High level functions for the intuitive use of an assistive robot

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***Abstract*— This document presents the research project ARMEN (Assistive Robotics to Maintain Elderly People in a Natural environment), aimed at the development of a user friendly robot with advanced functions for assistance to elderly or disabled persons at home. Focus is given to the robot SAM (Smart Autonomous Majordomo) and its new features of navigation, manipulation, object recognition, and knowledge representation developed for the intuitive supervision of the robot. The results of the technical evaluations show the value and potential of these functions for practical applications. The paper also documents the details of the clinical evaluations carried out with elderly and disabled persons in a therapeutic setting to validate the project.**

Keywords— assistive robotics, evaluation protocol, mobile manipulation, elderly and disabled people, intuitive HMI, empathy emotion understanding, object recognition.

I. Introduction

There are approximately 69.2 million people over 80 years old in the world today. This number is expected to reach 379 million by 2050 [18]. 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. In order to offer a robot that meets the expectations of users and caretakers, ARMEN has focused on the following issues:

- The reliability of the mobility of the robot in 3D in an indoor environment,
- The usability and intuitiveness of the Human Robot Dialog by using 1) semantic analysis of images, 2) an avatar, 3) emotion understanding from speech analysis, 4) a semantic level knowledge representation, 5) the design of various robot behaviors,
- The development of several automatic functions of mobile manipulation to assist the user and the caretakers such as "*find a lost object*", "*bring it back*" or "*manipulate object*",
- The proof of concept with patients under medical control,
- The development of a prototype that has the potential of becoming an industry product.

One of the main efforts of the work presented here has been to facilitate the usage of a highly technical device by a non-specialist. To reach this goal, we developed a set of functions to make the robot autonomous. We used a semantic level analysis to allow a dialogue between the patient and the machine with familiar terms (non-technical). We also developed an efficient supervisor with an intuitive Human Machine Interface (HMI).

We first present the state of the art of assistive robotics. The previous project ANSO, which motivated us to undertake the ARMEN project, is presented in the second part. The third and the fourth parts are focused on the robot and its services. We then describe the technical and clinical evaluation procedures before briefly describing future projects.

II. Related work

A. State of the art

Assistive robotics is a field of research that has been getting an increasing amount of attention since the early 1970's. In this document, we refer to assistive robots as robots which are designed to either maintain an independent lifestyle or improve the quality of life of elderly, disabled and possibly non-disabled people. Research projects in assistive robotics are very diverse. Here we differentiate robot systems by their capacity to manipulate objects or not.

ARMEN's objectives are distinct from those of *companion robots* (such as PARO [12]), which mainly focus on emotional interaction between the machine and the user and on the usage of robots for social purposes such as cognitive stimulation, and social networking.

Mobile robots with no manipulation capacities offer services such as:

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- Security: they help watch over the user and can give emergency calls;
- Coaching: they remind user of things to do, appointments, medications to take and give advice and stimulate physical activities;
- Facilitation of social interaction with family and healthcare staff;
- Collaboration with healthcare staff, including exchange of data;

This is the case for the ExCITE project based on the technology of the GIRAFF robot. ExCITE is focused on trialing the technology in real homes: twelve different test sites located in Europe provide continuous patient monitoring and regular feedback of users in order to enhance the services and the robot. The DOMEO robot [7] also offers such capabilities. Other robots such as MySpoon [17] or Bestic [13] 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 aim to assist people in their everyday tasks. They can offer services in different domains because of their capacity to manipulate objects of the immediate surroundings. The 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 [10] or the ANSO (Autonomic Networks for Small Office) project [1] assessed in several campaigns, El-E or PR2 robots are developed for research purpose only, see [11] and [3].

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

B. *Motivation of the project "ARMEN"*

The project ANSO ended with a clinical evaluations made under the aegis of the APPROCHE association [4] in a multi-centric approach. The clinical evaluations involved 34 healthy people (32.44±11.2 years old) and 29 quadriplegic patients (37.83±13.3 years old) of different aetiology (muscular dystrophy, spinal cord injury, spinal muscular atrophy, multiple sclerosis, amyotrophic lateral sclerosis, cerebral palsy, rheumatoid arthritis, post-polio syndrome, locked-in syndrome and other severe motor paralysis). The clinical evaluations consisted in asking patients to complete three tasks three times using the robot SAM:

- Picking up an object and bringing it back to the user;
- Retrieving an object situated at a predetermined location in another room (bedroom). In this case, the object was out of the patient's direct line of sight but he knew where this object was. He had to ask the robot to bring it back to him.
- Finding an object in a distant room (kitchen) and bringing it back. In this case, the object was out of patient's direct line of sight and the user did not know the location of the object in the kitchen. The patient needed first to tele-operate the robot to explore the scene and to find the object, and then to ask the robot to pick up the object and bring it back.

Occupational therapists conducted the evaluations in therapeutic apartments in two rehabilitation centres following a pre-set protocol. We evaluated the time taken for the designation of the object (drawing a square around it on the screen), the time taken for the designation / validation of the object and the number of failures in the designation of the object.

As shown in TABLE I. , in column Δ (representing the difference of arithmetic means between the results of evaluations made for healthy and disabled people), it takes more time for disabled people than for healthy people to indicate the object to grasp and the location to reach within the apartment.

The study shows that the robot is well accepted by both the healthy and disabled person (3.97/5 on average for the disabled person and 3.68/5 on average for the healthy person). However, we can notice that the robot usage is fatiguing for these people (4.62/5 on average for disabled person). These results highlight that improvements needed to be made in order to provide concrete services to people and to be able to install the robot within their home. This is the objective of the ARMEN project. The population we targeted includes people with severe physical deficiencies as well as elderly people suffering from mild cognitive deficiencies. To answer the critics about the fatigue aspect of the robot (see TABLE I.) we carried on our efforts on simplifying the usage of the machine. We improved the assistances like the capacity to recognize and grab objects automatically. We focused our efforts on taking into account the remarks of the users on the capabilities of grasping, the process speed [4] and on the machine aspect (the volume and design).

In the following parts, we discuss the technologies used in the ARMEN project, the technical evaluations and the upcoming clinical evaluations of SAM. Clinical evaluations will begin this summer.

III. DESCRIPTION OF THE ASSISTIVE ROBOT

The robot SAM (Fig. 1) is made of two parts: a non-holonomic mobile platform, RobuLAB10 from Robosoft, and a six degrees of freedom JACO assistive robotic arm

TABLE I. DIFFERENCE BETWEEN HEALTHY AND DISABLED PEOPLE

script stage		***Δ(in seconds)***
Time taken for the designation of the object	scenario 1	-6.68309
	scenario 2	-10.37731
	scenario 3	-2.12884
Time taken for the designation / validation of the object	scenario 1	-36.33271
	scenario 2	-37.67177
	scenario 3	-36.62315
Number of failures in the designation of the object	scenario 1	0.029
	scenario 2	0
	scenario 3	0.029
Number of failures in the designation/validation of object	scenario 1	0.024
	scenario 2	-0.04
	scenario 3	-0.055

Fig. 1 : Robot SAM

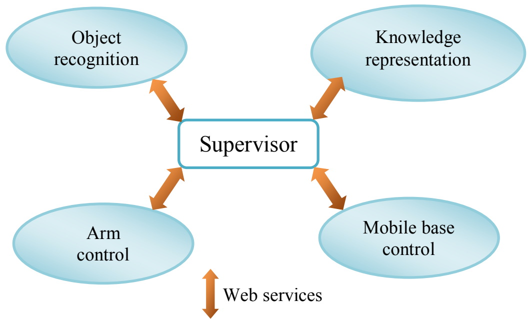

Fig. 2. Interaction between supervisor and servers

manufactured by KINOVA set atop the RobuLAB10. The JACO arm carries a three finger gripper. SAM is fully qualified to work alongside people (CE certification). SAM is battery-operated and able to perform mobile manipulation operation up to three hours.

Mobile platform – The mobile has one laser sensor used for navigation and nine ultrasonic sensors for obstacle avoidance. The mobile platform comprises a small shelf to drop the object caught with the arm.

Manipulator - The arm grasps different kind of objects and bring them back to the user on demand. A stereo rig fixed to the gripper enables SAM to perform object recognition and to control the arm motion automatically with visual servoing. The arm is able to carry up to 1.5kg, which is enough for the manipulation of many everyday objects such as cans and books.

IV. THE HIGH LEVEL FUNCTION FOR SAM

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. We used DPWS [6] protocol to define web services. Services such as mobile, manipulation, object recognition, and knowledge representation are thus independent plug and play devices. One service implementation can be easily replaced by another one, e.g., object recognition service can be replaced by different object recognition software and then dynamically plugged in to the supervisor.

A. Supervisor

We developed the HMI to let the user control SAM easily. We emphasized the developments on intuitiveness. 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]. This may be easily done by selecting a scenario in a list of buttons with large icons (scenarios are explained in part V.A).

A very limited amount of interaction with the user is required to complete a task. This limited activity is an important factor for the acceptance of the system since the operators are disabled and most of the time they have no computer literacy. To facilitate the usage of the HMI we designed different display modes giving access to different sets of buttons and allow the user to act according to the 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 (see Fig. 3). Color-coded messages are displayed during the execution of the scenario to inform the user of the current step of the scenario and of whether a problem has occurred and what to do.

A virtual conversational agent represented by an avatar (see Fig. 3) [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.

B. Arm control

We developed generic control functions facilitating an easy switch to another robotics arm; hence, the server which controls the arm is absolutely generic regarding the manipulator arm. The arm server ensures low-level control and visual servoing control.

Our visual servoing method is described in [1]. Visual servoing is used to automatically grab objects and only requires a stereo rig set on the effector of the arm. The object recognition server is first used to compute the position of the selected object in the plane. The stereovision system is then able to compute the 3D coordinates of this object in the space and start the visual servoing process. Users can also manually select objects in the scene by drawing a rectangle around the object without using the object recognition service. The last step uses object identification service, semantic information and knowledge representation service to understand the scene and to carry out an adapted procedure to manipulate the object.

The arm can also be manually controlled through the HMI thanks to clickable directional buttons. It lets the user search for the desired object in the scene.

Control of the arm is thus achieved through the collaboration of different services: object recognition, knowledge representation and the HMI. Universality and interoperability of the arm server is guaranteed by its capacity to work in combination with different services or by itself.

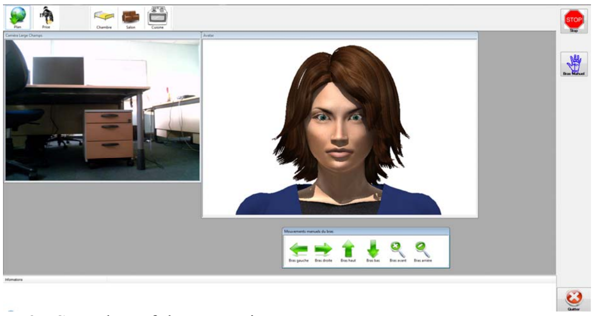

Fig. 3 : Snapshot of the supervisor

C. *Mobile station control*

One of the assets of our framework is that there is no time-consuming 3D reconstruction of the environment. It allows accurate navigation without extra processing and can be used with a large set of cameras.

Autonomous navigation using vision is a challenging and active field of research. Among the different approaches, visual memory-based navigation strategies have gained increasing interests in the last few years. This consists of representing the mobile robot environment with visual features topologically organized and gathered in a database (visual memory). The method we propose can be divided in three steps 1) visual memory building, 2) localization, and 3) autonomous navigation (see Fig. 4).

In the first off-line step (visual memory building), a sequence of 2D images is acquired during a human-guided navigation. It allows us to derive paths driving the vehicle from its initial location to its goal location. In order to reduce the complexity of the image sequences, 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 robotic system is performed before the robot starts moving. During this stage, no assumption about the robot's position is made.

The localization process consists of finding the image which best fits the current image in the visual memory. To achieve this goal, we use a hierarchical process combining global and local descriptors.

In the last stage, given an image of one of the visual paths as a target, the robot navigation mission is defined as a concatenation of visual path subsets, called visual route. 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. Note that in our approach, the control part takes into account the kinematic constraints of the robot.

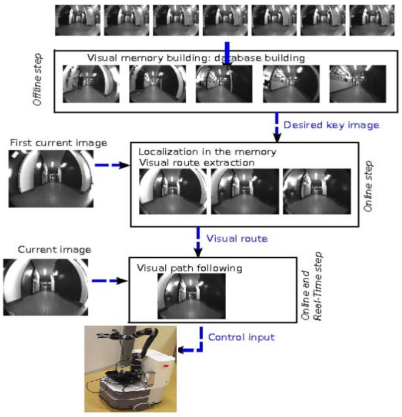

Fig. 4 : Method overview

D. *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. Different techniques of knowledge representation exist: production rules, frames (object centered representations), semantic networks, and concept diagrams.

Knowledge representation is a key to the introduction of intelligence into robotic systems. Each technique has its advantages and drawbacks. One has to pay attention to system slowness issues when the amount of data and the links between concepts increase. The solution we chose relies on the concept of ontology. Ontology provides a homogeneous way to represent knowledge. They allow interoperability between different domains of expertise. They provide a common access to information and a shared understanding of concepts.

Some ontologies represent knowledge on mobile manipulation robotics, such as KnowRob [14] and ORO [16]. The specificity of our approach is that the ontology is designed to facilitate the on-line enrichment by a non-specialist. The ontology contains knowledge related to robotic mobile manipulation domains such as knowledge on objects and knowledge on user profiles and robot capacities.

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 (Fig. 5).

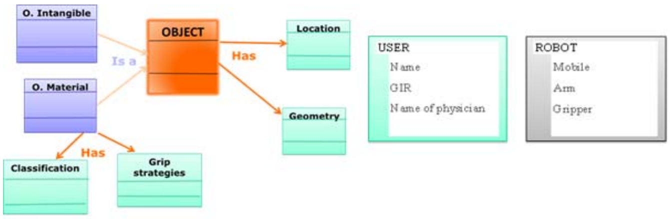

Fig. 5 : Ontology concept

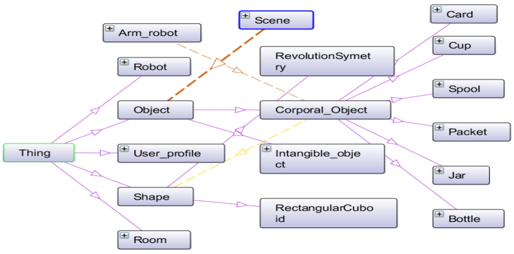

Fig. 6 : Ontology with Protégé

The ontology was designed using "Protégé"[1] (see representation Fig. 6). Two interfaces are developed to facilitate adding new users and new objects.

E. Recognition software

The "Object recognition" is the software package that associates semantic information to objects in the environment. It is one of the key elements to allow the robot to act automatically when objects are identified. "Object recognition" relies on the PIRIA software (Program for Indexing and Research Images by Affinity) developed at CEA LIST. It 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. In Fig. 7 we show examples of the image databases used by PIRIA for object recognition.

V. Evaluations

LIMSI laboratory evaluated the usability of the Human Robot Dialog, the emotions understanding module and the virtual conversational agent under the aegis of the association APPROCHE with elderly people with speech disorders. One can find methods and results of these evaluations in [19] and [2].

A. Technical evaluations

In anticipation of clinical evaluations, a campaign of technical evaluations enabled us to estimate capabilities of different services SAM offers. During this technical evaluation campaign, each service was individually evaluated.

Fig. 7 : Examples of images from the database

Mobile station control was evaluated by acquiring grey level images at a rate of 15 fps. A learning stage has been conducted off-line. A panoramic camera is embedded on the robot. The visual path contains 95 key images (640x480 pixels) and the path is approximately 27 meters. Given a target image, a visual path is computed. A key image in the path is reached when the "image error" is smaller than a fixed threshold. The robot successfully followed a visual path at a translational velocity of 140mm/s [9].

Technical evaluations of the recognition software PIRIA show that we can compute distance between each object and the camera with a few centimeters accuracy within one-meter operating range. Interactive object interpretation is made possible by the processing time (less than one second for more than a hundred images in the database). PIRIA software is transferred to Xedix Company which takes advantage of the improvements made in the ARMEN project on the object localization and on the camera-object distance estimation.

Knowledge representation system offers the ability to use the appropriate behavior for each object SAM may encounter. One can see how it works in the video[2].

The clinical evaluationsof SAM will be carried out in an an environment similar to the one we used to conduct our technical evaluations. SAM had to follow three different scenarios described in the next part. Technology enthusiasts from the medical staff and patients helped us during these evaluations.

Here we explain the process for one of the scenarios. (1) We first ask SAM to retrieve a soda can. (2) SAM has to move to the location designated as the kitchen. The user is able to watch where SAM is located at every moment thanks to the panoramic camera. (3) Once SAM arrives at the desired location, the arm starts moving and the visual feedback of the camera located atop the gripper is displayed to allow the user to select an object in the scene. (4) The user has to click one time to launch the recognition service and one more time to select the desired object. (5) Visual servoing is then enabled to get closer to the object. Ontology is subsequently consulted to define an appropriate grip strategy. (6) The selected object is released on the shelf, the arm moves back to a safe position and (7) SAM returns to the user. (8) SAM puts the object on the table at a reachable position for the user.

SAM has successfully achieved all three scenarios without any error in different environments. Hence, the next step is to evaluate SAM in a real clinical environment alongside end users.

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

[2] http://projet_armen.byethost4.com/images/videos/ARMEN.avi

B. *Clinical evaluations*

One of the key objectives of the ARMEN project is to carry on the clinical evaluations of assistive robotics directly with frail and disabled persons and their family. The targeted population is the same as the one for the ANSO project. The clinical assessments will take place in two rehabilitation centers in France (Berck-sur-Mer and Cerbère) in their therapeutic apartments. They will be conducted under medical supervision, abiding by the usual methodology for clinical trials. Evaluation in an ecological environment is essential to ensure that the device is adapted to the needs and abilities of persons with disabilities and that the product is reliable and useful. It will target a group of disabled people and a control group of healthy individuals.

The main objective of this evaluation is to study the usability of an assistive robotic prototype by severely disabled people.

Secondary objectives are to conduct an acceptability study on this type of assistive robot with potential users and caregivers, and to conduct a study on the emerging needs and expectations expressed by users and their caregivers.

Protocols – The evaluations will last five months. Two groups will participate in the experiments: a group of patients (disabled people) and a group of control subjects (non-disabled people). Each group contains at least ten persons. A standardized protocol will ensure the inter-center reproducibility of the evaluations and a homogenous analysis of the results. The clinical evaluations will consist in completing three scenarios several times with the SAM robot:

- Picking-up an object on the floor and bringing it back to a table. In this case, the object is in the immediate proximity of the user.
- Retrieving an object in another room (kitchen), in a predetermined location. In this case, the object is out of reach of the patient and needs to be placed close to him.
- Finding an object in an unknown location and placing it on the table as described above. In this case, the object is out of reach of the patient and requires the patient to manually manipulate the robot through the HMI.

This evaluation is preceded by a session allowing patients to get familiar with robot SAM and to learn how to use it as well as the human-machine interface.

Evaluation criteria - The main evaluation criteria are usability parameters: number of errors, error rates, type of human errors, machine errors, task completion speed, and learning curve. Secondary evaluation criteria will be qualitative parameters: acceptability and satisfaction, acceptability questionnaire for the patients and the therapists, patient and therapist satisfaction (Likert scale), and an open questionnaire on emerging needs. Processing of the results will be conducted in partnership with a team of biostatisticians.

VI. CONCLUSION

In the ARMEN project we gained technical experience. Compared to ANSO, most of the improvements of the system are made in knowledge representation, object recognition and HMI.

We introduced the architecture of SAM, which offers different services to the user. We pointed out the fact that services are plug and play and interoperable. The results of the technical evaluations of SAM are positive and let us expect that SAM robot is one important step forward in assistive robotics for disabled people. Conclusions of biostatisticians will enable further improvements to our system.

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