Improving the Quality of Life of People with Dementia through the Use of Socially Assistive Robots

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***Abstract*—In less than 25 years, 37 million people are expected to have dementia and/or Alzheimer's disease. This significant figure is a result of several factors, including increasing life expectancy and an ageing population in developing countries. Alzheimer's disease, a form of dementia, is a progressive brain disorder that causes memory loss, and behavior and personality changes. People suffering from this disease become increasingly physically and cognitively impaired; they usually need help with all aspects of daily living. While there is currently no cure for dementia, special therapies (e.g., arts and crafts, music therapy) can help people with dementia to live as good a life as possible. We propose to use socially assistive robots as customized/individualized helpers as a complement to humans. This work proposes a new adaptive socially assistive robotic (SAR) system that aims to provide a customized protocol through motivation, encouragement, and companionship for users suffering from cognitive changes related to aging and/or Alzheimer's disease. The robot aims to maintain/improve the user's cognitive attention in a cognitive music game setup.**

***Keywords*-socially assistive robotics; customized robotic therapy; learning and behavior adaptation**

I. INTRODUCTION

Currently the 2 percent growth rate for the world's older population exceeds the 1.2 rate for the world's population as a whole. This difference is expected to increase rather than diminish so that by 2050, the number of individuals over the age 85 is projected to be three times more than there are today. Most of these individuals will need physical, emotional, and cognitive assistance. In the recent past years, the rehabilitation and assistive technology focused on developing more flexible and customizable robotic systems. The main goal of these kind of robots is to support disable and elderly people with special needs in their home environment, and therefore to improve their quality of life. Moreover, most advanced countries are becoming aging societies, and the percentage rate of people with special needs is already significant grow.

The American Alzheimer's Association [1] 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. 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 disorder that progressively affects the brain. People with dementia may not be able to think well enough to do normal activities, such as getting dressed, eating, speaking, etc. They usually lose their ability to solve problems or control their emotions. Their personalities and usual behavior change. Memory loss is a common symptom of dementia. 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. Therefore, most of these people need some kind of assistance. While there is no cure to dementia, medication and special therapy may improve symptoms or slow down the disease. 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 [2], 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 work to date has been done in assistive robotics for people suffering from cognitive changes related to aging and/or Alzheimer's disease. Libin and Cohen-Mansfield [4] describe a preliminary study that compares the benefits of a robotic cat and a plush toy cat (NeCoRo) as interventions for elderly persons with dementia. Their system was tested with elderly women and they demonstrated that the robotic system served to diminish agitation [5]. Furthermore, Kidd, Taggart and Turkle [3] used Paro, a stuffed seal

Figure 1: Robot test-bed: Bandit II humanoid torso mounted on the Pioneer mobile base

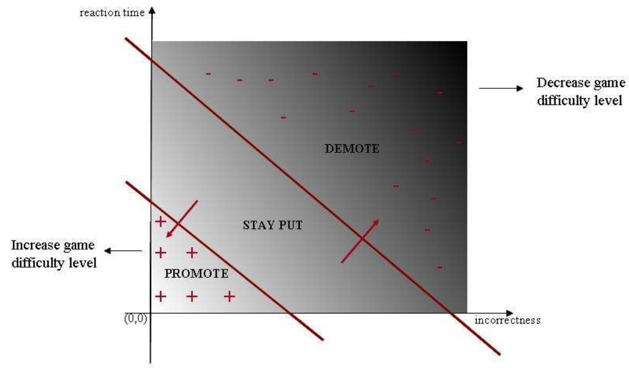


Figure 2: Adaptation System

robot, to explore its potential role in improving conversation and social interaction of a group of elderly users. Marti, Giusti and Bacigalupo [6] justified a non-pharmacological therapeutic treatment for dementia that focuses on social context, motivation, and engagement by encouraging and facilitating non-verbal communication during the therapeutic intervention. In contrast, this work proposes a new adaptive socially assistive robotic (SAR) [9], [8] system that aims to provide a personalized protocol through motivation, encouragement, and companionship for users suffering from cognitive changes related to aging and/or Alzheimer's disease. The robot aims to maintain/improve the user's cognitive attention in a cognitive music game setup.

II. Robotic Test-bed

The experimental testbed is a humanoid torso mounted on a mobile platform (Figure 1). The mobile platform is an ActivMedia Pioneer 2DX robot equipped with a speaker, a Sony Pan-Tilt-Zoom (PTZ) color camera, and a SICK LMS200 eye-safe laser range finder. The biomimetic anthropomorphic setup involves a humanoid Bandit II torso, 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. All actuators are servos allowing for gradual control of the physical and facial expressions.

We are particularly interested in utilizing the humanoid's anthropomorphic but not highly realistic appearance as a means of establishing user engagement, and comparing its impact to our prior work with non-biomimetic robot test-beds [7], [10].

III. Learning and Adaptation

This work tries to validate that a personalized robotic system can establish a productive interaction with the user, and can serve to motivate and remind the user about specific cognitive exercises in order to encourage cognitive and/or physical exercises that maintain health and quality of life. The research work presented in this paper focuses on the study of the adaptable social, interactive, and cognitive aspects of robot behavior in an assistive context designed for the elderly and/or individuals suffering from dementia. A new learning and adaptation system that allows for maximizing the user's performance on a cognitive task was developed. The main goal is to minimize the user's reaction time and maximize the number of correct answers to the game questions, signifying improvement of cognitive attention. The level of the cognitive music game (easy, medium, and difficult) is initialized based on the user's level of impairment and it adapts based on the user's task performance (i.e., reaction time and number of correct answers). The robot uses its embodiment, as well as pre-recorded speech, to praise and motivate the user. The vocabulary is positive and encouraging, regardless of the participant's performance. The volume of the music and the robot's voice is set at a high yet comfortable level as determined by the users nurses and music therapist. The learning system consists of two phases, the supervised learning phase and the adaptation phase. The supervised phase adjusts the initial state of the system. The system learns for each game level and for each disability bucket (mild, moderate, and severe) an Accepted Variation Band (AVB) as a function of users' task performance to the cognitive game and the correctness of their answers. The learning phase is followed by an adaptation phase where the robot adapts its behavior so as to minimize reaction time and maximize user correct answers. The adaptation phase continues throughout the experiment and enables the robot to adjust the game difficulty level in response to the user's performance. If the user's task performance is below the Accepted Variation Band (AVB), this indicates that the user is performing better than during the learning phase and results in promoting the user to the higher the game difficulty level. In contrast, if the user's task performance is above the Accepted Variation Band (AVB), this indicates that the user is not performing well enough and the game difficulty level is decreased, as shown in Figure 2.

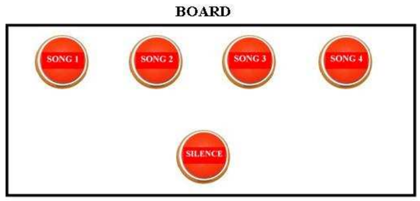


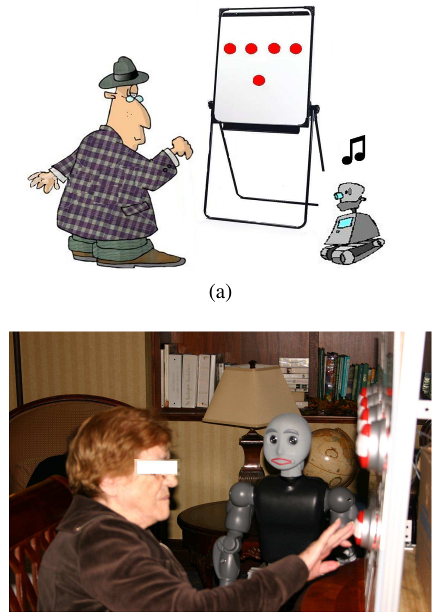
Figure 3: Cognitive Game: Name That Tune

IV. Experimental Setup

The experiment consists of repeated sessions, during which the user and the robot interact in the context of a cognitive game. The first session is the orientation, in which the participant is 'introduced' to the autonomous mobile robot. The robot is brought into the room with the participant, but is not powered on. During this introduction period, the experimenter or the participant's nurse/physical/music therapist explains the robot's behavior, the overall goals and plans of the study, and what to expect in future sessions. The participant is also asked about his/her favorite songs from a variety popular tunes from the appropriate time period; those songs are later used in the subsequent sessions. At the end of the session, the Standardized Mini-Mental State Examination (SMMSE) cognitive test is administered so as to determine the participant's level of cognitive impairment and the stage of dementia. This test provides information about the cognitive (e.g., memory recall) level of impairment of the participant for use in initializing the game challenge level. The data determine the participant's initial mental state and level of cognitive impairment, and serve as a pre-test for subsequent end-of-study comparison with a post-test.

This experiment is designed to improve the participant's level of attention and consists of a cognitive game called Song Discovery or Name That Tune. The participant is asked to find the right button for the song, press it, say the name of the song, and sing along. The criteria for participation in the experiment (in addition to the Alzheimer's or dementia diagnosis) include the ability to read large print and to press a button. The participant stands (see sketch Figure 4a) or sits (see Figure 4b) in front of a vertical experimental board with 5 large buttons (e.g., the Staples EASY buttons - see Figure 3). Four buttons correspond to the different song excerpts (chosen as a function of the user's preference) and the last button corresponds to the SILENCE or no song excerpt condition. Under each button, a label with the name of the song (or SILENCE) is printed.

The robot describes to each participant the goal of the game before each session, based on the following transcript: "We will play a new music game. In it, we will play a music collection of 4 songs. The songs are separated by silence. You will have to listen to the music and push the button corresponding to the name of the song being played. Press the button marked "SILENCE" during the silence period between the songs. The robot will encourage you to find the correct song."



(a)

(b)

Figure 4: Human-Robot Interaction Cognitive Game Setup: (a) standing position; or (b) sitting position

Each participant is first asked by the music therapist or the robot to read aloud the titles of the songs and to press a button. Some additional directions are given. The participant is also directed to press the SILENCE button when there is no music playing. After a review of the directions, the participant is asked by the robot to begin the music game. The music compilation is composed of a random set of song excerpts out of the four different songs that form the selection and the silence condition. The entire music compilation lasts between 10 and 20 minutes, and is based on the user's level of cognitive impairment: the larger the impairment, the shorter the session. A song excerpt can be vocal, instrumental, or both. The order of song excerpts is random.

The experiment was repeated once per week for a period of 6 months in order to capture longer-term effects of the robot therapist. A within-subject comparison was performed to track any improvement over multiple sessions. No between-subject analysis was done due to the small sample size and large differences in cognitive ability levels.

V. Experimental Results

The initial pilot experimental group consisted of 9 participants (4 male, 5 female), from our partner Silverado Senior Living care facility. All the participants were seniors over 70 years old suffering of cognitive impairment and/or

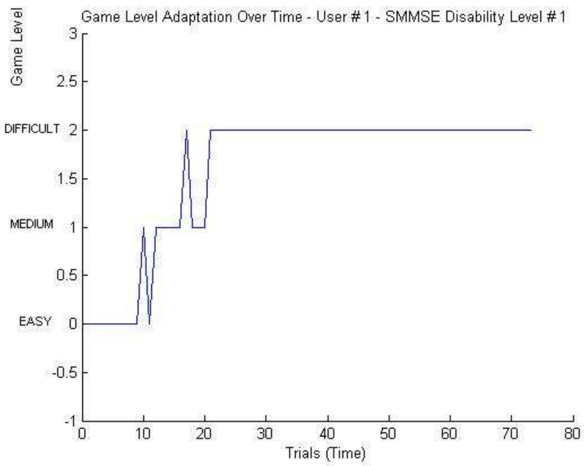


Figure 7: Game Level Adaptation and Evolution Over Time (6 months) for User Id 1

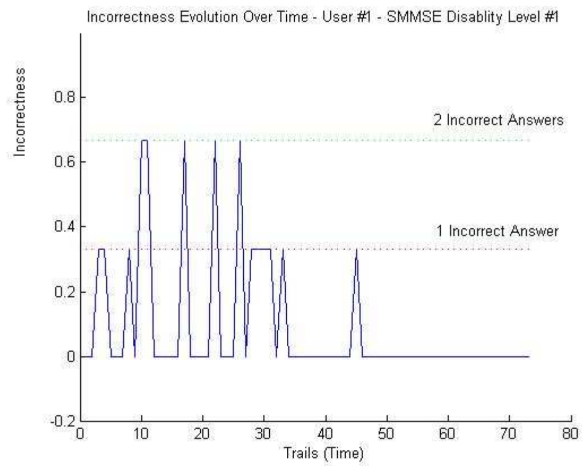


Figure 8: Incorrectness Evolution Over Time (6 months) for User Id 1

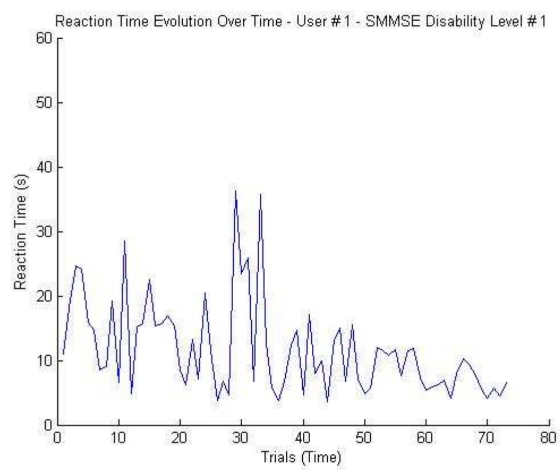


Figure 9: Reaction Time Evolution Over Time (6 months) for User Id 1

Alzheimer's disease. The cognitive scores assessed by the SMMSE test were as follows: 1 mild, 1 moderate, and 7 severe. Due to the total unresponsiveness of 6 of the severe participants, only 1 severely cognitively disabled participant was retained for the rest of the study, resulting in a final group composed of 3 participants (3 female).

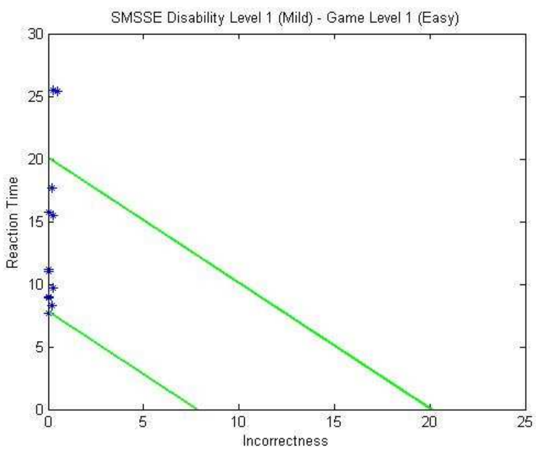
We constructed the training data and built a model for each cognitive disability level and for each game level. The participants played each game level 10 times (stages) in order to construct a robust training corpus. An example of the learned AVBs for mild cognitive impairment users for each game level are illustrated in Figure 6.

The results obtained over 6 months of robot interaction (excluding the 2 months of learning) suggest that the elderly people suffering of dementia and/or Alzheimer's can sustain attention to music across a long period of time (i.e., on average 20 minutes for mildly impaired participants, 14 minutes for moderately impaired participants, and 10 minutes for severely impaired participants) of listening activity designed for the dementia and/or Alzheimer's population. Figures 7, 8, and 9 illustrate the evolution of the game difficulty over time, as well as response incorrectness and reaction time for user_id 1.

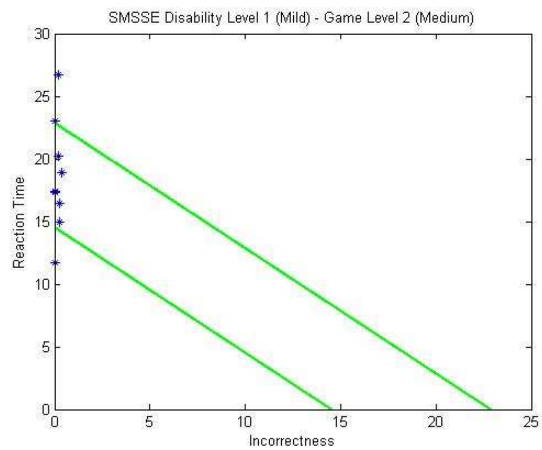
Outcomes are quantified by evaluating task performance and time on task. Based on the results to date, it can be concluded that the SAR system was able to adapt the challenge level of the game it was presenting to the user in order to encourage task improvement and attention training. Figure 7 shows the evolution in time of the game level for user_id 1. The participant started at the easy game level and remained there for several sessions. The participant then started to perform better and diminished the reaction time and reduced the number of incorrect answers, which, in turn, resulted in a game level evolution from the easy level to difficult. Starting from the 22nd trial, the participant consistently remained at the highest level of difficulty in the game (see Figure 5). Figures 8 and 9 depict the evolution of the reaction time and the number of incorrect answers. The decrease of those metrics indicates improvement on the task. Similar improvement was observed for all participants.

The participants recognized the songs and identified the silence periods with the same probability. Hence, the analysis of the "no answer" situation among our elderly participants provides us with additional information. From our experiments, we noticed that the average rate of absence of response to silence was higher than the average rate of absence of response to songs, and that this phenomenon increased with the severity of the cognitive impairment. Our conjecture is that music stimulates the interest and

Figure 5: Human-User interacting with the robot during the actual music game: the robot is giving hints related to the music game, the user answers, and the robot congratulates and applauses the correct answer of the user



(a)



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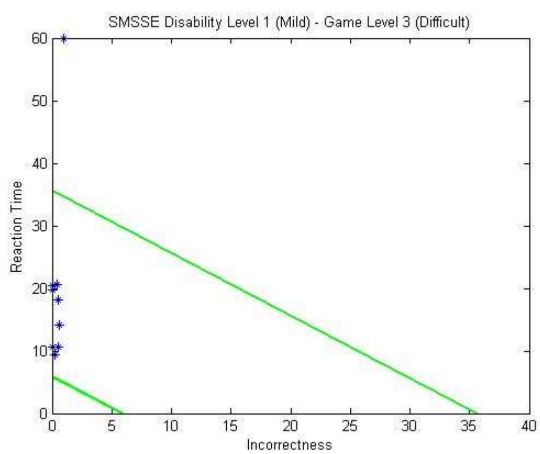

(c)

Figure 6: Learned Accepted Variation Bands for Mild disability level and all game levels: (a) easy; (b) medium; and (c) difficult

responsiveness of the patients.

Another interesting observation that deserves more study is the users' ability to participate simultaneously in different tasks (multitasking): the participants were able to sing and push the correct buttons at the same time. This is notable in particular for participants with cognitive disability, since multitasking requires dividing attention.

The results obtained to date support both of the hypotheses. First, our social robot was able to improve or maintain the cognitive attention of the patients with dementia and/or cognitive impairments through its encouragements in a specific music-based cognitive game. Second, the robot's capability of adapting its behavior to the individuals' level of disability helped to improve the user's task performance in the cognitive game over time.

This study is ongoing; two more months of active experimentation with the current group of participants are needed to complete the results. Once the study is complete, we will perform an SMMSE post-test and look for any possible differences from the pre-test. We will also collect feedback from the facility's music therapist (via a Likert-type questionnaire) about the participants' attentional and cognitive responses in the music attention settings. Finally, caregivers will also be asked about the improvements and the possibility of transfer of knowledge (interactive format with the patients, family members, and the robot).

VI. Conclusion

The described research aims to develop methods toward socially assistive therapist robots for individuals suffering from dementia and/or other cognitive impairments. The proposed approach involves the use of an adaptive SAR system in the context of a music-based cognitive game. The pilot study results show promise for the approach. Additional results with a larger study population are expected in the near future. In addition to serving as personalized social and cognitive tools, SAR systems will be capable of providing detailed reports of patient progress to caretakers, physicians, and therapists, thereby both improving the standard of care and quality of life.

Acknowledgment

The author would like to thank to Silverado Senior Living - The Huntington, Alhambra, CA, USA. Many thanks to Vida Gwinn (Facility Administrator), Cheryl Stollman (Activities Program Director), Jessi Nunez and Zena Buccola (Activities Assistants), Rudy Medina (Plant Operations Supervisor), Tamara Mitchel (Administrator Assistant), and all the personnel for all their help and their support.

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