# Cognitive Assistance and Physical Therapy for Dementia Patients Using Socially Assistive Robots

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***Abstract*—The world population is growing older, introducing a wide array of societal challenges. Most elderly individuals require physical and cognitive assistance of some kind. This paper presents a hypothesis-testing preliminary study that aims to develop affordable customized socially assistive robotics (SAR) tools that can help to provide such care. The work aims to use SAR to aid motivation and companionship to users suffering from cognitive changes related to aging and/or Alzheimer's disease.**

## I. Introduction

The recent trend toward developing a new generation of robots capable of operating in human-centered environments, interacting with people, and participating in and assisting our daily lives has introduced the need for robotic systems capable of learning to use their embodiment to communicate and to react to their users in a social and engaging way. Social robots that interact with humans have thus become an important focus of robotics research.

*Human-Robot Interaction (HRI)* for assistive applications is still in its infancy. *Socially Assistive Robotics* (SAR) [1], which focuses on aiding through social rather than physical interaction between the robot and the human user, has the potential to enhance the quality of life for large user populations. The world's population is growing older, thereby introducing a wide array of societal challenges. It is estimated that in 2050 there will be three times more people over the age 85 than there are today. Many are expected to need physical and cognitive assistance. Even if nursing homes and other care facilities can provide assistance, space and staff shortages are already becoming an issue. As the elder population continues to grow, a great deal of attention and research will be dedicated to assistive systems that allow the elderly to live independently in their own homes.

The American Alzheimer's Association reported that more than one million residents in assisted living residences and nursing homes have some form of dementia or cognitive impairment and that number is increasing every day [2]. The rapidly increasing number of people suffering from Alzheimer's disease could cripple healthcare services in the next few decades. The latest estimate is that 26.6 million people were suffering from Alzheimer's disease worldwide in 2006, and that the number will increase to 100 million by 2050 — 1 in 85 of the total population. More than 40% of those cases will be in late-stage Alzheimer's, requiring a high level of attention equivalent to nursing home care. Dementia is a progressive brain dysfunction that affects the global functioning of the individual progressively impairing cognition (e.g., impaired memory and orientation, limitations of concentration, speech and hearing disorders), and changing personality and behavior. Dementia appears in the second half of the life, usually after the age of 65. The frequency of dementia increases with age, from 2% in 65-69-year-olds to more than 20% in 85-89-year-olds. Thus, individuals suffering from moderate or severe dementia are restricted in their daily activities and in most cases need for special care. As with numerous other diseases, there is no cure for dementia but medication and special therapy can improve disease symptoms. Non-pharmacological treatments focus on physical, emotional, and mental activity. Engagement in activities is one of the key elements of good dementia care. Activities (e.g., music therapy, arts and crafts) help individuals with dementia and cognitive impairment maintain their functional abilities and can enhance quality of life. Other cognitive rehabilitation therapies and protocols focus on recovering and/or maintaining cognitive abilities such as memory, orientation, and communication skills. Finally, physical rehabilitation therapies that focus on motor activities help individuals with dementia rehabilitate damaged functions or maintain their current motor abilities so as to maintain the greatest possible autonomy.

Very little research has been done in the area of therapeutic robots for individuals suffering from dementia and cognitive impairment. Libin and Cohen-Mansfield [3] describe a preliminary study which compares the benefits of a robotic cat and a plush toy cat as interventions for elderly persons with dementia. Furthermore, Kidd, Taggart, and Turkle [4] use Paro, a seal robot, to explore the role of the robot in the improvement of conversation and interaction in a group. Finally, Marti, Giusti, and Bacigalupo [5] justify a non-pharmacological therapeutic approach to the treatment of dementia that focuses on social context, motivation, and engagement by encouraging and facilitating non-verbal communication during the therapeutic intervention.

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Our approach is based on a hypothesis-testing pilot study of *socially assistive robotics technology* aimed at providing affordable personalized cognitive assistance, motivation, and companionship to users suffering from cognitive changes related to aging, dementia and/or Alzheimer's disease. The work aims to validate that a robotic system can establish a productive interaction with the user, and can serve to motivate and remind the user about specific tasks/cognitive exercises.

This paper focuses on the study of the social, interactive, and cognitive aspects of robot behavior in an assistive context designed for the elderly and/or individuals suffering from dementia. In addition to serving as a social and cognitive tool, the robot will also be capable of providing detailed reports of patient progress to caretakers, physicians, and therapists.

## II. HRI MODEL

This research is focused on the interaction modalities, and on the motivational and cognitive strategies for elderly users suffering from cognitive changes related to aging and/or Alzheimer's disease. The expected advantages of the proposed approach are that it provides time-extended personalized cognitive and social interaction and exercise in a robot-supervised fashion, facilitating ongoing monitoring and companionship. We focus on contact-free strategies, where there is no physical contact between the robot and the user, and where social interaction, motivation, and engagement play key roles instead [6,7,8,9]. This is a novel area of research in assistive and rehabilitation robotics that opens up a broad avenue for future discovery and development.

We propose to use a multi-modal behavioral approach that will allow the robot to be responsive both in terms of temporal and social appropriateness. This research builds on a previous HRI model we designed for post-stroke rehabilitation that focuses on the role of physical embodiement, personality, and empathy [6,7]. Our prior results demonstrate the robot's capability to express personality and empathy through several modalities: (1) proxemics (social use of space; extroverted personalities used smaller personal distances); (2) speed of movement (extroverted personalities moved more and faster); and (3) vocal content (extroverted personalities talked more aggressively, using a challenge-based style compared to a nurture-based style on the introversion end of the personality spectrum). Our past experiments compared personality-matched vs. personality-mismatched (random) conditions and found two statistically significant results: (1) participants consistently performed better on the task (more pages turned, more sticks moved, etc.) when interacting with the personality-matched robot; and (2) extroverted participants reported preferring the personality-matched robot while introverted participants did not report any statistically significant preference [6].

In this work, the robot's behavior will be expressed through multi-modal cues indlucing interpersonal distances/proxemics, verbal and non-verbal communication (gestures), and activity.

Communication is a rich multi-modal process. Our approach will be accordingly multi-modal, involving both verbal (e.g., vocal content) and non-verbal (e.g., gestures, body movement, and posture) interaction to express empathy and assist the user during the therapeutic program.

Mimicry and imitation will be used as means of capturing and holding the user's attention and obtaining engagement. The robot will map the observed behavior of the user to its own behavior repertoire and perform the best possible imitation, in terms of overall body movement. The ability to imitate will be used to induce the user to mimic the robot in return, regardless of the quality of the imitation itself. The embodiment of the robot that enables articulated movement will allow for demonstrations and imitations of the user's performance to demonstrate errors and directions for improvement.

## III. EXPERIMENTAL DESIGN

As a first step of the research, we performed a set of focus group studies at a Silverado Senior Living site that is a partner in this project. The studies involved interviews with Silverado staff and residents. This section briefly summarizes the hypotheses and the experimental scenarios that were developed based on the insights gained from the focus group studies.

### *A. Hypotheses*

1. Individuals with dementia and/or cognitive impairments will verbalize more while interacting with the social robot than when the robot is absent.
2. The child-like physical appearance of the robot and its playful interaction will be socially engaging to individuals with dementia and/or cognitive impairments.
3. The social robot will successfully encourage individuals with dementia and/or cognitive impairments to perform their fitness programs and/or physical or occupational therapy.

### *B. Experimental Scenarios*

Two basic experimental scenarios will be used:

**1)** One-on-one interaction between the robot and the user, either in a separate room or in public areas of the facility.

**2)** Group interaction between the robot and multiple users, with the robot forming a social focus for the group.

Three types of roles for the robot will be evaluated:

- **Social aid**: the robot will provide social cues (pointing, prompting, asking, playing music, reciting/reading books and newspapers, etc.) for the user while proactively attempting to engage the user in a companionable social interaction.
- **Cognitive games**: the robot will monitor the user while the user is performing a cognitive task, such as a trivial game, and will provide help, motivation, and

encouragement. The game will be custom-designed to employ simple yes/no questions and to be appropriate to the user's cognitive abilities, background, and areas of interest. The robot itself will also serve as a discovery tool for a cognitive challenge for the user; the user will be able to control the robot's movements with its own.

- **Encouraging physical activity**: the robot will encourage the user to perform mild exercise, providing examples of simple movements and encouraging imitation. Imitation will be used as means of capturing and holding the user's attention. The robot will map the observed behavior of the user to its own behavior repertoire and perform the best possible imitation. The ability to imitate will be used to induce the user to mimic the robot in return. The user will also be able to use arm gestures to command the robot to move about the room (e.g., by raising the left arm the robot would move to the left). All physical activity will be based on exercise activities already employed at the facility, and will be performed in the familiar setting, slowly, safely, and while the robot is providing verbal encouragement.

## IV. TEST-BED

### A. *Robotic Platform*

To address the role of the robot's physical embodiment, we use a biomimetic anthropomorphic robotic platform that consists of a humanoid torso, mounted on an ActivMedia Pioneer 2DX mobile base (equipped with a speaker, and a SICK LMS200 eye-safe laser range finder), and consisting of 22 controllable degrees of freedom, which include: 6 DOF arms (x2), 1 DOF gripping hands (x2), 2 DOF pan/tilt neck, 2 DOF pan/tilt waist, 1 DOF expressive eyebrows, and a 3 DOF expressive mouth (see Figure 1). All actuators are servos allowing for gradual control of the physical and facial expressions.


Figure 1: Humanoid torso mounted on a mobile base (Bandit II - the hands-off therapist robot designed at the USC Interaction Lab)

### B. *Hardware Development*

In order to quantitatively measure patient response, we designed and developed two types of user-appropriate input devices. The first device (1) is intended for use during question and answer sessions, and the second (2) during exercise sessions:

(1) During the question and answer sessions, 'yes' or 'no' questions are posed to the participants. An accurate method of measuring each participant's response is needed. For this purpose, we obtained table-mounted off-the-shelf push buttons and modified them for our experimental purposes. Each time the button is pushed, the analog voltage level of the output changes, allowing us to log participant responses.

(2) During the exercise sessions, the participants raise and lower their legs while seated. This is based on a standard exercise already used in the facility, which we hope to integrate into a social interaction with the robot. To interface this exercise with the robot, we need a means of counting the number of times the participant raises and lowers his/her legs. For this purpose, we developed a 'foot sensor.' The sensor consists of a metal plate and four strain gauges used to measure deflection. The advantage of our design is that the flat plate used in the sensor is no more than a quarter of an inch above the ground, providing an accurate account of the user's activity, but presenting no hazard to the physical stability of the user.

The developed sensors and components used are non-emitting electrical devices, and are safe for use with our participant population.

## V. PRELIMINARY EXPERIMENTAL RESULTS

### A. *Focus Group*

In order to test participant preference between the speech and button interfaces with the robot in the context of the question and answer scenario (cognitive games of Section IV.B), the feasibility of our experimental design, and the acceptance of our devices by the Silverado Senior Living residents, we performed a preliminary experimental test.

Six residents suffering from mild cognitive impairment and one therapist volunteered to participate in the preliminary study. The therapist was charged with asking the participants 20 questions with 'yes' or 'no' answers. The participants were asked to answer these questions either by pressing the button, by speaking, or by using both speech and the button. Two members of our team were recording their verbal answers and observing their preferences between speech, the button, and both. The audio records of the interaction were stored for use in developing a small learning corpus for the robot's speech recognition module, to enable the robot to understand parts of the participant's answers.

We observed that 4 participants preferred the combination of the speech and button interface, 1 participant preferred the button, and 1 participant preferred speech over pressing the button. This preliminary experiment involving no robot helped us to understand the challenges in working with users with dementia and to refine our experimental design. More experiments with the robot will be performed once the pending IRB approval is obtained, expected before the workshop.

*B. Upper-body kinematics extraction*

We plan to use imitation as a key component for maintaining user engagement during physical activities with the robot. In order to perform a best-effort imitation, and also to evaluate and provide motivational feedback to the user on the exercise routines, the robot must be able to recognize the user's gestures. To accomplish this, we are developing a vision system that recognizes the user's arm gestures/poses in real-time, with minimal requirements for the surrounding environment and none for the user.

Several different approaches have been developed to accomplish tracking of human motions, both in 2D and 3D, including skeletonization methods [10,11], gesture recognition using probabilistic methods [12], color-based tracking [13], and others. We opted to create an arm pose recognition system that takes advantage of our simple 2D experimental setup in order to achieve real-time results without imposing any markers on the user.

To simplify the visual recognition of the user, a black curtain is used to provide a static and contrasting background for fast segmentation of the user's head and hands, the most important features of the arm pose recognition task, independent of the user's skin tone.

The experimental scenario calls for the user to be seated in a chair facing the robot, and for arm movements to be performed largely in the plane of the body. In this scenario, arm gestures that extend the arms forward are currently not allowed/recognized. The camera used by the robot has a wide-angle lens to allow for a large field of view, so as to capture the full range of motion of the user even when in close proximity, and has a resolution of 640x480 pixels.

The arm pose recognition algorithm consists of the following five major steps:

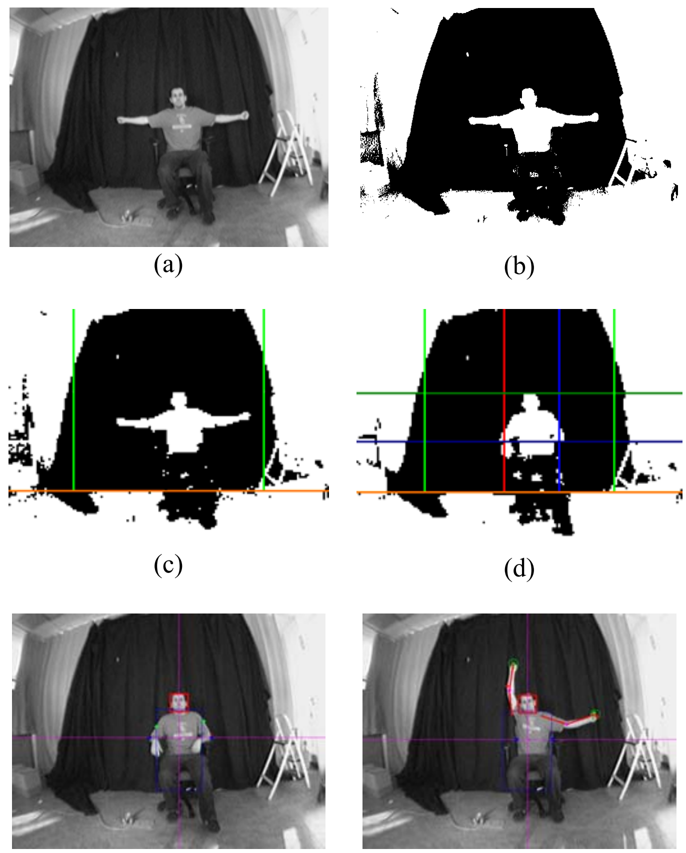
1) Create thresholded image: The original gray-scale camera frame is converted into a black/white image by applying a single threshold over the image. All pixels below the threshold are set as black, and the rest to white. Figures 2(a) and (b) show an original grayscale image and subsequent thresholded image.

2) Detect the exercise area: The exercise area is comprised of the black background and the seated user in front. Figure 2(c) illustrates the detection of the exercise area.

3) Detect the user's face: The OpenCV frontal face detector is used to determine the location and size of the user' s face. Figures 2(d) and (e) show an example subwindow location and final face detection result.

4) Determine hand locations: The hand locations are determined by examining the extrema points of the user's body inside the region above the chest and to the side of the face. The algorithm applies a simple set of rules to choose which extrema points correspond to the hand location for the given arm. Figure 2(f) shows an example of body area and hand location estimates.

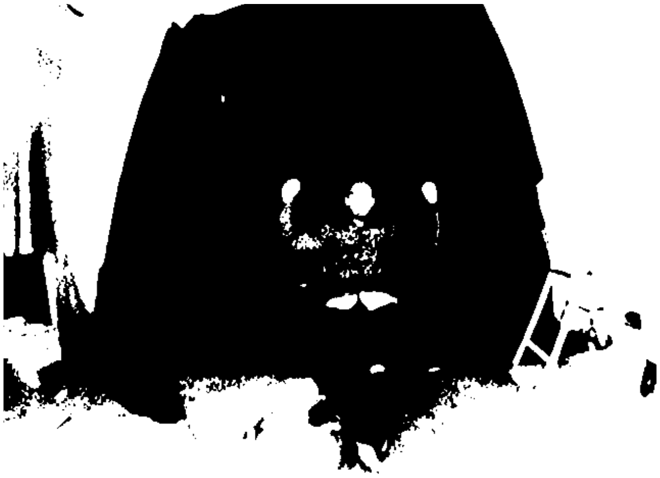
5) Determine arm angles: Once the hand location for a given arm is found, the elbow point is estimated, which in turn provides the desired arm angles. The arm angles represent the arm pose for the robot to evaluate and imitate. The elbow point is estimated as furthest from the line connecting the hand position and the shoulder position, while not exceeding the maximum allowable distance from the hand (enforcing fore-arm length restriction). For cases where there is no arm information available (e.g., user wearing dark-colored long sleeve shirt), inverse kinematics is used to estimate arm angles from the hand position. Inverse kinematics is not used as the primary solution because the length of the arm depends on whether the user's fingers are extended or in a fist, in addition to the distortion provided by the wide-angle lens of the robot's camera.



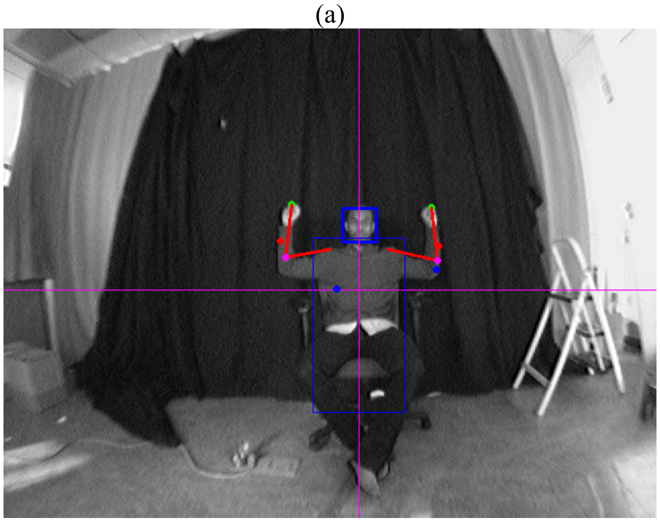
(a) (b) (c) (d) (e) (f)

Figure 2: Steps of the arm pose recognition algorithm

The arm pose recognition algorithm runs with an average frame rate of 30fps on a 1.8GHz Intel Pentium 4 processor, which satisfies our real-time processing requirement. The arm angles estimated by the algorithm are sufficiently correct for the purposes of imitation, and the visual recognition is fairly robust to different types of clothing and lighting. Preliminary results of the algorithm were achieved by processing captured logs of members of our lab performing various arm gestures in front of the robot camera, examples of which are shown in Figure 3. Further results including data from experiments with the Silverado Senior Living residents will be available by the time of the workshop.



(a)



(b)

Figure 3: Example of arm pose recognition results. (a) Thresholded image detailing patchy body/arm appearance due to dark clothing. (b) Final arm angle outputs, along with face detection result.

## VI. CONCLUSION

This research aims to develop a socially assistive therapist robot for individuals suffering from dementia and/or other cognitive impairment that will improve through the social interaction their cognitive abilities and therefore their quality of life. Our assistive human-robot interaction model is being tested with a biomimetic robotic system with human users suffering from dementia. Our model involves empathy and user engagement through proxemics, speech, gesture, and imitation. Engagement, in particular, is considered one of the most important element in the dementia care. The preliminary focus groups and early studies already show promise for our approach. More experimental results validating our hypotheses will be available by the time of the workshop, as this paper reports on ongoing work in progress.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