SIRMAVED: Development of a comprehensive monitoring and interactive robotic system for people with acquired brain damage and dependent people

Miguel Cazorla[1], José García-Rodríguez[1], José María Cañas Plaza[2], Ismael García Varea[3], Vicente Matellán[4], Francisco Martín Rico[2], Jesús Martínez-Gómez[3], Francisco Javier Rodríguez Lera[4], Cristina Suarez Mejias[5], and Maria Encarnación Martínez Sahuquillo[5]

[1] Computer Science Research Institute. University of Alicante
P.O. Box 99. E-03080. Alicante. Spain
[2] Rey Juan Carlos University
Fuenlabrada. Madrid. Spain
[3] University of Castilla-La Mancha
Albacete. Spain
[4] University of León
León. Spain
[5] Hospital Universitario Virgen del Rocio
Sevilla. Spain

Abstract. The care of dependent people, whose dependence is caused either by disease, accident, disability, or age, is a high-priority area of research in developed countries today. This care, besides providing assistance and company, is even considered therapeutic. Moreover, such care is intended to be provided at the patient's home, in order to minimize the cost of therapies.

In this paper, we present the first steps of a Spanish project in which we have brought together a multidisciplinary team that is able to address each area of specialism separately, thus providing an integrated overall solution. The main scientific objective of this project is to promote the health and welfare of society via the design, development and evaluation of a novel therapy for the cognitive rehabilitation of people with acquired brain injury or dependent people. This therapy will be based on the design and use of an intelligent and active environment monitoring system and a social autonomous robot providing interactive stimulation at home.

Keywords: Acquired brain damage, dependent people, robotic system of multimodal interaction, intelligent environment monitoring, 3D object recognition, GPU acceleration

1 Introduction

The care of dependent people, whose dependence is caused either by disease, accident, disability, or age, is a high-priority area of research in developed countries today. This care, besides providing assistance and company, is even considered therapeutic. Moreover, such care is intended to be provided at the patient's home, in order to minimize the cost of therapies.

In the EU, this issue has been widely discussed in the FP7 programme. An example of an existing system is Companion-Able[2], which aims to take advantage of the synergy from robotics and ambient intelligence and their semantic integration in a caregiver environment. The same objective was pursued in the FLORENCE[11], MOBISERV[25] and KSERA[6] projects, which make use of an external sensor network, placing the robot in a structured indoor environment.

However, to be a true partner, robots need to be reliable, intelligent and able to work in close collaboration with humans (`http://cordis.europa.eu/ictresults`). The need to provide robots that can work with people (companion robots) is included explicitly at the heart of Challenge 2: "Cognitive Systems and Robotics of the EU Frame Work Program". For example, the Hobbit project[7] develops an assistant robot to help seniors feel safe at home. Its main goal is to keep people active with games and exercise, as well as detecting emergency situations and acting accordingly. Moreover, the GiraffPlus project[4] proposes a complex system capable of monitoring the activity taking place in a house through a network of sensors (distributed around the house or on the body of an elderly person), together with a robot that serves as an interface that allows different users, family members, caregivers or health staff, to virtually visit the elderly person at home.

In Spain, there are also ongoing projects that are closely related to the one proposed in this paper. The Therapist project[3] proposes the use of social robotics in physical rehabilitation therapy for pediatric patients, and the Talisman project[1] monitors the behavior of patients.

In this paper, we present the first steps of a Spanish project in which we have brought together a multidisciplinary team that is able to address each are of specialism separately, thus providing an integrated overall solution. The main scientific objective of this project is to promote the health and welfare of society via the design, development and evaluation of a novel therapy for cognitive rehabilitation of people with acquired brain injury or dependent people. This therapy will be based on the design and use of an intelligent and active monitoring environment system and a social autonomous robot providing interactive stimulation at home. This requires the integration of several existing technologies and solutions to a variety of technological challenges that such systems involve. In addition, we propose an experimental evaluation with real patients, which will be conducted by clinicians who assess the effectiveness of the system in improving the quality of life of dependent people. The evaluation will be conducted to assess both the autonomy and the positive cognitive-affective state of the patient.

The paper is structured as follows. In Section 2 we describe the aim of the research. Then, Section 3 describes the main current results of the project. Finally, in Section 4 we draw some conclusions and outline future work.

2 Aim of the research

To achieve the overall objective proposed it is necessary to address certain scientific and technological challenges which are divided into the following specific objectives:

1. To develop an intelligent environment monitoring system, which allows the localization and tracking of the mobile agents in a scenario.
2. To develop a system for human-robot interaction that provides multimodal interaction capabilities in a human way.
3. To develop a system for the recognition and manipulation of small 3D objects on the robot providing patient assistance.
4. To develop robust topological/metric self localization techniques in order to facilitate the robot with autonomy and freedom of movement.
5. To develop a cognitive system that allows the robot to behave intelligently.
6. To design an assistance and care rehabilitation stage, and identify metrics, with a pilot and final evaluation of the system with real patients and scenarios.

The expected results of this project are diverse. At the scientific and technical level it is expected to achieve significant advances in the technologies involved. In terms of social impact, we hope to improve the quality of life of patients with acquired brain injury or dependent people. In terms of economic impact, we expect to obtain a low cost system, with a potential commercialization of it, so that we could start a technology-based company, increasing the technology transfer to society and enabling new researchers to continue developing their career, and thereby promoting employment in the area of information and communications technology.

Figure 1 shows the complete system. It consists of two main parts: an intelligent monitoring system that is able to identify and track people, and a robot with all the necessary capabilities for communication and rehabilitation.

3 Current results from the project

In this section, we describe the current results of the project, pointing out the milestones reached and the publications obtained from it.

3.1 Intelligent monitoring system

The intelligent environment monitoring system is based on several RGB-D sensors distributed around the home and a robust people segmentation and 3D

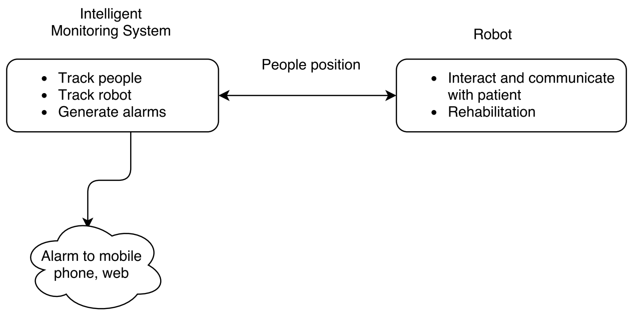

Fig. 1. Complete system.

tracking algorithm. It continuously delivers a 3D position estimation of all the people in the monitored area. In addition, several alarms are programmed into the system, such as falls, abnormally long stays in the bathroom, absences of person for a given period, intrusions, etc. In the event of any of these situations happening, the system automatically triggers an alarm and sends it to the relatives, caregivers or medical staff for further attention. This system has been completed and is working in several homes. Figure 2 shows an example of the system's GUI.

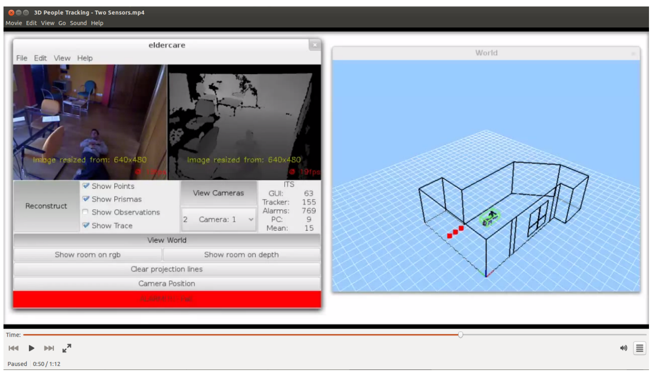

Fig. 2. Intelligent monitoring system.

It works day and night as the main sensor data are the depth images from the RGB-D devices. It has been designed to be non intrusive and so it does not require monitored people to wear any specific device or perform any specific action at all to be detected. The system complies in with the "Ambient Assisted Living" topic in the Active Assisted Living European research programme (`http://www.aal-europe.eu`).

Several low cost computing nodes are distributed throughout the monitored area, all of them connected via the network (wired or wireless). One of them runs the alarm communication module and this is the only one which talks to the outside world. Each node can gather information from up to two RGB-D devices. All the sensors are calibrated at installation time: their absolute position and orientation are known. This allows easy data fusion as all are located in the same absolute framework.

The tracking algorithm may run in parallel using several nodes. The depth data are sampled according to their distance from the sensor (to keep a similar 3D density) to reduce the required computing power. A foreground-background segmentation is performed by taking into account the people estimation in the last iteration. Several filters are also introduced to discard pets, chairs, objects, etc.. An optimization technique matches and adjusts 3D volume primitives to the foreground segments.

3.2 Robot platform

The mobile robot used in the project is named MYRABot. This platform has been evolving since 2012, as shown in Figure 3. The platform was designed with two goals in mind: be a low cost tele-presence system and be able to interact using augmented reality. The first will allow elderly people to keep in touch with their family and friends. The augmented reality was introduced to improve person-robot interaction.

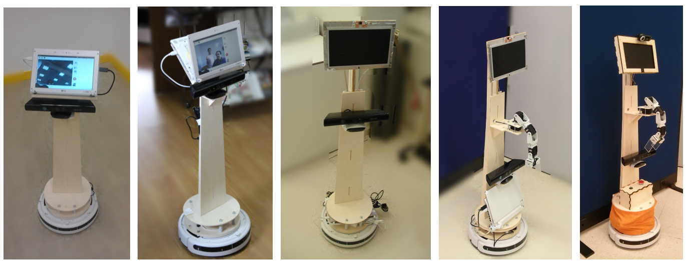

Fig. 3. MYRABot Evolution: Model I, II, III, IV

This platform has been tested in the RoCKIn challenge [10]. The RoCKIn challenge is a European competition held since 2013. It is a new system of competition divided into two phases each year: a cooperation camp and a competition. The camp lasts just one week and is where experiences are shared, and even researchers without a robot can go to the camp to test their algorithms using an available platform. The competition measures all the different components of the robots: overall performance, reliability, different algorithms for computer vision, localization, navigation, context recognition, basic manipulation, etc.

The challenge is focused on assisting the elderly or impaired. The robots help an elderly lady called "Grannie Annie" in her mock home. We have chosen this competition as a testbed for many of the goals of our project.

The competition is divided into tasks and functionalities. Tasks are tests where robots have to face a complex problem that usually involves navigating in the environment and interacting with persons and objects. Current tasks are:

Getting to Know My Home . Here the robot will be required to generate a map of its environment and detect random changes in the location of furniture and other items that will be made before each task.

Welcoming Visitors . This task assesses the robot's capability to identify and to react appropriately to four different visitors to the apartment.

Catering for Granny Annie's Comfort . Granny Annie will ask the robot to help her with general tasks throughout her day, including lifting the shutters, tilting the windows and switching off the lights.

Functionalities are basic tests that only evaluate the resolution of a single problem:

Object Perception . The objective of this functionality benchmark is to assess the capabilities of a robot in processing images to determine the type, position and orientation of objects from a given list.

Navigation . This functionality benchmark assesses the robot's capability to traverse a sequence of way points without colliding with obstacles and reaching its target within a reasonable time. In Figure 4 we can see our robot navigating in the real environment.

Speech Understanding . This functionality benchmark aims at evaluating the ability of a robot to understand speech commands that a user gives in a home environment.

Manipulation . This functionality benchmark addresses the ability of the robot to perceive a light switch and interact with it. In Figure 5 we show our robot switching on a light.

We participated in the 2014 edition in Toulouse and we are participating in the next competition in Lisbon, in November 2015.

3.3 Semantic localization

The semantic localization problem in robotics consists in determining the place where a robot is located by means of semantic categories. The problem is usually addressed as a supervised classification process, where input data correspond to robot perceptions, and classes to semantic room/place categories, such as kitchen, bathroom, or corridor.

Our expertise in this field started with our participation in the first three editions of the Robot Vision task at ImageCLEF. We have also been involved in the organization of the last few editions of the challenge [12]. As a result of this

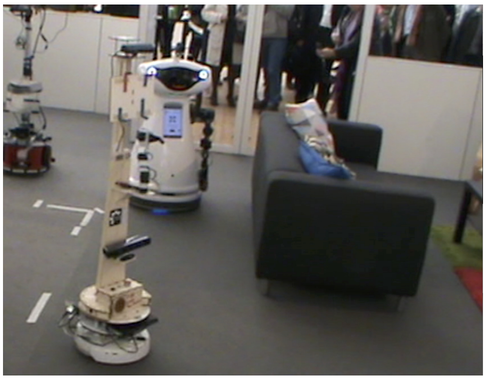

Fig. 4. MYRABot navigating in the real benchmark environment.

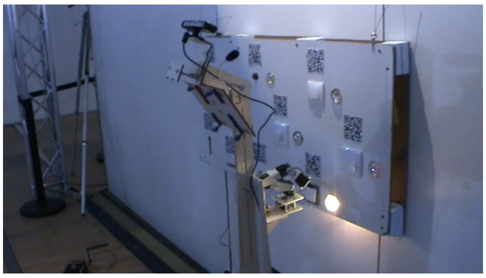

Fig. 5. MYRABot in the manipulation benchmark.

involvement, over the last five years we have proposed, reviewed and evaluated different proposals for the Semantic Localization problem.

In particular, we have proposed the use of particle filters, clustering techniques, SIFT similarity, multi-cue discriminative approaches, and online SVMs for developing several visual place classifiers [14]. As organizers, we acquired sequences of RGB-D images to be used as the official benchmark in the competition, which finally resulted in the release of the ViDRILO dataset [13]. This dataset provides five sequences of frames acquired with a mobile robot in two similar office buildings under different lighting conditions. Each frame consists of a pointcloud representation of the scene and a perspective image. The frames in the dataset are annotated with the semantic category of the scene, but also with the presence or absence of a list of predefined objects appearing in the scene. ViDRILO is distributed with a set of tools for its use in both place classification and object recognition tasks, including features extraction, learning, classification, evaluation and visualization issues.

In order to facilitate participation in the Robot Vision task, we also released baseline functional semantic localization systems. That allowed participants to focus on specific aspects of the semantic place classification system rather than developing a complete system from scratch. More recently, we have proposed a pointcloud Library [23] implementation of the Bag-of-Words approach [5]. This proposal enables the generation of an image representation that is suitable for semantic localization, from any type of 3D local feature [15].

Consequently, we have used all this expertise in designing and implementing the semantic localization system to be included in the project.

3.4 3D data processing and GPU acceleration

In this section, we describe advances in several areas related with 3D pointcloud processing, including object recognition. Our main input sensor is an RGB-D camera, so we need to efficiently manage and process these data.

First, we have on a 3D pointcloud representation. In [22], [21] and [17] we use a Growing Neural Gas (GNG) [8] for 3D surface reconstruction together with a 3D map representation. This GNG provides good neighborhood and topology preservation. This method is also applied to object recognition in [20].

We have also carried out several studies on 3D registration. In [24] the combination of the GNG neurons with visual features yields an improvement in final registration. Regarding 3D registration, we studied the different methods developed, and published our findings in a survey in [19].

Finally, due to the huge amount of data that an RGB-D camera provides, we developed a geometric compression method [18] that is able to obtain compression rates below the current ones. Furthermore, traditional 3D processing methods are not efficient with those data so we developed several GPU strategies to speedup some processes. In [16], the classical Iterative Closest Point method is implemented on the GPU and a complete study of its parameters is performed. [9] yields a method that estimates motion in real time.

3.5 Rehabilitation

Acquired Brain Injury is a serious public health problem because of its high incidence. Acquired Brain Injury comprises Traumatic Brain Injury (TBI) and Cerebral Palsy (CP). These illnesses can produce motor and cognitive impairments, and rehabilitation is required to recover patient functionalities. In this project, the target is cognitive rehabilitation. For this purpose, some cognitive exercises have been defined by therapists and physicians. The cognitive exercises will be implemented using the system developed in the project that provides multimodal interaction. Using different interfaces (gesture , voice and touch) allows patients with motor impairments to carry out their rehabilitation.

Once development has been completed, the pilot will take place with control cases. The control group will train with conventional treatment and the experimental group will use the robot and the exercises designed. The pilot study will last for three months and during that period the patients belonging to the control and experimental groups will train using their training plan for 20 minutes every day. All the patients will be evaluated at the beginning and the end of the pilot study by means of the following test: Minimental Test, Brief Neuropsychologist scale and Ranchos Los Amigos levels of cognitive functioning scale (LCFS). The inclusion criteria are: cognitive function Ranchos Los Amigos scale >4, age over 16 and patients that can cooperate with the robot. Also, a satisfaction survey will be administered to patients, caregivers and health professionals. With these tests we should be able to reach conclusions about rehabilitation and the use of the robotic platform.

4 Conclusions

In this paper, we have presented an ambitious project in which a team of interdisciplinary researchers have come together to achieve a real goal. This goal is to promote the health and welfare of society via the design, development and evaluation of a novel therapy for the cognitive rehabilitation of people with acquired brain injury or dependent people. The project is divided into two related systems: one for intelligent monitoring of people and the other for building a robot capable of interacting with dependent people.

We have presented the main goals of the project and the results obtained at the halfway point of its development. Both the part that has already been developed and the scientific output obtained show the excellent progress of the project. As future work, we plan to continue reaching the milestones marked in the schedule.

Acknowledgments.

This work has been supported by the Spanish Government DPI2013-40534-R Grant, supported with Feder funds. The research leading to these results has also received funding from the RoboCity2030-III-CM project (S2013/MIT-2748), funded by Programas de Actividades I+D en la Comunidad de Madrid and cofunded by Structural Funds of the EU. Jesus Martínez-Gómez is also funded by the JCCM grant POST2014/8171

References

1. Ausen, D., Lopez-de Ipina, D., Bravo, J., Valero, M.A., Florez, F.: Talisman+: Intelligent system for follow-up and promotion of personal autonomy. In: Bravo, J., Hervas, R., Villarreal, V. (eds.) Ambient Assisted Living, Lecture Notes in Computer Science, vol. 6693, pp. 187–191. Springer Berlin Heidelberg (2011)
2. Badii, A.: Integrated cognitive assistive and domotic companion robotic systems for ability and security (june 2015)
3. Calderita, L., Bustos, P., Suarez-Mejias, C., Fernandez, F., Bandera, A.: THERAPIST: towards an autonomous socially interactive robot for motor and neurorehabilitation therapies for children. In: 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops, PervasiveHealth 2013, Venice, Italy, May 5-8, 2013. pp. 374–377 (2013)

4. Coradeschi, S., Cesta, A., Cortellessa, G., Coraci, L., Galindo, C., Gonzalez, J., Karlsson, L., Forsberg, A., Frennert, S., Furfari, F., Loutfi, A., Orlandini, A., Palumbo, F., Pecora, F., von Rump, S., timec, A., Ullberg, J., tslund, B.: Giraffplus: A system for monitoring activities and physiological parameters and promoting social interaction for elderly. In: Hippe, Z.S., Kulikowski, J.L., Mroczek, T., Wtorek, J. (eds.) Human-Computer Systems Interaction: Backgrounds and Applications 3, Advances in Intelligent Systems and Computing, vol. 300, pp. 261–271. Springer International Publishing (2014)
5. Csurka, G., Dance, C.R., Fan, L., Willamowski, J., Bray, C.: Visual categorization with bags of keypoints. In: Workshop on Statistical Learning in Computer Vision, ECCV. pp. 1–22 (2004)
6. Cuijpers, R.: Knowledgeable service robots for aging (june 2015)
7. Fischinger, D., Einramhof, P., Papoutsakis, K., Wohlkinger, W., Mayer, P., Panek, P., Hofmann, S., Koertner, T., Weiss, A., Argyros, A., Vincze, M.: Hobbit, a care robot supporting independent living at home: First prototype and lessons learned. Robotics and Autonomous Systems pp. – (2015)
8. Fritzke, B.: A Growing Neural Gas Network Learns Topologies, vol. 7, pp. 625–632. MIT Press (1995)
9. Garcia-Rodriguez, J., Orts-Escolano, S., Angelopoulou, A., Psarrou, A., Azorin-Lopez, J., Garcia-Chamizo, J.: Real time motion estimation using a neural architecture implemented on gpus. Journal of Real-Time Image Processing pp. 1–19 (2014)
10. Lera, F.J.R., Casado, F., Hernandez, C.R., Matellan, V.: Low-cost mobile manipulation platform for rockin@home competition. In: XV Workshop en Agentes Fisicos (WAF 2014) (12-13 June 2014)
11. Lowet, D.: Multi purpose mobile robot for ambient assisted living (june 2015)
12. Martínez-Gómez, J., Caputo, B., Cazorla, M., Christensen, H., Fornoni, M., García-Varea, I., Pronobis, A.: The robot vision challenge. where are we after 5 editions? IEEE Robotics and Automation Magazine (2015)
13. Martinez-Gomez, J., Cazorla, M., Garcia-Varea, I., Morell, V.: Vidrilo: The visual and depth robot indoor localization with objects information dataset. International Journal of Robotics Research (2015)
14. Martinez-Gomez, J., Jimenez-Picazo, A., Gamez, J.A., Garcia-Varea, I.: Combining invariant features and localization techniques for visual place classification: Successful experiences in the robotvision@imageclef competition. Journal of Physical Agents 5(1), 45–54 (2011)
15. Martínez-Gómez, J., Morell, V., Cazorla, M., Garcia-Varea, I.: Semantic localization in the pcl library. Robotics and Autonomous Systems (2015)
16. Montoyo, J., Morell, V., Cazorla, M., Garcia-Rodriguez, J., Orts-Escolano, S.: Registration methods for rgb-d cameras accelerated on gpus. In: International symposium on robotics, ISR (2014)
17. Morell, V., Cazorla, M., Orts-Escolano, S., , García-Rodríguez, J.: 3d maps representation using gng. Mathematical Problems in Engineering 2014 (2014)
18. Morell, V., Orts, S., Cazorla, M., Garcia-Rodriguez, J.: Geometric 3d point cloud compression. Pattern Recognition Letters 50, 55–62 (2014)
19. Morell-Gimenez, V., Saval-Calvo, M., Azorin-Lopez, J., Garcia-Rodriguez, J., Cazorla, M., Orts-Escolano, S., Fuster-Guillo, A.: A comparative study of registration methods for rgb-d video of static scenes. Sensors 14(5), 8547–8576 (May 2014)
20. Orts Escolano, S., Garcia-Rodriguez, J., Morell, V., Cazorla, M., Garcia-Garcia, A., Ovidiu-Oprea, S.: Object recognition in noisy rgb-d data. In: 6th International

Work-Conference on the Interplay between Natural and Artificial Computation (2015)
21. Orts-Escolano, S., Garcia-Rodriguez, J., Morell, V., Cazorla, M., Saval-Calvo, M., Azorin, J.: Processing point cloud sequences with growing neural gas. In: Neural Networks (IJCNN), The 2015 International Joint Conference on (2015)
22. Orts-Escolano, S., Garcia-Rodriguez, J., Serra-Perez, J., Jimeno-Morenilla, A., Garcia-Garcia, A., Morell, V., Cazorla, M.: 3d surface reconstruction of noisy point clouds using growing neural gas. Neural Processing Letters (2015)
23. Rusu, R., Cousins, S.: 3D is here: Point Cloud Library (PCL). In: IEEE International Conference on Robotics and Automation (ICRA). Shanghai, China (May 9-13 2011)
24. Viejo, D., Garcia-Rodriguez, J., Cazorla, M.: Combining visual features and growing neural gas networks for robotic 3d slam. Information Sciences 276, 174–185 (2014)
25. Wonen-Welzijn-Zorg, A.: An integrated intelligent home environment for the provision of health, nutrition and well-being services to older adults (june 2015)