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The Evaluations of the Assistive Robot SAM with Elderly and Handicapped People

*Mohamed Walid Ben Ghezala, *Olivier Lebec, *Christophe Leroux, ****Laurence Devillers,**Charles Fattal, ***Isabelle Laffont,**Violaine Leynaert ,and *****Youcef Mezouar.

*CEA LIST, Bat 660 Rue Noetzelin, Moulon, France, (firstname.lastname@cea.fr)

**Association APPROCHE, Montpellier, France, (delegation@approche-asso.com

***CHU Montpellier, Montpellier, France, (i-laffont@chu-montpellier.fr)

****LIMSI, B.P. 133, 91403 Orsay CEDEX, France, (devil@limsi.fr)

*****Institut Pascal, Clermont Ferrand, France, (fistname.lastname@ifma.fr)

Abstract —There are approximately 69.2 million people over 80 in the world in 2014. This number is expected to reach 379 million by 2050 [**¡Error! No se encuentra el origen de la referencia.**]. This demographic trend is an incentive for policymakers to promote the development of new services, such as robotics, to help elderly people in their everyday life. Such services would include improving their safety on public transportation or at home, the improvement of their health and wellbeing and the facilitation of social inclusion. The objective of "ARMEN" is to develop an assistive robot providing advanced functions to help maintain elderly or disabled people at home. The assistive robot SAM aims to compensate for caretaker's limited availability. We want to give an opportunity for caretakers to restructure their schedule to concentrate on patients' needs. One of the main efforts of the present work was to facilitate the use of a highly technical device by a non-specialist. To achieve this goal, we developed a set of functions to make autonomous robot. This assistive robot has been tested in a real environment with people suffering from physical deficiencies.

Key words: Assistive robotics, Mobile manipulation, Intuitive HMI, Emotion understanding, Object recognition, Knowledge representation.

1. Introduction

Nowadays, technologies and services for autonomy are a promising economic sector. Innovation in these technologies is strongly encouraged in some countries by academic research, creating an industrial structure of very dynamic SMEs that reinvest a significant portion of their revenues on R & D (Research and Development). The most notable innovations in the autonomy of people with loss of faculties, due to an accident, illness or age are not specifically dedicated to this from any site. In France, the first experiments of assistive robotics with people with disabilities date back to the 1975. Some of the earlier robots (Spartacus manipulator) deriving from the technology developed by CEA as a follow up of his experience in robot manipulators in a hostile environment. Two types of tools are currently available robotics, embedded mobile stations and fixed robotic workstations.

The MANUS ARM Unit is the most used manipulator arm most used in the world. Originally designed in 1988 for patients with muscular dystrophy it is manufactured and sold by Exact Dynamics in the Netherlands. In 2007 CEA List developed a robotic platform dedicated to object mobile manipulation for people with disabilities in the European project ITEA- ANSO (Autonomic Networks for SOHO users), and AVISO [1] national project. In 2009 started the project ARMEN a continuation of the robot project (AVISO / ANSO). The goal was to further develop advance assistances to simplify the interactions between the user and the robot SAM. The objective was to provide advanced assistances to help maintain elderly and disabled at home, offsetting the limited availability of the caregiver duties. To provide a robot that meets the expectations of users and caregivers, ARMEN focused on the following issues:

• The reliability of the mobility of the robot in an indoor environment in 3D,

• The ease of use and intuitiveness of the dialogue between the robot and the human using 1) the semantic analysis of images, 2) an avatar, 3) understanding of the emotion of the speech analysis 4) a knowledge representation, 5) the design of various behaviors of the robot,

• The development of several automatic mobile manipulation functions to help users and providers of care, such as "find a lost item", "bring the object to the person" or "manipulate the object"

• Experimenting with SAM with patients under medical supervision

• The development of a prototype with a potential to become an industrial product.

One of the main efforts of the present work was to facilitate the use of a highly technical device by a non-specialist. To achieve this goal, we developed a set of functions to make autonomous robot. We used an analysis of the semantic level to enable a dialogue between the patient and the machine with familiar terms (non-technical). We also developed an effective supervisor with an intuitive human-machine interface (HMI). In the following paper, we first present a state of the art assistive robotics. Then we focus on the presentation of the assistive robot SAM, its technology and features. Finally, we describe the technical and clinical assessments deducted from his experiment in a real environment before concluding by stating the research topics in perspective.

2. Related work

Assistive robotics is a wide field of research in which many actors are involved. It is also a field that has been getting an increasing amount of attention since the early 1970's. We here only take into consideration assistive robots which tends to maintain independent lifestyle or improve quality of life of elderly, disabled and possibly non-disabled people. We also chose to differentiate robot systems by their capability to manipulate object or not.

ARMEN is not aimed to develop a *companion robot* such as PARO 0 which is focused on human-machine interaction for social purposes.

Mobile robots with no manipulation capacities offer services such as:

- Security: they help watch over the user and can give emergency calls
- Coaching: they act as a reminder to the user: things to do, medicine to take… They can also give advice and stimulate physical activity.
- Facilitation of social interaction with family and healthcare staff;
- Collaboration with healthcare staff, including exchange of data;

GIRAFF robot offers such functionalities. GIRAFF is developed for the need of the ExCITE project which aims a trialing assistive robot in real homes. GIRAFF is trialed in twelve different sites located in Europe and regular feedbacks help to enhance the services and the robot. We could also mention DOMEO robot 0 which offers similar services. Robots such as MySpoon 0 or Bestic 0 allow disabled people to eat with no aid from people. They have very specific goals, a unique function, and try to be as discreet as possible.

Robots equipped with an arm can offer a wider range of services thanks to to their capacity to manipulate object and help people in their everyday life. Their capacity to execute complex manipulation tasks is a key factor for the acceptance of these machines by users. Of the robots which are able to carry out all of these tasks, only a few of them were clinically evaluated. Unlike Care-O-Bot 3 [**¡Error! No se encuentra el origen de la referencia.**] or the ANSO (Autonomic Networks for Small Office) project [**¡Error! No se encuentra el origen de la referencia.**] assessed in several campaigns, El-E or PR2 robots are developed for research purpose only, see [**¡Error! No se encuentra el origen de la referencia.**] and [**¡Error! No se encuentra el origen de la referencia.**].

In the following subsection, we present the clinical evaluations of the project that motivated ARMEN.

3. Context of Work

3.1. The ARMEN project

ARMEN is an ANR project launched in February 2010 and ended in July 2013. The objective of this project was to develop an assistive robot, named SAM, supplied with advanced functions to maintain elderly or handicapped person at home in order to offset the limited availability of caregivers. To provide a robot meeting the needs of users, ARMEN has focused on the following questions:

- The reliability of the mobility of the robot in an indoor environment.
- The ease of use and intuitiveness of the dialogue between the robot and the human using 1) the semantic analysis of images, 2) an avatar, 3) understanding the emotion of speech analysis, 4) knowledge representation, 5) various design robot behaviors.
- The development of many automatic functions of mobile manipulation to help users and caregivers such as "find a lost object", "bring the object to the person" or "manipulate the object".
- The experimentation of the robot with patients under medical supervision.
- The development of a prototype in order to become an industrial product.

3.2. The robot Smart Autonomous Majordomo (SAM)

SAM (Smart Autonomous Majordomo) is a multi-robotic platform and compact, designed to receive various services as applications, communication, education, health and research. The compactness of the robot, its load capacity up to 30 kg, its dedicated navigation sensors, its maneuverability and ease of use allow us to imagine a large number of uses, including the non-initiated people to robotic.

The mobile platform is surmounted by a Jaco arm (Kinova Robotics Company). This arm weighs 5.7 kg. It has a range of 90 cm, it has 6 degrees of freedom and can carry up to 1.5 kg. It is powered by 24 volts from the batteries robuLAB10. The end of this arm is equipped with a clamp with three fingers on which are placed two simple webcams. They allow to have stereoscopic vision.

Fig. 1 : Robot SAM

4. Architecture fonctionnelle de SAM : Les fonctions développées

SAM’s main functionalities are navigation, object recognition and manipulation.

SAM software architecture relies on client-servers. Services are implemented on different servers and the HMI is a client connected to different services (see Fig. 2) through web services [6]

This HMI supervises the robot. Every software component which enables SAM to navigate, to manipulate, to recognize objects or to manage knowledge representation is standalone and plug-and-play. This component oriented architecture lets SAM being able to be updated with state of the art functionalities. Plus, one service can be easily replaced by another one thanks to dynamic plug-and-play and services discovery functionality of SAM.

In the following subsection we present currently integrated components of SAM.

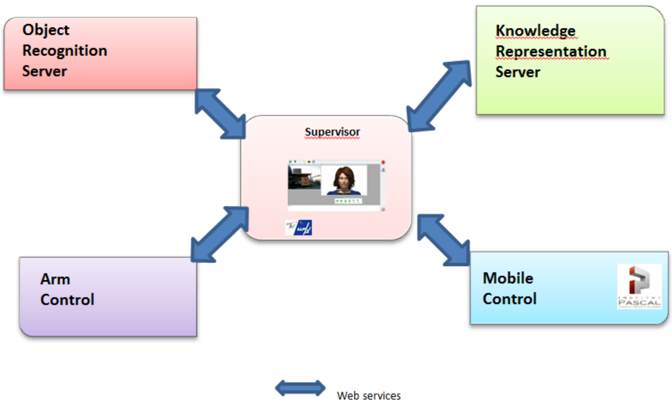

Fig. 2. Interaction between supervisor and servers

4.1. The Supervisor

Intuitiveness has been our watchword throughout the development of SAM supervisor. We wanted to let the user control SAM easily. Occupational therapists took part to this process. Advice was focused on what type of action should be offered to the user, location of buttons within the HMI and pictures that should accompany them.

The supervisor allows the user to choose the task he wants the robot to do. Tasks to achieve consist of behaviors executed and controlled using the scenario interpreter "ISEN" developed at CEA [15]. "ISEN" engine is event-driven to coordinate tasks to be achieved by the robot. This may be easily done by selecting a scenario in a list of buttons with large icons (scenarios are explained in part **¡Error! No se encuentra el origen de la referencia.**).

A very limited amount of click is required to complete a task. This limited activity is important for the acceptance of SAM for persons who do not have or a limited computer literacy. Different display modes giving access to a set of different actions were designed for ease of interaction between the user and SAM. Modes is activated or disabled with regard of the current situation (e.g. selecting an object in a scene or choosing a scenario cannot be achieved in the same mode). Visual feedback from the embedded cameras is displayed to allow the user to localize the robot in the apartment or the objects in a scene. Color-coded messages can be displayed during the execution of a task or a scenario to keep the user informed of SAM current situation and state. If SAM encountered an issue these messages can guide the user to a solution. A virtual conversational agent represented by an avatar [5] allows the user to have an empathetic interaction with SAM. The agent is able to take into account emotional reactions from the user's speech and to act and talk accordingly [2]. It could be used when the robot is out of sight of the user to bring him comfort.

4.2. Arm control

We developed generic control functions independent regarding the robotic arm. These functions are embedded on an arm server which then ensures low-level control and visual servoing.

Our visual servoing method is described in [1]. It only requires a stereo rig on the effector of the arm. SAM uses it to automatically grab objects. 3D position of the object to grasp is computed thanks to the position of the object in the plane. This information can be given by the object recognition component or can also be defined by the user by drawing a rectangle around the object.

The grasping step relies on knowledge representation service to understand the current scene and trigger the most appropriate grasping strategy. One can also manually control the arm through clickable directional buttons on the HMI. This functionality gives to the user the ability to manually search an object in the scene. Universality and interoperability of the arm server is guaranteed by its capacity to work in combination with different services or by itself.

4.3. Mobile station control

One of the assets of our control algorithm is that it enables the robot to move with high localization accuracy with no 3D reconstruction or map of the environment. The algorithm can be used with a large set of cameras (classic cameras, catadioptric, fish-eye) without reconfiguration.

Autonomous navigation using vision is a challenging and active field of research. Our approach can be divided into three steps: 1) visual memory building, 2) localization, and 3) autonomous navigation.

The first step consists in acquiring a sequence of 2D during a human-guided navigation through points of interest of the environment. This step is made off-line. In order to simplify computation, only key views are stored and indexed on a visual path. The set of visual paths can be interpreted as a visual memory of the environment. In the second step the localization of the robot is made thanks to the previously built visual memory. The localization is thus made in the perception space (and not in 3D space) which brings strong robustness properties to our method. The localization process consists of finding the image which best fits the current image in the visual memory. To increase accuracy and reduce computation- we use a hierarchical process combining global and local descriptors.

In the last step, navigation process is defined as a concatenation of visual path subsets, called a visual route, which links the images acquired by the camera and the desired ones. A navigation task then consists of autonomously executing a visual route. A vision-based control law adapted to its non-holonomic constraint controls the robot. This control guides the vehicle along the reference visual route without explicitly planning any trajectory.

4.4. Knowledge representation

Knowledge representation is central to an efficient management of the robot actions and of a good dialog between the user and the machine. It is a key point to the introduction of intelligence into robotics systems. We decided to use the concept of ontology for our knowledge representation. Ontologies allow interoperability between different domains of expertise and provide a common access to information and a shared understanding of concepts.

Ontologies such as KnowRob [14] or ORO [16]0 represent mobile manipulation knowledge. We designed our ontology to be easily enriched on-line and by non-specialist users. Our ontology contains mobile robotics manipulation knowledge such as knowledge related to objects user profiles and robot capabilities.

The objects in the ontology are gathered into categories (e.g. “coca” belongs to the concept “can”). Two concepts have been assigned to each object in order to inform of its geometry and location. The concept “Object” is composed of two concepts: “Material Object” and “Intangible Object”. Each material object is mapped to a grip strategy. The concept “Robot” contains a structured knowledge about robots, while the concept “User” is used to describe user profiles and capacities. The file format of the ontology is OWL. We use Xpath (XML Path Language) for OWL file queries. This is the mechanism used to add concepts, properties and individual users in our ontology. The ontology was designed using “Protégé”1. Two interfaces were developed to facilitate adding new users and new objects.

4.5. Objects recognition

Object recognition is one of the key components which give the capability to SAM to act automatically when object are identified. This component relies on the PIRIA software (Program for Indexing and Research Images by Affinity) developed at CEA LIST. PIRIA allows us to associate semantic information to objects in the environment.

[1] http://protege.stanford.edu/overview/protege-owl.html

PIRIA is a Content-Based-Image Research engine (CBIR). This means that the content of the image (color, texture, shapes, etc.) is analyzed to find similar images for an image query. Several descriptors capture color, texture or shape features to create multiple signatures. For the ARMEN project, we use a modified version of SURF (Speeded Up Robust Features) features [8]. This choice is motivated by the speed of analysis, which allows interactive utilization of the software.

5. The evaluations

The main objective of the study was to investigate the usability and relevance of a robotic prototype "SAM" with a quadriplegic population that has a great level of dependence.

Secondary objectives were to examine the acceptability of such a device with this population and their carers.

5.1. Assessment scenarios

The assessing of the usability of SAM was based on three scenarios of manipulation of objects by SAM.

Scenario 1: **Grasp the object, located in the same room as the operator.**

Go to grasp a soda can in the same room at a predetermined location, and place it on a table in front of the user.

Scenario 2: **Grasp the object, visible by the operator, in a room other than the operator's room.**

Grasp an object on the ground (remote TV) located in another room, but visible to the operator, carry up to table height (height 90 cm) and drop it there. In this case, the object is in an extracorporeal deep space.

Scenario 3: **Grasp the object, non-visible by the operator, located in another room than the operator's room.**

Go find a book in another room, not visible to the operator and unknown position.

5.2. Technical evaluation

In anticipation of the clinical assessments, a technical evaluations campaign has allowed us to estimate the abilities of different functionalities that SAM offers. These technical evaluations took place in April 2013 at the Functional Rehabilitation Centre Jacques Calvé in Berck sur Mer.

During this technical evaluation, each functionality has been evaluated separately [2] [19] [9]. The controller of the mobile base was assessed by acquiring images in grayscale, at 15 frames per second. A learning phase is performed off-line. Panoramic camera was on board the robot. The visual path contains 95 key frames (640x480 pixels) and the path is about 27 meters.

A visual path has been calculated taking into account a target image. A key frame of the track is reached when the "image error" is less than a threshold. The robot has successfully completed a visual way to a translation speed of 140 mm / s [9]. The technical assessments of the PIRIA, the software of the object recognition have shown that we can calculate the distance between each object and the camera with millimeter precision in a range of one meter. Interactive interpretation of objects is made possible by the short treatment time (less than one second more than a hundred images in the database). Indeed, PIRIA is transferred to a SenSEEtive company that takes advantage of improvements in the ARMEN project on the location of the object and on the estimation of the distance camera-object. The knowledge representation system provides the ability to use appropriate behavior for each object that SAM may encounter. You can see how it works in the video. Technical evaluations of all technologies and integrated into SAM were performed in a similar planned for clinical evaluation environment. SAM had to follow three scenarios described in the previous section. The amateur of technologies among medical staff and patients supported us during this phase. 8 steps are taken to make the first scenario. (1) We first ask SAM to bring a soda. (2) SAM moves to the designated location (e.g, kitchen). The user is able to see where SAM is at every moment with the panoramic camera. (3) Once SAM arrives at the desired location, the arm begins to move and the visual feedback of the camera at the top of the clip is displayed to allow the user to select an object in the scene. (4) The user must click once to start the service object recognition and once more to select the desired object. (5) The visual servoing starts to move closer to the object. The ontology is the consulted to define a strategy for the proper outlet. (6) The selected object is taken by the robot gripper arm then folds to a safe position and (7) The robot returns to the user. (8) SAM puts the object on the table in a location accessible to the user. SAM was able to achieve the three scenarios without any errors in different environments. Therefore, the next step was to evaluate SAM in a real clinical environment with the end user.

5.3. Clinical evaluation

It is a bicentric study, prospective and controlled, conducted under the ARMEN project (ANR TecSan) and under the auspices of the APPROACH (Association for the promotion of new technologies for handicapped people). Participants included in the study were recruited from two Physical Medicine and Rehabilitation institution located in Berck sur Mer (62) and Cerbère (66). These participants are adults (> 18 years and <90 years) with functional quadriplegia causing significant disability grip (neuromuscular diseases, spinal cord injury, LIS, SLA). They have the ability to stay in a wheelchair at least 2 hours and to manipulate an interface of scoring and validation for computer (Man machine interface used with no scroll function). Were excluded from the study the persons which have visual or auditory sensory disturbances, significant disorders in the upper functions and hinder learning ability and attention, an unstable psychiatric diseases or intercurrent acute diseases. The number of this population (target population) is 17 people. A witness able-bodied was associated. The exclusion criteria were the same as for the target population. The size of this population is 20. The subjects received oral and written information and gave their agreement by written consent. The study had a favorable opinion of the Committee for the Protection of Persons (CPP) dated 04.09.2013.

The evaluations were done according to the protocol described in the deliverable of ARMEN "assessment protocol". In this protocol, it is noted that assessments are conducted in 2 to 3 sessions per participant, depending on the degree of fatigue and availability:

- V0 Visit: Circular, inclusion criteria and signed consent
- V1 Visit: Learning scenario
- V2 Visit: Evaluation of the scenarios and Likert scale questionnaire.

The assessing of the usability of robot relied on the three scenarios described in V.A. Each scenario was repeated 3 times. Spaces' configuration used was identical for the 2 centers and the distances between objects and users were standardized. The responses to the questionnaire of satisfaction with the target population have been very positive. In fact, 10 people found that the interfacing with SAM is easy and they are very satisfied. 7 people found it satisfactory. 16 people have considered the use of the system is little or not at all tiring. The confidence of the robot is high: 70.27% of people (76.47% of the target population and 65% of the control population) who used the robot say they trust totally in SAM. It was also founded that SAM is seen as a machine for everyday use by handicapped people. The usefulness of SAM is thus confirmed. During these reviews, we noted areas for improvement of the IHM and the technologies used.

5. Conclusions

Assessments made during the ARMEN project show that SAM is a assistive robot accessible to people who have difficulty whatsoever with new technologies. The installation and takes over of SAM takes a few hours only which is quite comparable to the handling of a conventional electronic equipment. This ease of use comes from the approach chosen in ARMEN. This approach is based on the design of functions to handle complex tasks automatically. Automatic functions lead to the design of a very simple human machine interface, accessible to all. The dialogue between human and machine based on semantic concepts albeit limited in number but not on technical jargon. The project has shown that the technology used for an intuitive dialogue between humans and the machine including the consideration of emotions were appreciated by subjects. The implementation and use of the robot does not need to define geometric model of the environment or things to be manipulated. The results of the project show the interest of the people suffering from physical deficiencies. The next step is to apply these technologies in living environments to meet the needs of daily living such as food intake, help with dressing, recreation.

Achievement of the initial objectives

The initial objectives of the ARMEN project to design a assistive robot easy to use and to install are met. These objectives could be achieved thanks to the approach relying on a semantic level of interaction with the operator and through the use of functionalities making the robot autonomous. Usage of the arm JACO from Kinova proved very advantageous in assessments with patients in comparison with the tries made with the Exact Dynamics MANUS arm.

Scientific impact, challenges, outlook

The approach does not require a geometric model for mobile manipulation. This makes the approach with the assistive robot SAM distinct from existing assistive robots. Clinical trials have shown the relevance of the approach. Installation time and takeover of the machine by non-specialists is the same as for conventional electronic equipment. The robot is accessible to everyone including severely handicapped people. Several improvements are possible: avoiding obstacles while moving the arm, coordinated control arm and mobile for decision objects, learning to enrich the behavior of the robot and its capabilities from its experience. Clinical evaluations have demonstrated the maturity for technology object manipulation.

The dialogue between human and machine is based on semantic concepts and not on technical jargon. Implementation of a spontaneous dialogue is addressed at several levels: verbal and non-verbal language comprehension, manipulation of semantic concepts by the machine, strategy expressivity of the agent supporting HMI, dialogue management.

Economic and societal impact

Several tracks are being explored to transfer all or parts of the project results from either integrators or manufacturers specialized in robotics.

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