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RoboTherapy with Alzheimer patients

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***Abstract*—Humanoids have become an increasing focus of attention in robotics research in last years, especially in service and personal assistance robotics. This paper presents the application developed for humanoid robots in therapy of Alzheimer patients, as a cognitive stimulation tool. The behavior of the robot along the therapy sessions is visually programmed in a session script that allows music playing, physical movements (dancing, exercises...), speech synthesis and interaction with the human monitor. The application includes the control software onboard the robot and some tools like the visual script generator or a monitor to supervise the robot behavior along the sessions. The robot application's impact on the patient's health has been studied. Experiments with real patients have been performed in collaboration with a centre of research in Alzheimers disease. Initial results show a slight or mild improvement in neuropsychiatric symptoms over other traditional therapy methods.**

***Index Terms*—Social Robotics, Humanoid robot, Robot Therapy**

I. INTRODUCTION

ONE field of growing interest in robotics are humanoids. Prototypes such as the Honda Asimo or the Fujitsu HOAP-3 are the basis for many research efforts, some of them designed to replicate human intelligence and maneuverability. Their appearance similar to people facilitates their acceptance and natural interaction with humans as a personal assistant in the field of service robotics, for instance. As a representative sample, the functionality achieved in the Asimo humanoid has progressed significantly in recent years, allowing it to run, climb stairs, push carts and serve drinks.

On other hand, neurodegenerative dementia is a disease that progressively deteriorates brain functionality. One of the most common symptoms of dementia is memory loss. In addition, patients usually lose the ability to solve problems or control their emotions and present changes in personality and normal behavior. Over time, people with dementia are unable to properly perform the basic activities of daily living such as maintaining personal hygiene or food. Estimates point that in 2016 there will be 26.6 million people worldwide with Alzheimer's disease, and this figure will be three times bigger by 2050. On that date, the Alzheimer will affect 1 in 85 people of the total world population. And 40% of them will be in an advanced state of disease, requiring a level of care that involves high consumption of resources [1].

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While there is no causal cure for the disease, palliative medication and nonpharmacological therapy are the only ways patients can improve symptoms and slow down its progression.

Nonpharmacological therapy focuses on strengthening the activities mentally, physically and emotionally. Such actions seek to maintain the functional capacity of the person, while ensuring her levels of quality of life and autonomy. Animal therapy has also shown good results, especially with elderly that live alone. However, it is not always possible. Sometimes the entrance of animals in elder residences it is not allowed due to health and safety reasons. Other times it is the cost of maintaining these animals and the care they need which precludes their presence in the residence. Another issue to consider is that the therapeutic interaction at the cognitive level needed in older people with dementia is not resolved with the presence of animals in the environment of the patient [2].

Regular therapy includes several sessions per week with a human therapist monitoring a group patients. The therapist asks them simple questions, tells them stories, talks to them, interacts with them, hugs them, suggests games, riddles or guides them while doing physical exercises. These activities pursue the cognitive, affective and physical stimulation of the patients.

In this paper we describe the use of a humanoid robot as a cognitive stimulation tool in therapy of Alzheimer patients. Several software modules have been programmed to generate the robot behavior in the therapy sessions. Three types of robotherapy sessions have been developed: physiotherapy, music and logic-language sessions. The robot and the developed software have been used in a pilot study with real patients to evaluate the feasibility and usefulness of robots in dementia therapy.

The remainder of this paper is organized as follows. Second section presents some works with social robots and their use in dementia therapies. Third section explains all the software developed for this humanoid application, including some tools designed to visually program the robot behavior for the robotherapy sessions. The fourth section describes the experiment performed with real patients to measure the impact of this robotic tool on their health and some preliminary results are presented. Finally, some conclusions are summarized.

II. RELATED WORKS

The interest in social robots is growing, as one of upcoming application fields of the next generation robots. For instance as game platforms [3], personal assistants, nursing robots [4] or assistive tools in rehabilitation [5].

In the past 5 years, several projects have been initiated with the therapeutic use of social robots [6] as reasonable substitutes for animal therapy in people with dementia. Robots do not involve the responsibility or the need for an animal facility and their sensors can respond to environmental changes (movements, sounds ...) simulating an interaction with the patient [7]. At the same time, they provide the opportunity to monitor patients and perform cognitive therapy, unlike animal therapy [8]. Other potential benefits of therapy with robots are that it has no secondary effects (like drug therapy) and does not require specially trained personnel (as opposed to the other therapies such as music therapy, pet therapy, etc..).

The Paro robot, which has seal shape, has been used in dementia therapies [9] with positive results.

Broekens et al published in 2009 [10] a systematic review analyzing the literature on the effects of social robots in the health care of the elderly, especially in the role of the company to the patient. It is noteworthy that all studies are after 2000, which indicates the novelty of this research area. Most studies have been conducted in Japan, Southeast Asia and the U.S. [11]. The main results of analysis of these studies are:

- Most of the elderly like robots.
- The shape and material of the robot influence the acceptance and the effect of the robots.
- Improving health by lowering stress levels (measuring stress hormones in urine) [12] and increased immune system response [13].
- Improvement of humor (through surveys and the evaluation of facial expressions)
- Decreased sense of loneliness (using scales measuring loneliness)
- Increased communication (measured by the frequency of contact with robots and family).
- Remember the past (especially with a robot as a baby).
- Some studies indicate that the use of robots helps to reduce the severity of dementia in some patients.

III. Robot software for robotherapy

We created a programming framework, named Behavior-based Iterative Component Architecture (BICA) [14], to develop autonomous applications for our humanoid robots. It has been used in research for several years around the RoboCup environment, and it has also been used for robotherapy.

We have developed several software pieces for the use of humanoids in therapy. The robot behaviors in therapy sessions are described mostly as a sequence of basic movements, music or text playing and light turning on-off operations. A file format syntax has been developed to store these behavior descriptions, they are called *session scripts*.

Some specific components inside BICA have been developed, like one that runs session scripts or other that provides access to robot lights from application software. In addition, some tools have also been created: a session script generator that allows an easy and visual "programming" of robot behavior in therapy sessions, and the session monitor tool that helps the human therapist to control the session progress. They are all described in this section.

A. BICA architecture

The software of our humanoid robot is organized with a behavior-based architecture. It is implemented in a component oriented software architecture, BICA, programmed in C++ language. Components are independent computation units which periodically execute control iterations at a pre-configured frequency. Every component has an interface to modulate its execution and to retrieve the results of its computations.

Behaviors in BICA are defined by the activation of perception components and actuation components. Actuation components take movement decisions, send commands to the robot motors, or locomotion system, or activate other actuation components. They run iteratively to periodically update their outputs. Perception components take data from robot sensors or other perception components and extract information. They basically provide information to the actuation components. The output of a perception component is refreshed periodically and can be read from many other components in the system.

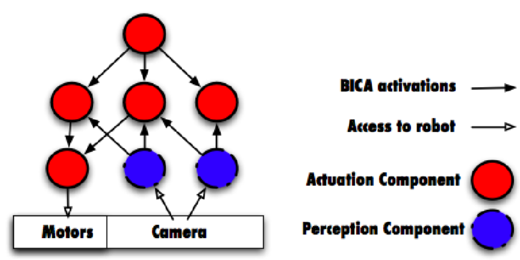

Fig. 1. Behavior in BICA composed by actuation and perception components

Not all the perception capabilities of the robot must be active at the same time, consuming computing resources. Even more, the whole set of behaviors that the robot is able to eventually perform is not suitable to deal with the current situation. Only a subset of behaviors and perception units are relevant to the current situation. In BICA each component is activable and deactivable at will, so it remains inactive until the situation demands it, when another component activates it. Typically an actuation component activates the perception components it requires and the child actuation components (if any) that implement its control decisions. This activation chain creates a dynamic component tree to cope with the robot's current situation. Figure 1 shows an component activation tree with both perception and actuation components.

Beyond being a framework to integrate perceptive and actuation capabilities for autonomous behaviors, the BICA architecture also includes components that provide access to the basic sensors and actuators of the robot, a Hardware Abstraction Layer (HAL) for robot applications. BICA is built on top of Naoqi, the manufacturer middleware, and offers this HAL as a set of object method invocations. For instance, the `Body` component provides access to the motion capabilities, both the legged locomotion and the arm movements. The `Perception` component provides access to the camera images. The `LED` component provides access to several lights on the robot head and chest, which can be turned on and off from the application software. The `Head` component provides access to the neck of the humanoid, allowing to rotate the head horizontally or vertically. The `Music` component provides the capability of playing sound files. It has been specifically developed for the robotherapy application. The stories, questions, songs involved in therapy sessions are stored as sound files and played back using this BICA component.

The behavior based organization of the software of the robot in BICA allows a modular development of robot functionalities, with new components to accomplish new robot tasks or to perceive new associated stimuli.

Beyond the humanoid behavior in the RoboTheraphy application, this architecture has also been used for the programming of humanoid behaviors in other scenarios like the RoboCup competition. We have developed several perceptive and actuation components for the robot soccer player inside the RoboCup Standard Platform League. Some actuation components were programmed as PID reactive controllers and others as Finite State Machines, depending on the complexity of the behavior.

B. Session script generator

The robot behavior set required for robotherapy application is smaller than for other fully autonomous applications like the robotic soccer in RoboCup. In essence, the robot behaviors in therapy sessions are described mostly as a sequence of basic movements, music or text playing and light turning on-off operations. They are usually launched together as the robot may be playing a song and dancing at the same time, for instance.

A high level language has been developed to store these behavior descriptions. They can be stored in text files following a given syntax and read from them. They are called *session scripts*. The language includes three basic instructions: `move`, `music` and `light`. Two or three basic operations of different type can be grouped together, in group instructions, to be executed simultanously. The robot behavior is a sequence of these basic or group instructions. In the script some synchronization points can be included to wait for the termination of all the basic intructions inside a group. In addition, the `wait` instruction causes the robot to stop execution until the human therapist provides the continue order, striking one button in the robot body or using any monitoring tool. This allows the human therapist to control the session progress.

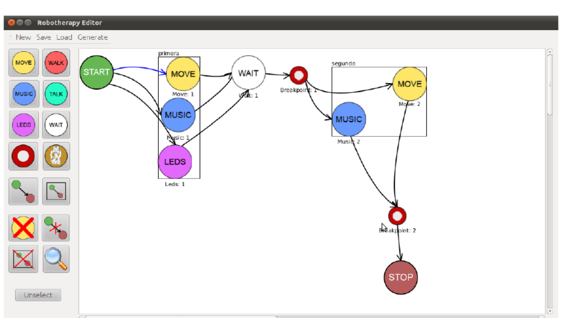

Fig. 2. Session script generator

The scripts are generated and stored in text files. Their contents are designed by medical doctors and health assistants, attending to the desired stimulation in the Alzheimer patients. At the beginning they were created directly editing text files. Recently we have developed a graphical tool, the session script generator (Figure 2), that allows a fast and visual creation of these scripts.

C. Movie component

One specific component has been developed inside BICA for the robotherapy application, the `Movie` component. It accepts session scripts as input and runs the corresponding orders to robot motors and actuators, at the proper timing, unfolding the specified robot behavior. It uses several HAL components available in BICA, like the `Body`, `LED`, `Music` and `Head` components, as shown in Figure 3.

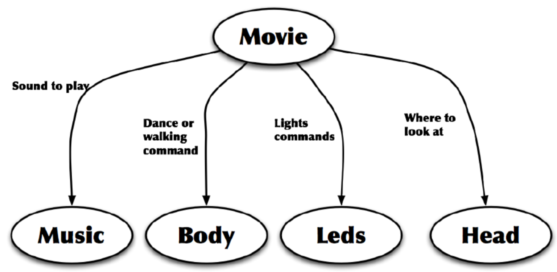

Fig. 3. Movie component in BICA runs session scripts on board the robot

For dancing the robot has previous descriptions of its movements. They are stored as single files following a given syntax, and they can be referenced in the scripts run by the `Movie` component. Those movement files include the position of all robot joints and the right time for each one. For singing or story telling the corresponding song and text are stored as sound files, and they can also be referenced in the session script.

D. Session monitor

The human therapist needs a way to communicate with the robot, to start a robotherapy session, to stop its execution while the patients answer one of the robot questions, to repeat any script step, etc.. The basic interface with the real robot was the set of buttons on its feet and chest. At the beginning these buttons were used, but we developed two session monitor applications to allow an easier way to control the robot.

The first session monitor is an application running on a regular computer. It offers a Graphical User Interface with sliders, selectors, visual buttons, etc. as shown in Figure 4. It allows the teleoperation of the robot body and head, in order to approach the robot towards the patients at the beginning of the sessions, for instance. It can be operated from an external computer, or used in conjuntion with a *wiimote*. This device is more convenient than the regular screen, keyboard and mouse configuration. In this case the session monitor reads the therapist orders from the *wiimote* buttons and accelerometers using bluetooth.

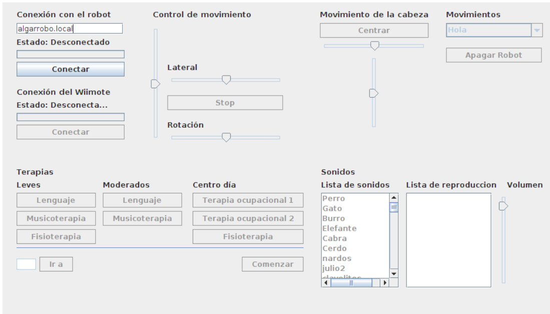

Fig. 4. Session monitor at a regular computer

In order to improve the tool usability, a second session monitor has been created that runs on mobile devices like Android tablets or smartphones (Figure 5). Using it no extra computer nor wiimote is required, just the robot and the tablet or smartphone. With this monitor the human therapist has full control of the progress of the therapeutic session.

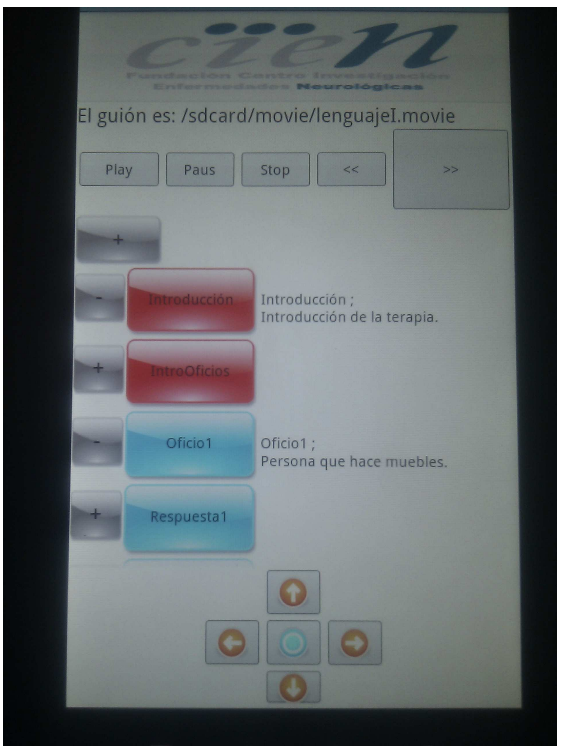

Fig. 5. Session monitor at a tablet

Interaction between different BICA components is performed as method invocation of other component objects. An specific module has been developed for communication between BICA and software outside the robot, for instance the communication between these session monitor tools and the `Movie` component onboard the robot. This module and the session monitor use ICE as communication middleware.

IV. Experiments

The platforms available for this project were initially three: the robot seal Paro, the Aibo robot dog and the Nao humanoid. One of them should be selected for the real experiments.

The mobility of the robot seal Paro is mainly confined to its head (it moves the eyes). It also produces sounds that simulate those of a baby seal. In the opinion of the involved neurologists in this evaluation, this robot is not effective in diseases of dementia, but better suited for patients with diseases related to autism.

The robot dog Aibo and the Nao humanoid offer much more functionality: they are both also nice to look, they walk, move their head, have lights and make sounds. At the beginning psychologists in the project team estimated that cognitive activation in patients would be similar with these last two robots. The larger size of humanoid makes it more visible than the robot dog. In addition, the humanoid robot is most useful in physical therapy, as it can perform physical exercises that can be directly mimicked by patients. This is a key issue.

From a technical point of view, the development of software for the robot seal Paro is complicated because it is a closed platform. Our group has extensive experience in the programming of the other two platforms in the RoboCup environment. One difference in favour of humanoid robot Nao is the availability. Although we have several Aibo robots and was a best-selling commercial robot, since 2008 its manufacturing has been discontinued. Currently our group is participating in the Robocup with the Nao humanoid, and the software architecture developed to control the robot in this environment, BICA, is general enough to host the robot software for robotherapy application.

Due to all these reasons, the Nao humanoid was the selected platform. Before making this selection definitive the robot was presented to a group of 20 patients with differing severity of the dementia. The robot was accepted by most of them: 80% showed a very positive attitude, 15% did not react and 5% (one person) showed aggression towards the robot (and also to therapists and psychologists). Most patients identified him as a child, and tried to talk to him.

Nao robot is a fully programmable humanoid robot. It is equipped with a x86 AMD Geode 500 Mhz CPU, 1 GB flash memory, 256 MB SDRAM, two speakers, two cameras (non stereo), Wi-fi connectivity and Ethernet port. It has 25 degrees of freedom. The operating system is Linux 2.6 with some real time patches. The robot is equipped with a ARM 7 microcontroller allocate in its chest to control the robot's motors and sensors, called DCM.

A. *Therapy sessions*

The therapy session contents have been designed by therapists specialized in the disease of dementia. The robotics work focused on developing the software required so that these sessions can be carried out with maximum similarity to how they were conceived. We developed all the required software components, sounds and robot movements and proposed new tools to be used and evaluated.

Fig. 6. Real sessions with Alzheimer patients

We conducted two experimental phases. In the first one we performed cognitive therapy and physiotherapy sessions, 2 days/week during 3 months with a humanoid robot in a group of 15 patients (Figure 6) and compared with conventional therapy (15 patients). Evaluation at baseline and follow-up was carried out with scales to detect neuropsychiatric symptoms and dementia severity. Most of the patients had moderate dementia (Figure 7), mean age 86.2 years (range: 74-100); 83.34% woman.

Each session took between 30 and 45 minutes and was recorded by three cameras. These recordings were later analyzed by experts to observe the reaction of patients. We designed four types of sessions: language, music therapy, storytelling and physiotherapy. Cognitive therapy included music therapy, ludic activities and language sessions. In the language sessions the robot asked about numbers, days of the week, made riddles and questions aimed at cognitive activation. In the music therapy sessions the robot combined basic questions related to popular songs. Physiotherapy sessions consisted in a set of exercises that the robot explained and performed: movements of arms, head, torso and walking exercises. In storytelling sessions the robot told a story, moving itselft and turning its lights on at the same time, there was no direct interaction with patients.

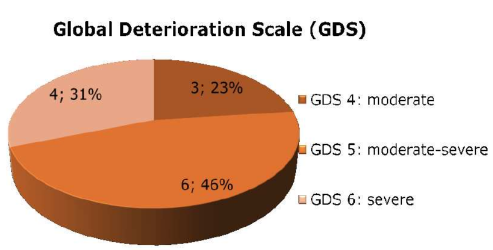

Fig. 7. Global Deterioration Scale of the group involved the first phase

One general conclusion of this first phase was that patients accepted well the robot and participated as much as actively in robotherapy sessions as in the regular sessions without robot. In addition, some preliminary medical results are showed in Figure 8. They have been presented in medical forums and are better explained in [15]. Evaluation showed no significant differences between robotherapy and control groups at baseline. Dementia severity worsened significantly in control but not in the robotherapy group. Neuropsychiatric symptoms and apathy tended to improve after robotherapy in patients with moderate dementia. They are promising, but further research and analysis is required. A serious clinical study about using robots for cognitive therapy in dementia patients was estimated useful and feasible.

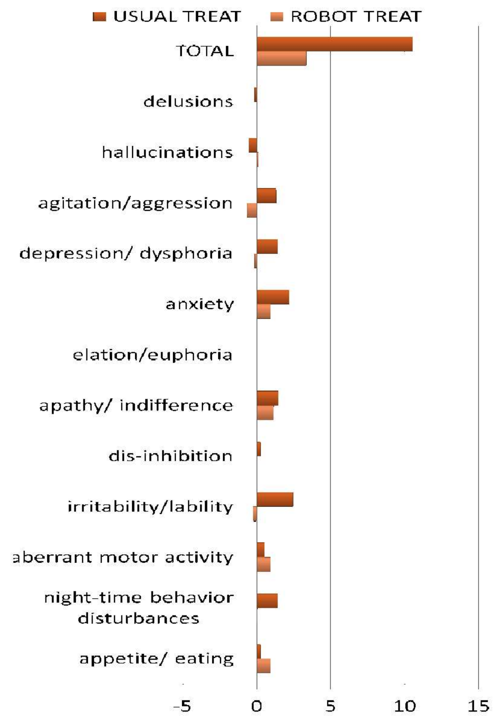

Fig. 8. Some preliminary results of the experiments

The second phase depended on the success of the first phase, and it is now under development. It takes one year and the composition of the groups is different (Figure 9). There are three groups, each one with patients with different degrees of severity of the disease: mild, moderate and severe. The methodology is similar: 30-45 minutes each session and they are being recorded and analyzed. Storytelling sessions were discarded as it became clear that without interaction all patients quickly lost attention in the robot.

The sessions for patients with severe dementia can not be structured as those for people with moderate dementia because they are unable to maintain attention long enough to be effective. For them we designed a set of activities to be carried out by the robot: Walking towards a patient, “looking at” her face, making sounds of animals ... These actions seemed to improve their apathy. Some of these activities (walking towards a patient and “looking at” her face) were also applied during the sessions in the rest of the group, improving their response. To carry out these activities, we extended the software and robotic tools to be easily managed

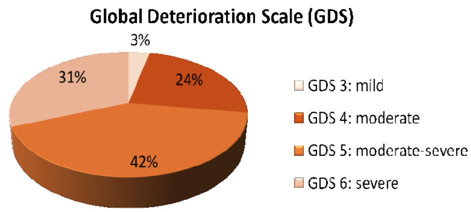

Fig. 9. Global Deterioration Scale of the group involved the second phase

by the therapists. The wiimote extension of the session monitor and the tablet based session monitor have been developed after observing in the experiments the the autonomy needs of the therapists.

V. Conclusions

In this paper we have presented a cutting edge application of humanoid robots in therapy of Alzheimer patients, as a new cognitive stimulation tool. They help to slow down the increasing impairment typical of this kind of dementia.

We have developed several software pieces to support this application. First, our BICA software architecture integrates all robot perceptive and actuation capabilities. Second, a software module helps to visually generate "session scripts". These session scripts are simple descriptions of robot behavior sequence along the therapeutic sessions. They involve the music playing, movements and light generation capabilities onboard the humanoid. They have been created with the knowledge and support of medical experts and are stored in single files. Third, a software module inside BICA runs the session scripts on the real robot. Fourth, a monitor module allows the human therapist to control the script execution, proceeding with the next behavior, repeating steps, etc. and so modulating the session development. Two different monitors have been develped, one running on a regular PC and another one running on an Android tablet. The wiimote device has also been used for easy robot control by the therapists.

Four kind of sessions have been prepared and performed: storytelling, music therapy, physiotherapy and logic-language therapy. In music sessions the robot plays songs from the years when the patients were young, trying to touch their affective and feeling stimulation. In physiotherapy sessions the robot performs several physical exercises with the intention of being repeated by the patients. Logic-language therapy is based on several simple questions to cognitive stimulate the patient responses.

The preliminary medical results on real patients with moderate dementia are promising. Their neurophyschiatric symptoms tend to improve over those of patients following classic therapy methods, but further research is required. Surprisingly the robot captures elder attention due to its human shape, its movements and music capabilities.

We are working on extending the direct interaction between the patients and the humanoid robot. For instance, the real patient showing colored cards to answer to questions done by the humanoid. Also we are programming the robot with more autonomous behaviors like face tracking or people following.

Acknowledgment

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