provides high level fusion.

The work presented here is an example of high level detection, with independent classifiers for pedestrian and vehicle detection, providing a robust system able to fulfill requirements of safety applications. Besides, the independence of the low level classifiers allow to use them separately even in extreme situations were one of them is not available.

3 Low Level Detection

As it was remarked before, the first stage of the approach consisted in a low level detection, based in the information given by the laser scanner and the camera independently. Later a higher level stage fuses this information.

Several configuration were tested for obstacle detection: pattern based monocular camera detection, stereo-based obstacle detection and laser scanner obstacle detection. The final configuration used the laser scanner to provide obstacle detection to both systems, laser scanner and camera. The higher trustability of the laser scanner helps to reduce the amount of false positives in the vision, since only the regions in the image where there is certainty given by the laser are check. Besides, laser scanner provides obstacle detection faster and more efficient in comparison to the stereo based system.

3.1 Laser Scanner Detection

The laser scanner is mounted in the bumper of the vehicle, thus the delayed detections given should be corrected according to the movement of the vehicle. Translation and rotation should be performed according to the information provided by a GPS with inertial measurement available in the platform (1) and Fig. 2a. Later, shapes of the detected obstacles should be estimated, this shape reconstruction is based in polylines [7], as it is shown in Fig. 2b.

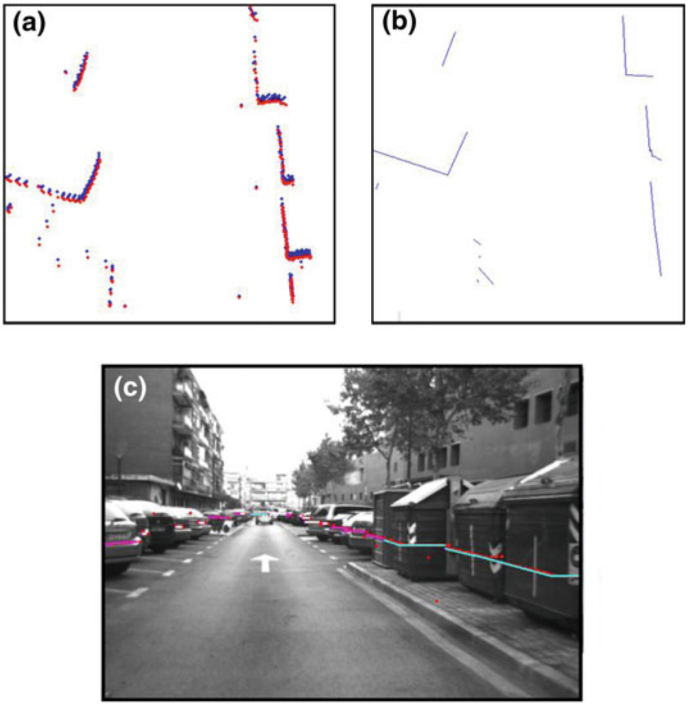

Fig. 2 Vehicle movement compensation of laser scanner information. **a** Shows the detection points, in *blue* the raw data and in *red* the compensated. **b** Shows the shape reconstructed after the movement compensation. **c** Shows the alignment of the laser scanner data and the image

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R\left(\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} + T_v + T_0\right), \text{ with } T_v = \begin{bmatrix} vT_i \cdot \cos(\Delta\theta) \\ vT_i \cdot \sin(\Delta\theta) \\ 0 \end{bmatrix}, \; T_0 = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix}, \text{ and}$$
$$R = \begin{bmatrix} \cos(\Delta\delta) & 0 & \sin(\Delta\delta) \\ 0 & 1 & 0 \\ -\sin(\Delta\delta) & 0 & \cos(\Delta\delta) \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 \\ 0 & \cos(\Delta\varphi) & -\sin(\Delta\varphi) \\ 0 & \sin(\Delta\varphi) & \cos(\Delta\varphi) \end{bmatrix} \begin{bmatrix} \cos(\Delta\theta) & -\sin(\Delta\theta) & 0 \\ \sin(\Delta\theta) & \cos(\Delta\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

where $\Delta\delta$, $\Delta\varphi$ and $\Delta\theta$ corresponds to the increment of the Euler angles roll, pitch and yaw respectively for a given period of time T_i. Coordinates (x, y, z) and (x_0, y_0, z_0) are the Cartesian coordinates of a given point after and before respectively to the vehicle movement compensation. R is the rotation matrix, Tv the translation matrix according to the velocity of the vehicle, T_0 the translation matrix according to the position of the laser and the inertial sensor, v is the velocity of the car, T_i the time between the given point and the first one in a given scan. Finally, (x_t, y_t, z_t) is the distance from the laser scanner coordinate system to the inertial measurement system.

After the shape reconstruction, the classification is performed using a pattern matching approach. The different obstacles that are possible to be differentiated are: big obstacles, small obstacles, road borders, L shaped, pedestrians or vehicles. The most important ones for this application are pedestrians and vehicles. Both detections were based in different patterns, obtained thanks to detailed studies in the movement of the different obstacles.

3.1.1 Vehicles

The pattern is based in the delay of the spots given by the laser scanner detection, this way, this spots provide a given pattern that depends on the movement of the vehicle. Thanks to this special pattern, classification can be performed as well as information about the movement of the vehicle estimated (Fig. 3). Deeper information of this algorithm is provided in [7].

3.1.2 Pedestrians

A pattern for pedestrians was defined based in the position of legs of the pedestrians (Fig. 4).

In this pattern, three polylines are presented, and the angles that connect the polylines are included within the limits of [0, $\pi/2$] (2).

Fig. 3 Typical pattern for vehicle detection

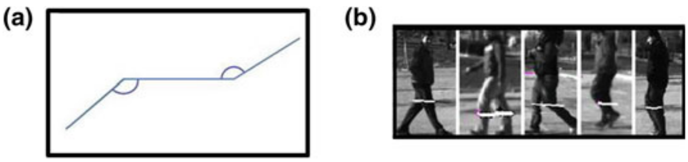

Fig. 4 Pattern for pedestrian detection. **a** The pattern used. **b** Examples of the pattern with real pedestrians

$$\text{Similarity} = \frac{2\theta_1}{\pi} \cdot \frac{2\theta_2}{\pi} \tag{2}$$

where θ_1 and θ_2 are the angles that connect two consecutive lines.

This similarity is computer between two consecutive angles and if the case arises that they match the pattern it is labeled as a possible pedestrian.

Finally a simple tracking stage is added at this level, to track the movement of the obstacle providing reliable detection. A voting scheme that takes into account the last 10 frames was created. Furthermore several filters are added to avoid false positives, these filters check wrong behavior along time, such as impossible movements, velocities or accelerations.

3.2 Computer Vision

As it was remarked, the vision approach makes use of the reliability of the laser scanner to provide region of interest. Thus only the obstacles detected by the laser scanner, with size similar to the object to be found, are provided to the vision system, allowing reducing the parts of the image where the algorithms perform the search. Thus computation cost and false positives are reduced (Fig. 5).

Coordinate change should be performed using pin-hole model and accurate extrinsic calibration (3) and (4) to provide information from the laser scanner to the camera coordinate system:

$$\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = R\left(\begin{bmatrix} x_l \\ y_l \\ z_l \end{bmatrix} + T\right) \tag{3}$$

where R is the rotation matrix shown in (1) corresponding to the Euler angles that represent rotation between the different coordinate systems. T is the translation vector $T = \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix}$ that corresponds to the distance between the coordinate systems, (x_c, y_c, z_c) are the camera coordinates and (x_l, y_l, z_l) the laser scanner coordinates.

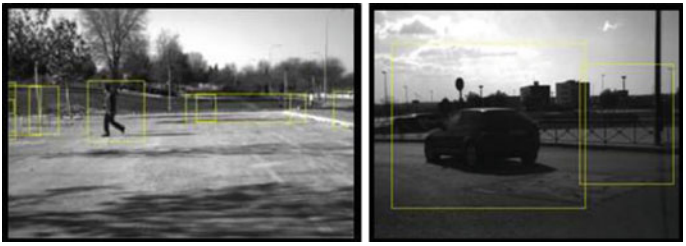

Fig. 5 Examples of obstacle sets for pedestrians (*left*) and vehicles (*right*)

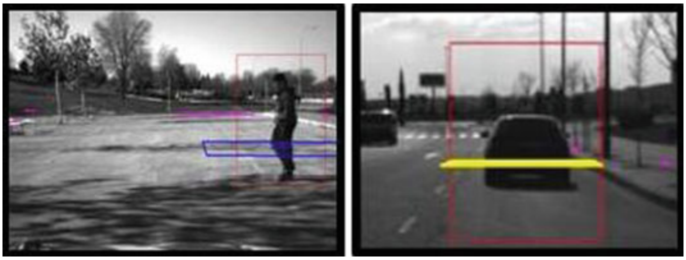

Fig. 6 Visual detection examples for pedestrians (*left*) and vehicles (*right*). *Red boxes* represents for visual detections, *blue boxes* represents laser scanner based pedestrian detections and *yellow boxes* vehicle detections

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ z_c \\ y_c \end{bmatrix} \quad (4)$$

where u_0 and v_0 are the center coordinates of the camera coordinate system in pixels. (u, v) are the coordinates in the camera coordinate system in pixels. x_c, y_c and z_c are the Cartesian coordinates from camera. And f is the focal length.

The computer vision algorithms used were different according to the obstacle to be found:

- **Vehicles**. Haar-Like features based approach with cascade classifiers was used (Fig. 6, right). The common features that can be found in the back of the vehicle allowed to used this fast algorithm originally used for face detection [8].
- **Pedestrian**. Based in Histogram of Oriented Gradients (HOG) features (Fig. 6 left). This approach is classical in Intelligent Vehicles, and was proposed in [9].

4 Fusion

Fusion stage retrieves the detections from both subsystems, providing fused detections (tracks). Kalman filter was used to estimate the movement of the different obstacles.

Two kind of tracks were defined, consolidated and non-consolidated. First corresponds to those tracks detected by both sensors, second correspond to the detected by a single sensor.

The association technique used to match the new detection with the old ones (tracks) was Global Nearest Neibors (GNN), based in the distance between the estimation of the track and the position of the detections. A distance based in the stability of the measurements was defined (5) and the gate used to eliminate the non likely pairs was based in a square approach (6).

$$d^2 = \frac{(x_i - \bar{x})^2}{\sigma_x^2} + \frac{(y_i - \bar{y})^2}{\sigma_y^2} + \ln(\sigma_x \sigma_y) \quad (5)$$

$$K_{Gl} \sigma_r \quad (6)$$

where σ_r is the residual standard deviation and K_{Gl} is a constant that was empirically chosen, d is the computed distance between previous and presented tracks to be associated. And (σ_x, σ_y) the appropriate values of covariance matrix of Kalman Filter.

A M/N policy was used to create and eliminate the tracks, thus a given track is created after M detection and is eliminated if N number of frames provide no matches for the track. In the case of a non-consolidated track which is not corroborated by the other sensor it is considered a false possitive.

5 Results

Different test were performed in both urban and interurban scenarios with more than 10,000 frames in real road situations. Result comparison is showed in Table 1.

The results proved that the system was able to enhance the low level approaches providing better results. In the low level detections, it was very interesting the high positive rate obtained with the limited information provided by the laser scanner, mainly in the case of vehicles. On the other hand the amount of misdetections was also very high.

It has to be remarked that the training process created for the camera approaches were performed taking into account the results of the laser scanner. Due to the high amount of false positives given by the laser scanner based system, the vision system was trained to obtain the lowest false positive rate possible. Besides, the camera systems did not include a tracking stage, thus the positive results expected were lower. This situation is visible in the case of vision based vehicle detection. Although the amount of no-detection errors for vehicles was high, it was proved that all the vehicles in the images were positively detected. Thus even in the worst case scenario any vehicle is detected after one or two frames. Finally the low

Table 1 Results

	Camera		Laser scanner		Fusion	
	% of positive detections	% of misdetections (per frame)	% of positive detections	% of misdetections (per frame)	% of positive detections	% of misdetections (per frame)
Pedestrians	72.97	5.27	74.56	13.3	77.69	3.11
Vehicles	47.72	1.13	91.03	8.19	88.25	2.59

amount of false positives in the visual approaches allowed overcoming the excessive number of these errors in the laser scanner approach.

6 Conclusions

Finally we can conclude, given the results presented in Table 1, that the fusion process allows to combine information from the camera and the laser scanner and helps to overcome the limitations of the system, enhancing the capacities of classic ADAS and providing reliable detection, ready to be included in a real road application.

Limitation inherent to each sensors and its algorithms are overcome thanks to the use of data fusion approach. First, computer vision have the trustworthiness limitations due to the unstructured information. The trustworthiness of the laser scanner detection allows to reduce the false positives. On the other hand, the limited information given by the laser scanner is completed thanks to the high amount of data given by the laser scanner.

Although nowadays a road application based in both technologies would represent a high cost, due to the high cost mainly of the laser scanner in comparison to the computer based approaches. Modern cars are already available with this technology to detect obstacles and perform avoiding maneuvers.

Acknowledgments This work was supported by the Spanish Government through the Cicyt projects (GRANT TRA2010-20225-C03-01) and (GRANT TRA 2011-29454-C03-02). CAM through SEGAUTO-II (S2009/DPI-1509).

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Knowledge Management by Means of the Digital Home Compliant Intelligence

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Abstract This work in progress presents the Digital Home Compliant Intelligence as a proposed solution to manage more efficiently knowledge about home devices, and thus enhance the experience in the digital home by offering an application to control all devices and to have information about them and their associated rules, above its operating system or architecture. The management of knowledge involves using databases. Databases can be found in almost every application, where different types of data are stored, with some structure behind the system being designed. In our case, we use data of devices, rules and services that will be stored in deductive database by using ontology. Through ontology, the system can update knowledge about the information collected by Digital Home devices.

1 Introduction

Our homes are increasingly becoming digital environments, providing services such as security, energy saving, cleaning, etc., by integrating smart devices. Thus, homes are being filled with many smart devices (smart appliances, services robots for cleaning, etc.) running without one single method of control. Besides, devices and applications (developed by different brands and companies) are focused on specific tasks and their integration is challenging.

This makes them a nest of devices such as temperature and light sensors, and many other commonly used ones, such as mobile phones, Smart TVs, tablets, etc. Each one of them can be individually controlled or by using a brand's specific

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I. González Alonso (ed.), *International Technology Robotics Applications*,
Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_9, © Springer International Publishing Switzerland 2014

software. The more gadgets we have, the more we have to learn how to control them with new interfaces, in itself a laborious task, leading to a composite digital home of multiple devices unable to interact with each other in a simple and effective way.

One solution to avoid having so many different interfaces is to use products of the same brand, as the company often provides similar interfaces in their various products. This is done to facilitate the user faster learning of the use of their products over other products from other manufacturers with the intention of restricting use to their own products, when in fact the real needs of the end user, are more likely solved with another different product.

There should be a solution that will not bind users to a particular brand or architecture, but will handle the digital home gadgets from a single application, which could communicate between them in a simple way, and looking to the future, integrate more devices without a large load on the maintenance of such an application.

In the light of the above, the aim of this work in process is to develop a communication protocol among appliances and services in the digital home, the Digital Home Compliant Intelligence (DHC Intelligence). There would therefore be no restrictions in the information exchange so devices and services would be able to interact with each other and with the Digital Home. The final goal of the work is to control all using a single program.

2 Antecedents

2.1 Databases

Databases [1] are a set of data concerning the same field of knowledge, and can be found in almost all applications. If a new type of data has to be added, the database must be redesigned, resulting in an updated version of the application. It has to be considered that if the application is running in the cloud, this must be more efficient to avoid an increase of the response times. There is a response delay time between the cloud and the user of the application that may not be increased.

Databases can be classified according to the data model that is employed, which is basically an abstraction that contains information about the actual data to be treated. The most widely used model is the relational model, which highlights the use of data sets (relations) instead of the way the data are stored. Thus, the model is more affordable to human thought.

In response to the relational model, several types of databases are appearing with their corresponding advantages and drawbacks. In the case study, the deductive databases [2] are the most appropriate to provide more scalability and data inference. These are well-known for providing logic advantages to the information system. Deductive databases are very often used in expert systems, knowledge representation, artificial intelligence, etc.

2.2 Cloud Computing

Cloud computing [3] is on the rise, providing information and computing services over the Internet. The application runs on a server and through different communications networks, so the desired information can be requested by any device connected to the network (laptop, smart TV, smartphone).

Among cloud computing features, it should be highlighted the adaptability of the resources depending on the required services. Therefore, only useful information is transmitted, saving resources and execution time. Another noteworthy characteristic of cloud computing is its independence of the system, so allowing users to access the information or services regardless of the device or operating system.

2.3 Ontology

The term ontology [4] is borrowed from philosophy and describes the types of entities in the world and how they are related. Ontology defines the terms used to describe and represent an area of knowledge; that is, to describe the artifacts with different degrees of structure. The term involves the description of the following types of concepts: classes, knowledge in the fields of interest, relationships within the domain and properties.

Technology Web Ontology Language (OWL) is a family of knowledge representation languages for ontologies. OWL is designed for use in applications where processing information is required instead of presenting information to humans. The main advantage of OWL ontologies is the availability of tools that can reason for themselves. Ontologies improve the control data when data are transmitted and a most dynamic storage is achieved [5] by using a cloud service that allows to communicate multiplatform devices.

OWL is intended to provide a model encoded in eXtensible Markup Language (XML) [6]. XML is a markup language created by the World Wide Web Consortium (W3C) and provides a surface syntax for structured documents, but imposes no semantic constraints on the meaning of these documents. XML will be used to display the selected ontology. XML offers database support, enabling communication among applications or the exchange of information.

3 State of the Art

As stated before, smart devices need to be connected in our home. Different solutions based on cloud computing have been developed in recent years. For example, Davinci Cloud Computing Framework [7] is a cloud-computing framework for service robots, as Roomba, which could perform higher intelligence functions such as location tracking. Marvell Home Server [8] provides an affordable and low consumption platform with Plug and Play installation with remote access to connected devices in the home. Another proposal is RoboEarth [9, 10], a network and database repository where robots can share information and learn from each other about their behavior and their environment. At MyRobots.com [11] users with robots can register them in this social network for robots, create robot profiles, allow themselves to update their own status and exchange information among them. Besides, other devices in the home could be connected to the platform.

Finally, DHCompliant project [12] aims to integrate home automation and robotics in the Digital Home and media communications network based on the Universal Plug and Play (UPnP) technology. DHCompliant proposes a solution to develop collaborative tasks between robots taking into account the information that home automation devices can provide, such as lighting conditions or presence detection.

4 Proposed Solution: DHC Intelligence

DHC Intelligence goes one step further than the DHCompliant project and proposes a solution to effectively manage digital homes. DHC Intelligence is based on Devices Profile for Web Services (DPWS) which involves cloud computing and the use of ontologies. Cloud computing enhances the communication among devices and only relevant data would be transmitted. Information about the Digital Home and devices will be stored on a deductive database by using OWL and XML technology. The latter allows:

- Non-related data storage.
- Adding related data to the previously non-related data stored to obtain more information.

Thus, the ontology can be completed by means of inference. Moreover, behavior rules for devices can be stored in this ontology, creating restrictions or patterns in certain actions. For example, vacuum cleaners should not be used at night or the house must be empty before turning the alarm on, etc.

The main information is contained in the ontology, as it can be seen in Fig. 1, where the DHC Intelligence diagram is represented. This shows the SysML model that will be used as the core of the DHC Intelligence, displaying two main interfaces to the actions on the ontology used. After loading the ontology into the memory, it will have a query system. The query system would allow the ontology to look for new knowledge from the data stored, deleting useless information and redundant data. Semantic information interface is responsible for creating and maintaining consistent information such as properties and relations. The ontology

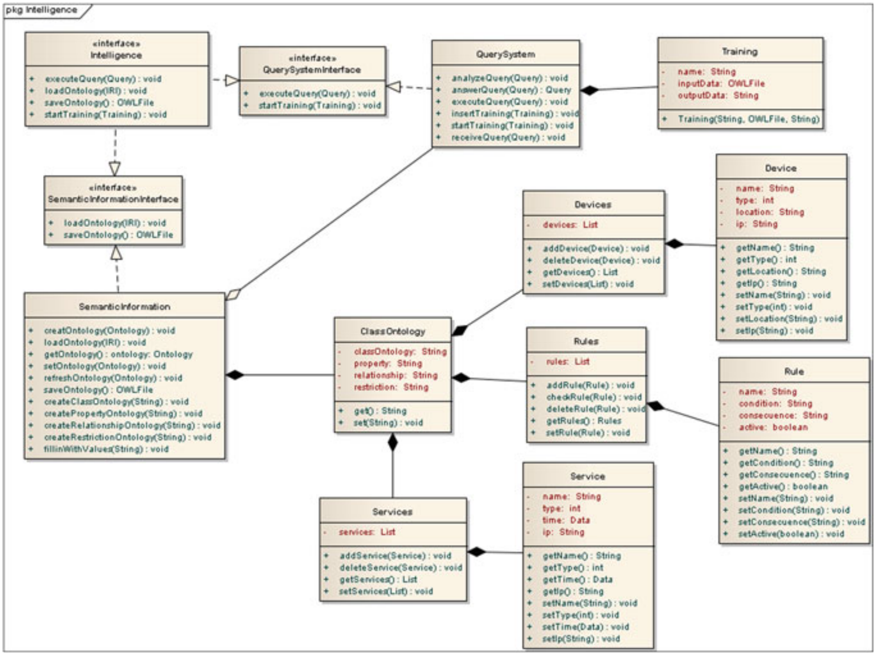

Fig. 1 DHC intelligence class diagram

information would be divided among various functional modules (rules, devices, etc.) making its use much easier.

The next ontologies have been created by means of the Protégé program [13] and are deployed below. The initial ontology, as can be seen in Fig. 2, is divided into devices, services and rules. The union of these ontologies is the logical scheme of digital home, ensuring that only useful information is managed. The smart devices are considered the intelligent elements in the house (smartphones or computers) and in recent years, devices such as service robots [14] and smart appliances (refrigerators, washing machines, etc.) are becoming more popular. Each node gets information about a device, a unique identification, position, profiles, etc. and so we can inventory of our appliances for future uses.

The deployment of the standard rules in DHC Intelligence is depicted in Fig. 3. The users would increase or decrease the set of rules according to their needs. This set of rules gives restrictions and attitudes to the system. The users can add rules for avoid no desired actions. For instance the user can restrict when a robot can clean, or when an appliance must be on or off. Also, system can skip certain rules for getting an optimization in response time.

Finally, the service ontology is presented in Fig. 4. The services will dynamically increase by introducing new smart devices into the home. For instance, if a vacuum cleaner robot is included, the system will be updated by adding cleaning services.

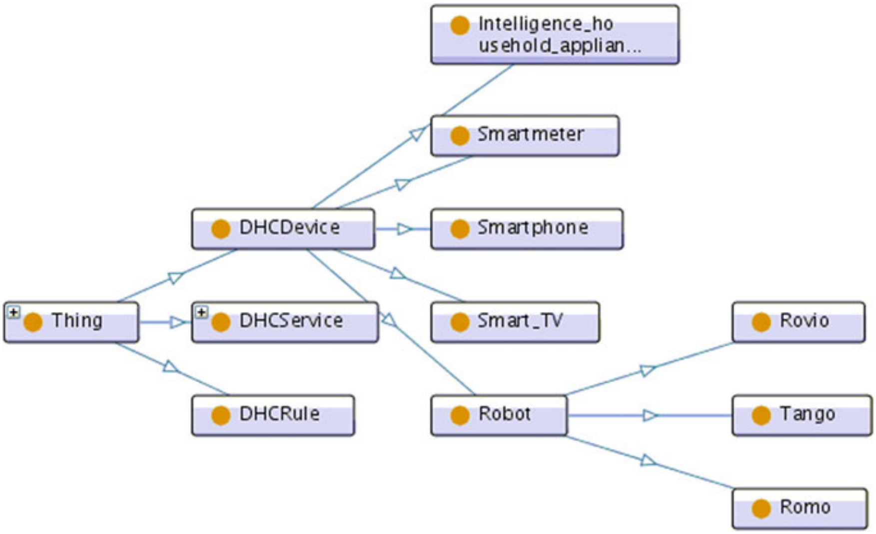

Fig. 2 Devices ontology diagram

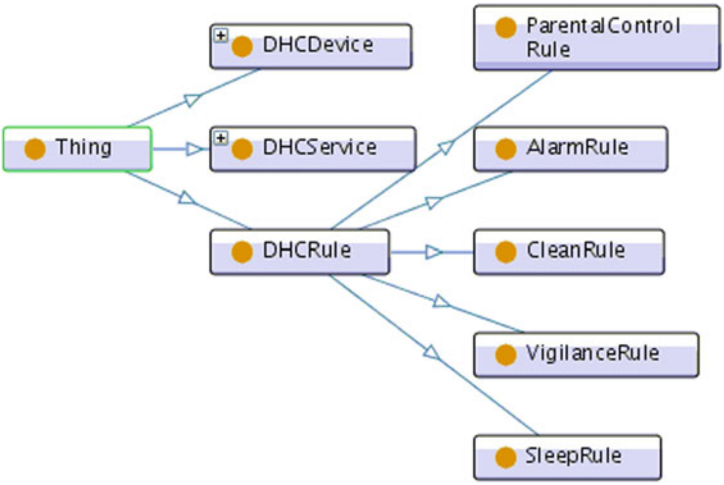

Fig. 3 Rules ontology diagram

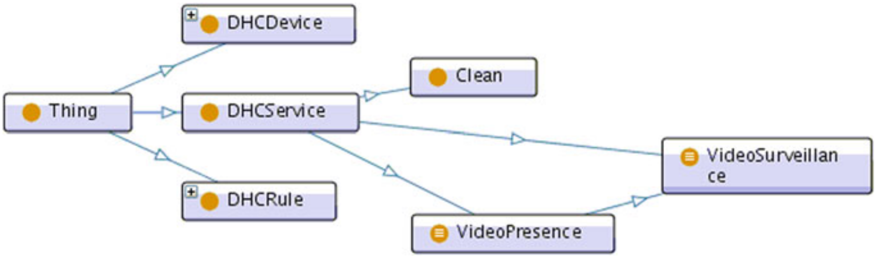

Fig. 4 Service ontology diagram

5 Conclusions and Future Work Lines

Research is progressing with the aim of making the experience of the Digital Home easier and creating a less chaotic environment. For this purpose, we will create an application, DHC Intelligence that covers the services provided by other applications. Thus all users, whether experts or not, may be benefited by the advantages of the Digital Home.

We will develop a system of requests for information, to relate this information with the appliances. This allows the devices to upload its own information to the cloud and receive information. Besides, generic training systems will be implemented for managing greater ranges of information without explicit maintenance of data. Finally, it is planned to develop an efficient OWL file processing. The management of great amount of data can generate large latency times, which prevents the user from real time working.

In summary, usability improvements that are needed in digital environments, would achieve faster data exchange between smart devices and applications than the current services. Consequently, users would be able to avoid delay times and would perform all tasks in real time.

Acknowledgments This work is possible thanks to the financial support of the Spanish Department of Science and Technology, the Ministry of Industry, Energy and Tourism and FEDER funds. We would like to acknowledge the continuous support given by the University of Oviedo, and also for providing all the resources that made possible our research and, in particular, their management of the DHCompliant 2 project (grant TSI–020100–2011–313). We are also very grateful to all the members of the DHCompliant 2 consortium, composed by Infobotica Research Group, Ingenium, Ingeniería y Domótica S. L. and Domotica DaVinci.

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An Integrated Autonomous Navigation and Decision-Making Architecture for Planetary Exploration Rovers

A. Medina, G. Binet and P. Colmenarejo

Abstract In recent years, there has been an increasing research into and experience with autonomy and automation of space missions, such as Earth observation, space station operations, planetary robotic exploration and deep space probes. Capabilities of such systems have grown exponentially, leading to the need of the development of autonomy for the space and ground systems, driven by the benefits that autonomy brings in terms of reducing mission operational costs, enabling long term missions and maximizing scientific return. In the area of planetary rovers the robotics autonomy must be achieved by implementing autonomous navigation capabilities in the functional layer and autonomous decision-making systems in the deliberative layer. In this paper, we propose a goal-oriented autonomous controller architecture over a functional layer based in the classical GNC (guidance-navigation-control) approach. The structure of this paper is the following:

- Section 1 provides an overview of autonomous system architectures;
- Section 2 describes the proposed architecture, as well as a description of the deliberative and reactive layer;
- Section 3 describes the functional layer of the proposed architecture, by providing details regarding the proposed GNC functions of the planetary rover;
- Finally, conclusions are drawn and the proposed next steps are detailed.

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I. González Alonso (ed.), *International Technology Robotics Applications*, Intelligent Systems, Control and Automation: Science and Engineering 70,
DOI: 10.1007/978-3-319-02332-8_10, © Springer International Publishing Switzerland 2014

1 Overview of Autonomous Systems Architectures

Software architecture is a methodology to give a structure to a number of algorithms, i.e. a set of languages, tools and a generic approach to create and integrate functionalities. One of the most important aspects to be addressed in any architecture is if this has to be deliberative or reactive. Generally speaking, in reactive architectures [1], actions are obtained from the information that is gathered from sensors, which can be a limited perception of the environment. Deliberative architectures, however, are based on a model of the environment, which is used to generate a plan of the actions that the system has to perform in order to fulfill an objective [2]. Hybrid approaches can also be implemented; these are architectures that mix both deliberative and reactive approaches. In addition to such architectures, others that can be variants of the above-mentioned have also been proposed, such as the layer-based architecture [3], the behavior-based [4], the architecture based on Belief-Desire-Intention [5], the one based on propositional logic [6] and agent-oriented one. To summarize, several autonomous architectures have been proposed in literature, and a way to categorize them is based in the methods that are used to generate decisions [1]. The following sections describe the three main architectures which have been proposed following such separation.

1.1 Three Layers Architecture

The three layer based architecture [7] or 3T [8]—P&S (planning and scheduling), executive and functional- is a hybrid architecture which has been extensively used [3]. Within 3T architectures, the higher layers are composed by deliberative behaviors, oriented to future and with slower working frequency, and the lower layers are composed by more reactive, and faster, behaviors. Many variants of 3T architectures have been proposed, some of them merging the deliberative with the executive layer. The deliberative P&S layer takes as input several mission objectives and has got as resources several activities that it can perform to fulfill those objective. Its aim is to organize the activities along an extended time span in order to achieve the mission objectives. In order to do that, the P&S needs to have a model of the environment, that enables it to understand the world and take decisions, and that is updated constantly as the plan is executed. The intermediate level is an executive layer which can perform the activities that have been scheduled by the plan. The lower level is the functional level, i.e. the interface between the software functions and the hardware of the autonomous system.

Since the early 1990s the hybrid three layer architecture has become a de-facto standard (with some minor variations) for complex robotic systems. Later on (in the period 1999–2003) this approach has successfully been applied to a number of NASA spacecraft's. The most outstanding layered architectures which have been used include AuRA (AUTONOMOUS ROBOT ARCHITECTURE, [9]), CLARAty [10], FAMOUS (Flexible Automation Monitoring and Operation User Station, tested on board the Japanese ETS-VII test satellite, [11, 12] and the LAAS architecture [13].

1.2 Subsumption Architecture

Subsumption architectures [14, 15] are reactive architectures based on behaviours instead of models of the reality; hence they do not need a deliberative system. Such architecture offers a way to combine real-time control with sensor-generated behaviours. These behaviours practically connect sensors to actuators, and are organized in layers, where each can inhibit behaviours in lower layers. One of its advantages is its simplicity and low computational effort needed [16].

1.3 Agent-Oriented Architecture

In this type of architecture execution and deliberation are interleaved, with several agents each in charge of a specific task. The main examples of such architecture are RAX (Remote Agent Experiment, which has flown on-board the Deep-Space One spacecraft in 1999, [17]), as well as TREX [18] and IDEA [19]. Agents are executing in a concurrent way and are communicating with each other, so that no inherent hierarchy is imposed, even if most implementations do end up with a layered structure. All agents use the same language, and every agent (“reactor” in T-REX) can have either a deliberative or reactive behavior. The implementation of such deliberative capability is in charge of each reactor, which can use a specific planner. In these architectures, planners typically are based on modeling the environment, using timelines and restrictions in order to represent and reason on resources of the platform and the environment.

2 Proposed Autonomous Architecture: The Goal-Oriented Autonomous Controller

The approach that we propose, the so called Goal-Oriented Autonomous Controller (GOAC) is based on an agent-oriented architecture. GOAC [20] is a hybrid architecture consisting of a set of reactors/timeline planners over a reactive/interrupible functional layer. The architecture is illustrated in Fig. 1. Each reactor (or teleo-reactor, according to T-REX terminology) is a sense-plan-act control loop working at a different level of abstraction and making decisions over a possibly different functional scope of the system. Reactors are differentiated based

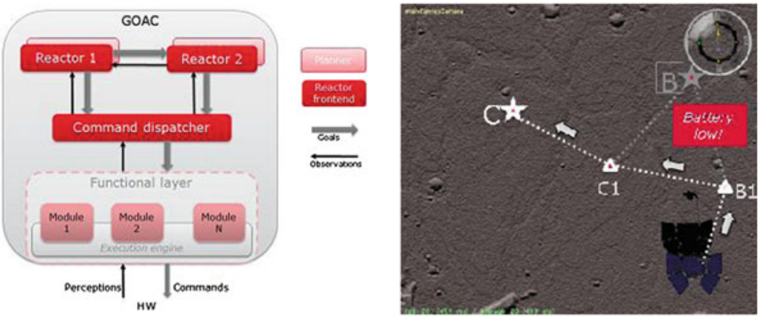

Fig. 1 GOAC architecture (*left*) and GOAC-3DROV case study scenario (*right*)

on whether they need to deliberate in abstraction (at the highest level) or be responsive to the inputs from the lower levels closer to the hardware. There is a well-defined messaging protocol for exchanging facts and goals between reactors: observations of the current state either from the environment or from within the platform, and goals to be accomplished.

The intelligence of the controller is in the planner, the problem solver, but instead of a single planner there can be several planners in GOAC. In that case, each planner is embedded into a different reactor. At the bottom of the deliberative-executive layer, there is a command-dispatcher reactor, which is purely reactive (non-deliberative, that is, it does not produce any plans). The controller can be seen as a network of reactors, where the output of each reactor (a plan) is the input (a set of goals) for another reactor.

Therefore, GOAC follows a divide-and-conquer approach to complexity, by splitting the deliberation problem into sub-problems, thus making it more scalable and efficient. The number of deliberative reactors to be instantiated in the on-board controller of a given space robotic system is a mission-specific design decision. Each reactor deliberates over a different part of the domain functionally; for instance, a science reactor and a navigation reactor take into account different aspects of the mission. On the other hand, the planning horizon is different for each reactor. For instance, whereas a mission-level reactor could consider the whole mission life (e.g., a day-long survey), a navigation reactor would look into the future for a single navigation unit, such as a traverse towards a given target point. Since the planning problem can be computationally intensive, by splitting it into several sub-problems, we achieve scales of efficiency. If, for instance, a lower-level deliberative reactor can cope with a re-planning need, higher-level reactors will not be informed. In this way, a subset of the planning domain can be used to efficiently satisfy a re-planning need.

Making decisions in GOAC relies on timeline-based planners. According to this technology, plans are flexible, that is, the time boundaries (start, duration and end) of planned tasks are not fixed. This way, plans are more robust in the frame of uncertain environmental conditions, than predefined, rigid sequence of activities.

The functional layer is based on GenoM [21] and BIP [22]. GenoM is a development framework specifically intended for the definition and implementation of modules that encapsulate algorithms embedded in target machines such as robotic systems. A module is a standardized software entity that is able to offer services which are implemented by a set of algorithms. Users can start or stop the execution of these services, pass arguments to the algorithms and read the data produced. GenoM provides a standard interface to interact with the services and data provided by modules.

Each GenoM module [23] of the functional layer is responsible for a particular functionality of the robot. For example, the basic sensors and effectors are managed by their own modules (e.g., one module for the camera pair and one module for the laser range finder). More complex functionalities are encapsulated in higher level modules (e.g., a module doing stereo correlation will use the image taken by the camera module). The most complex functions (such as navigation) can be obtained by having modules "work" together.

The set of modules comprising the functional layer of a robotic system is mission specific, especially for modules responsible for controlling hardware elements. However, like hardware devices, functional modules are reusable across different robotic platforms.

The BIP framework provides a methodology for building real-time systems consisting of heterogeneous components. BIP is used in order to reduce a posteriori validation as much as possible, by putting the focus on the following challenging problems: incremental composition of heterogeneous components; ensuring correctness-by-construction for essential system properties; and automated support for component integration.

GenoM along with BIP provides a framework for the development of the functional layer of robotic systems, featuring a modular and levelled structure wherein certain (both intra-module and inter-module) constraints can be enforced at run-time.

Next Fig. 2 provides an overview of the GOAC architecture instantiated on a virtual (3DROV) scenario differentiating between upper layer (T-REX reactors and timeline planners) and the bottom layer (GenoM modules supervised by the BIP run-time engine).

3 The GOAC Functional Layer: The Low Level GNC

3.1 Functional Layer Architecture

The GOAC architecture which has been introduced before provides a system that can be used for several missions. Lower level functionalities are, however, much more dependent on the type of application that has to be implemented. In the case of a planetary rover, the functional layer can therefore be considered as a low-level

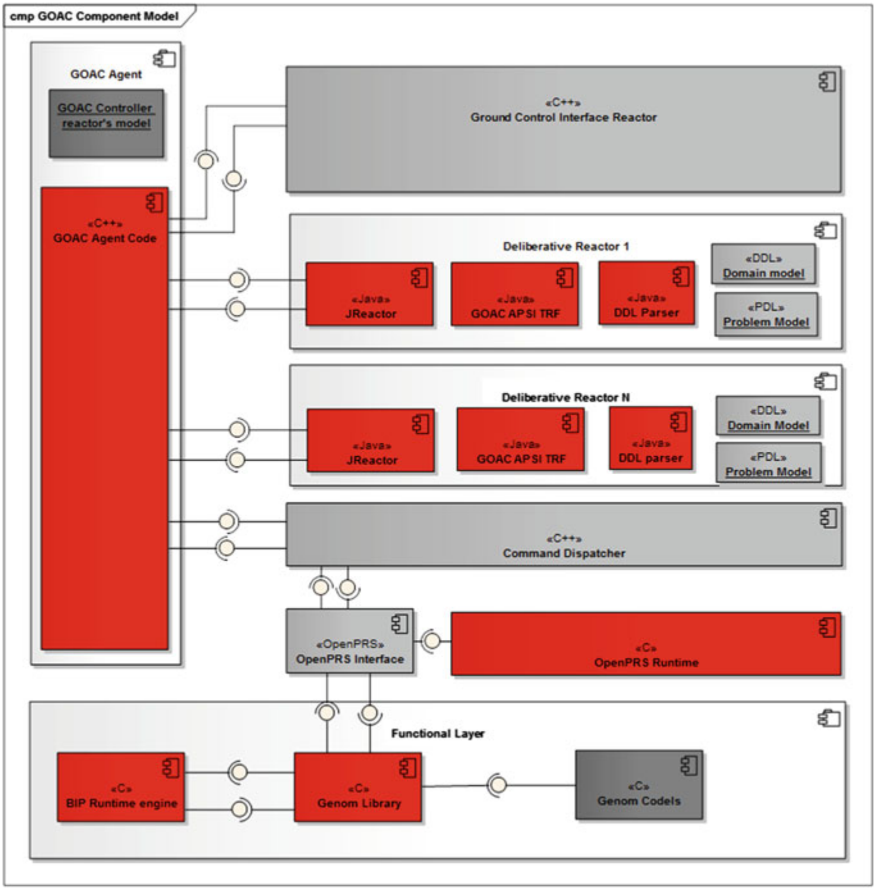

Fig. 2 GOAC instantiation for the 3DROV case study scenario

GNC (Guidance, Navigation and Control). This section describes our approach to the low-level GNC architecture for a planetary rover, which aims at providing as much autonomy as possible to this level.

Typically, autonomous navigation for planetary exploration rovers is based on sensorial data fusion using a combination of inertial measurement unit, mechanical wheels odometers, visual odometry using a hazard-cameras stereovision-bench and a panoramic stereovision camera system (rather than other perception systems such as LIDAR (Light Detection and Ranging) or TOF (time-of-flight) cameras due mainly to its lower power consumption). The stereovision bench is mounted on top of the rover at the maximum allowed height to provide a full panoramic 360° view of the surroundings using a pan-tilt unit while the hazard stereobench is mounted at the height of the wheels to detect unexpected obstacles. Panoramic high-resolution mapping are the basis for the DEM (Digital Elevation Map) and

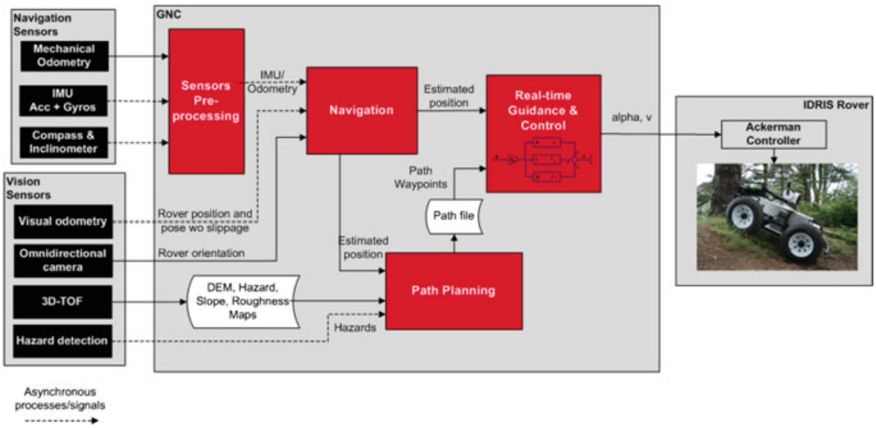

Fig. 3 EGP-Rover [25] GNC scheme adapted to IDRIS rover within FP7 ProViScout activity [26]

derived products such as slope map, hazard map and roughness map. These maps are analysed using a cost function which delivers, with the help of path-planning algorithms, an optimum path from the current rover position to the desired target location. In addition, stereo vision systems can be used to support other functionalities such as pattern detection (i.e. to look for rocks of scientific interest), to detect and follow a target (i.e. detection and tracking of an astronaut or detection of a light beam for spotting an interesting target point [24]).

In order to support such features the rover GNC architecture [25] must include the following components as shown in Fig. 3:

1. **Environment perception** (sensors pre-processing), in charge of formatting the raw DEM maps, received sensors measurements and estimates according to GNC needs and to perform some basic pre-processing (e.g. noise filtering).
2. **Path planning**, in charge of finding the best (in terms of safety, suitability and required travel time) path from the current rover location to the target location over the available DEM model.
3. **GNC Control cycle**:

- **Navigation**, in charge of providing an estimation of the rover state (position, velocity, orientation and orientation rate) from the sensors measurements and estimates.
- **Guidance and trajectory control (Real-time Guidance)**, in charge of executing in real-time the pre-defined path planning to the following waypoint, and also potentially in charge of short-range path planning update (due to wheels slip, small obstacles …).
- **Traction control (Rover Wheels Management)**, in charge of correcting the real rover translational state to the desired rover translational state. It translates the control commands to wheels actuators. This wheel commanding

Fig. 4 EGP-Rover over moon-like scenario (*left*) and IDRIS rover at Tenerife final test campaign (*right*) [27]

usually follows Ackerman formulation where a virtual wheel is placed in the middle point between the wheels axis and it is used to align the rover heading with the desired trajectory heading.

The above-mentioned GNC architecture has been successfully tested over the EGP-Rover and the IDRIS rover [26]. The EGP-Rover rover is a mobile platform sized 1.5 $\times$ 1 m as shown in Fig. 3, demonstrating the centaur concept (two robotic arms at the front of a four-wheels rover) aiming to assist astronauts in the construction and maintenance of a lunar or Martian base station. The goal of this rover is to achieve a highly-accurate mobile system either for short distance mobility in the lander vicinity (i.e. rear-wheels steering) or to transport an astronaut and/or another payload (up to 400 kg) to a target location, trespassing unknown terrain (Fig. 4).

The IDRIS rover was the selected mobile platform within the ProViScout EU FP7 activity with the objective of providing autonomous navigation to search for potential targets of scientific interests (i.e. rocks and outcrops) in the near environment. IDRIS is a 350 kg platform based on a robuCAR TT platform [28] with double-Ackerman steering, a panoramic stereo-bench and a omnidirectional camera used as visual compass [29] (see Fig. 3).

3.2 Environment Perception Process

Either from a stereovision system or from a laser 3D or TOF cameras we can obtain not only a digital elevation map (DEM) but also some other vision products of interest for our autonomous navigation approach as described here after:

- **Slope map**. The slope map represents the slope values of any (x, y) point from the DEM map with respect to its neighbours (see Fig. 5). The slope, as defined in [30], is the angle between the gradient vector (surface normal vector) and the vertical at that point. García [31] reviewed the Sobel operator approach against

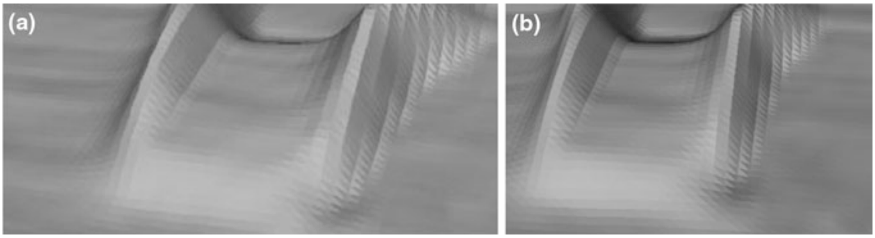

Fig. 5 Slope map generated using 4 neighbours (image **a**) or 8 neighbours (image **b**)

the four neighbours approach. At the edges of the map the previous equations cannot be applied directly but we were just assuming the nearest neighbours values (this assumption is reasonable as the rover is never trying to navigate through the map edges).

- **Orientation map**. It represents the orientation of the terrain with respect to the North. The orientation of a point is defined as the angle between the vector pointing North and the projection on the horizontal plane of the normal vector of the terrain surface at that point. At the edges of the map it is not possible to apply the previous equation and thus the orientation values are taken from the nearest point.
- **Roughness map**. The method for computing the roughness map is based on Hobson [32] approach: over a uniform and slightly rough terrain, the vectors perpendicular to the surface shall be approximately parallel and its vectorial addition will be high indicating a low dispersion. On the contrary, in a rough terrain, slope and orientation variations will make these vectors to present a greater dispersion and its vectorial addition will be low.
  According to Mardia [33] the spherical variance is a statistic that measures the dispersion of a sample of vectors. We are using this statistic as an indicator of roughness by computing the module of the vector sum of all perpendicular vectors to the terrain surface.
- **Shadow map**. The shadow map includes the terrain areas that are occupied by the shadow of the objects allowing differentiating between the true terrain surface and the non-measured terrain areas. This map represents the uncertainty of the terrain by marking the occlusions generated by obstacles during the image acquisition process.

After previous image products are generated, these are merged together by carrying out a traversability analysis (see Fig. 6), which output is the generation of the final navigation map. This traversability analysis is implemented as a fuzzy logic process with the Sugeno-type inference engine [34]. The fuzzy logic was chosen because of its intrinsic ability to map natural values to the terrain characteristics of elevation, slope and roughness generating the navigation map as a continuous cost-terrain index (painted in grey colour [0–255] in Fig. 6, right).

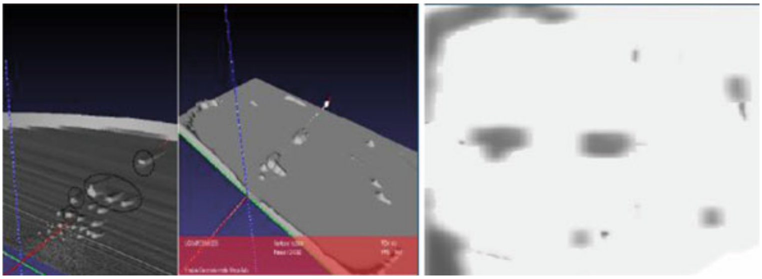

Fig. 6 DEM maps (*left*) and corresponding navigational map (*right*)

3.3 Path-Planning Algorithms

Path planning is an important and critic top-level task for the operation of planetary surface rovers. The input of this function is a navigation map, where keep-out regions are clearly identified. The output of the path planning is a path to be followed, generally in the form of a list of waypoints to be traversed by the rover. Previous GMV experiences like EGP-Rover [25] or MoonHound rover [31] (a 60 kg class skid-steering rover) demonstrated the need of generating smooth curved trajectories rather than sharp trajectories as they bring benefits in terms of energetic efficiency, slippage reduction and steering–motor efforts.

Several search-based algorithms have been proposed and developed to solve the rover path-planning problem: geometric-based algorithms like visibility and Voronoi graphs [35], sampling-based Search: Potential based search, rapidly-exploring random trees (RRT) and probabilistic roadmaps (PRM) [35, 36] and grid-search based like A* [35, 36], D* [37], ARA* [38] and AD* [39].

For planetary surface operations a complete, systematic, and optimal algorithm is preferred. Furthermore it must able to integrate differential constraints. Based on these considerations the grid-based search algorithms using the state lattice approach are selected to implement the path planning algorithm [40], despite of their relative high computational cost compared to the other search algorithms. Being the path planning a function typically computed when the rover is still, the drawback of the high computational cost and therefore longer computational time is considered to be acceptable.

A state lattice is a discretized set of all reachable configurations of the system. From the point of view of 2D rover navigation, the basic variables are the Cartesian coordinates (x, y) and the heading (θ) variables. Additionally, due to the non-holonomic constraints of car-like vehicles or Ackerman primitive-based vehicles the curvature (k) (reciprocal of the radius of the osculating circle of the trajectory) has to be considered. Furthermore we want to include back-driving capabilities; thus, the search algorithm has to know the sense of the motion (μ) of the current state and if the new state will be reached moving forwards or backwards.

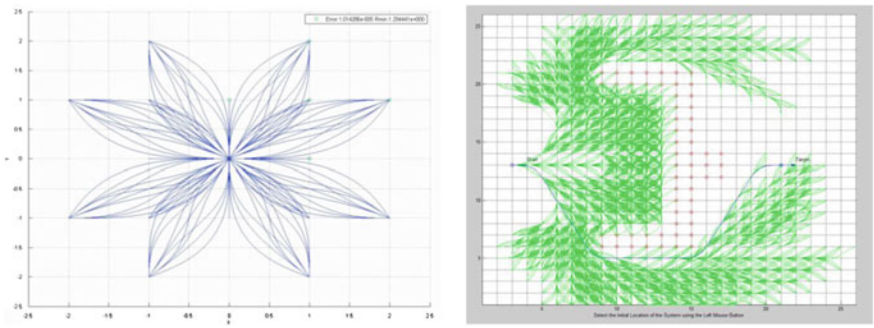

Fig. 7 State lattice discretized states (*left*) and path-planning search-space (*right*)

Therefore a state of the system will be defined by five variables: (x, y, θ, k, μ). Different types of curves (i.e. clothoids, polynomial spirals) have been considered in order to obtain proper trajectories from an initial state to a destination state (see Fig. 7). Trajectories based in curvature polynomials of cubic order are considered to be ideal for our purpose, because they can be used to determine a unique trajectory to a target state using a single primitive. Such curves are also the lowest order curves (high smoothness), which are continuous in the torque applied to the rover steering mechanism allowing to minimize the power consumption at steering motors level.

Conventional grid-search A* algorithm has been modified in order to integrate our state lattice approach. The heuristic cost function related to the estimated distance to the target is enhanced by including the heading and the curvature introduced by the state lattice approach as shown in Eq. (1):

$$h(s) = A\,d(x,y) + B\,\theta(s) + C\,k(s) + D\,\mu(s) \qquad (1)$$

In previous cost function weights C and D are over-ponderated to penalize rover heading and motion changes. Changing the motion sense is a high power-consuming operation as the rover has to stop completely and start moving again. Thus, the back-driving capability has to be used only when it is strictly needed (Fig. 8).

Further steps related to the path-planning problem are directed to the reduction of the CPU computing times due to the restrictions of space CPU's (150–300 MIPS). In this trend we are proposing a FPGA realization of the A* state lattice algorithm.

Such FPGA/VHDL coding requires analysing in depth the memory requirements and the potential of parallelism. Memory savings can be achieved by storing the map using only one bit per pixel (a map 400 $\times$ 400 pixels can be stored into 16 Kb), the 3-D space can be managed using one single integer storing its (x, y, heading) coordinates, closed lists can be reduced to a single flag bit within the 3-D space and look-up table can be used to host the 24 discrete headings of the rover and the possible headings of the next node for each one of them.

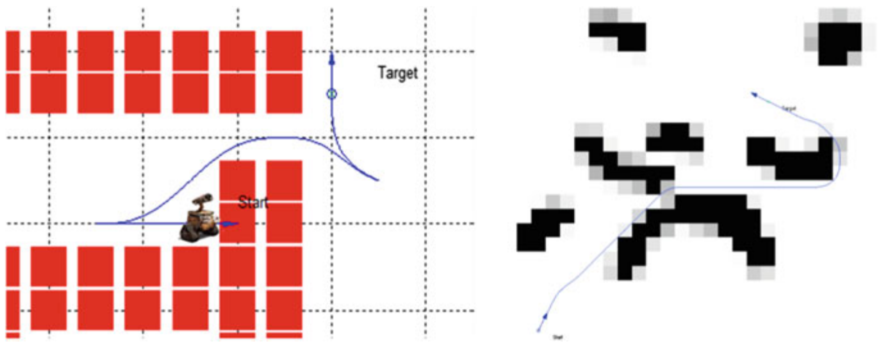

Fig. 8 A* state-lattice algorithm demonstrating back-driving capabilities (*left*) and avoiding obstacles (*right*)

3.4 Navigation, Guidance, Trajectory and Traction Control

Once the path has been defined by a list of waypoints to be travelled by the rover, the robot has to perform the motion to actually reach the desired destination. The aim of the guidance and trajectory control is therefore to constantly read the current state of the vehicle (such as linear velocity, position and orientation on the map) and to decide the optimal desired linear velocity vector of the vehicle in order to follow the given waypoints of the computed path (See Fig. 9, right). Our approach to implement such online trajectory control function is based on a Model Predictive Control based engine [41], which continuously computes an optimal motion command by taking into account the non-holonomic characteristics of the vehicle. The advantage of using such MPC control, with respect to classical PID reactive control, becomes particularly clear when the path to be followed is composed by sharp turns. In these regions, the MPC can predict and therefore better act by taking into account the geometric constraints of the motion system of the vehicle. The results of a comparison of the Integral of Square Error (ISE) for both MPC and classic PID trajectory control along a pre-given path are shown in Fig. 9; these results highlights the fact that MPC outperforms classic control in case of sharp turns.

Typically, in case the rover cannot follow the computed path because of wheel slippage or slope terrain, the rover is stopped, a new panoramic image is taken and a new path planning is computed. We propose however to include an online guidance function which is activated when the rover slips outside a corridor around the nominal path, and that continuously computes contingency paths to bring the vehicle back into the pre-defined track without needing to stop the vehicle. A solution of such guidance function based on MPC is given in [41]: in this work, MPC allows to perform online optimization by taking into account not only the vehicle non-holonomic characteristics, but also the presence of obstacles to be avoided between the rover position and the nominal path.

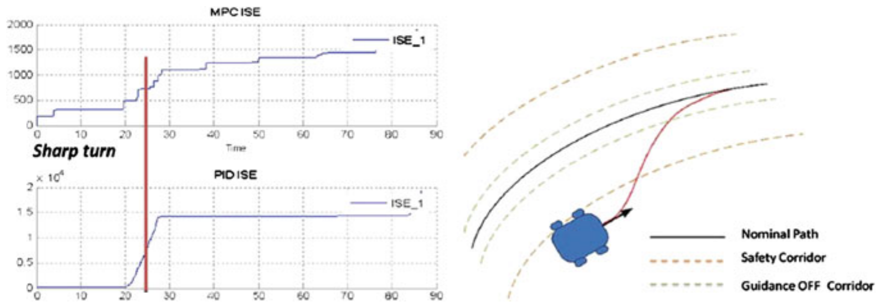

Fig. 9 MPC versus PID trajectory control (*left*) and guidance function (*right*)

The output of the guidance and trajectory control is the desired velocity vector, which is then fed to the traction control. Such function translates the desired velocity vector of the vehicle in a set of commands to the wheels, such as their desired rotation velocity and orientation. In a classical car-like vehicle such as the EGP-rover, Ackermann model is used. Note that in this function wheel slippage detection and control can also be included, as it can become an essential feature in case of rough terrain and, in particular, navigation through soils whose characteristics are relatively unknown (which is the case for planetary space rovers).

4 Conclusions and Future Works

Typically, space rovers have got an autonomy level that enables them to execute specific commands or, at best, a predefined plan of actions. Such approach needs the intervention of an operator to command for actions, such as the generation of a map, the decision of a target to be reached and a set of actions to be performed in sequence by the rover. This classic approach however needs heavy intervention from ground, therefore increasing the costs of the mission and decreasing the mission time allocated to surface activities, as the transmission delay between ground station and the rover location has to be taken into account (approximately 20 min for a one-way communication between Mars and Earth). In addition, ground support that takes the decisions does not have a full perception of the environment where the rover is operating. Such obstacles can be overcome by delivering more autonomy to the rover (by using our GOAC approach), meaning to be able to sense, plan and act with its environment.

This paper has described a brief overview of autonomous systems architectures, and has presented an approach for an integrated solution to autonomy for planetary exploration rovers covering the following aspects:

- an established architecture for on-board controllers of future space robotic systems where;

  - the executive and planning components are interleaved in a hierarchical approach allowing to afford complex systems,
  - and the functional layer is constructed over a robotics framework (GenoM) supervised by an external run-time agent (BIP).

- a consolidated GNC scheme allowing to perform long-range navigation without the need to stop motion (i.e. non-stop rover), thereby delivering more autonomy to the upper layers, and
- a methodology for the implementation of GOAC controllers which can be applied even for other non-space robotic systems.

It is envisaged to further develop and optimize the integrated autonomy solution, by directing future works to such GOAC implementation over other robotics platforms (UAV's/mobile manipulators). In addition, effort will be devoted to overcoming the restrictions that on board computational resources impose on the autonomous system; for instance, activities are under development for the hardware acceleration (FPGA/VHDL implementation) of vision and navigation algorithms.

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