# Performance of Daily Activities by Older Adults with Dementia: The Role of an Assistive Robot

Momotaz Begum, Rosalie Wang, Rajibul Huq, and Alex Mihailidis

***Abstract*— Older adults with cognitive impairment often have difficulties in remembering the proper sequence of activities of daily living (ADLs) or how to use the tools necessary to perform ADLs. They, therefore, require reminders in a timely fashion while performing ADLs. This is a very stressful situation for the caregivers of people with dementia. In this paper we describe a pilot study where a tele-operated assistive robot helps a group of older adults with dementia (OAwD) to perform an ADL, namely making a cup of tea in the kitchen. Five OAwD along with their caregivers participated in this study which took place in a simulated-home setting. The purpose of this study was to investigate the *feasibility* and *usability* of a robotic system in assisting the OAwD to perform ADL in a home setting. The findings from this study will contribute to achieve our ultimate goal of designing a full-fledged assistive robot that assists OAwD aging in their own homes. The assistive robots designed for people with dementia mostly focus on companionship. This is, to the best of our knowledge, the first attempt to design an assistive robot which will provide step-by-step guidance to people with dementia in their activities of daily living.**

## I. MOTIVATION

As a result of the rapidly growing elderly population (a vast majority of whom are suffering from a variety of chronic medical conditions, such as dementia) and the ever-increasing cost of health-care, the popularity of the concept of aging-in-place is quickly spreading. The research community is also focusing on developing smart-home technologies which will facilitate aging-in-place. Use of smart-home technologies is especially beneficial for OAwD hoping to age-in-place as they often have difficulties in remembering the proper sequence of activities of daily living (ADLs) or how to use the tools necessary to perform ADLs. Providing such constant assistance could be an overwhelming task for the caregivers staying with OAwD. Smart home technologies support OAwD to age-in-place by providing various services, such as within home navigational support [1], schedule management [2], safety assurance [3], [4], [5], [6] and responses to emergency situations [7], cognitive and social support [8], a means of communication with family and friends [9], and automated cognitive assessment [10]. Almost all of these smart-home technologies are static and embedded into the environment. In our previous research we also developed an automated artificial intelligence (AI)-based static technology, namely COACH (Cognitive Orthosis for Assisting aCtivities in the Home) which provides verbal and visual guidance, when necessary, to OAwD during their ADLs [11], [12]. The COACH system requires minimal hardware installation (a display screen, a microphone, and a speaker) and does not require any explicit input from the user to run. The system showed promising results when used with OAwD in completing a hand-washing task. The COACH, however, still suffers from a number of limitations which is generally present in almost all of the embedded assistive technologies [11].

The common limitations of embedded technologies to assist in ADLs can be summarized as follows.

- The embedded assistive technologies require multiple hardware units to be installed at different indoor locations where assistance could be required.
- There are places in a house where embedding assistive hardwares might not be feasible. Such areas remain out of observation.
- Due to static sensors the embedded assistive technologies can not properly perceive the dynamic activities of the user. This limits their capacity to deliver assistance in the most efficient manner.
- Receiving assistance from an entity with a physical body is psychologically more ‘acceptable’ than receiving that from someone without a physical body [13]. Apart from this improved acceptance, having a physical body makes it possible to physically assist the OAwD in conducting different ADLs and also opens up the possibility of having more meaningful interaction with the user.

Most of these limitations can be overcome by the use of assistive mobile robots. But as the target population for these technologies is extremely vulnerable, it is required to find the answers to a set of basic research and ethical questions before building assistive mobile robots in order to replace the static assistive technologies. Examples of such questions are, but not limited to, “Is the assistance delivered in this form (i.e. through a mobile robot) acceptable to the user?”, “What is the expectation about the physical appearance, interaction capacity, and type/level of assistance from the robot?”, “What are the safety issues involved in using or placing such a robot in the home of OAwD?”, and “What are the ethical issues involved?”. This research addresses some of these questions.

The ultimate goal of our research is to develop a full-fledged assistive robot which will reside in the natural home environment of an OAwD and will help him/her, if needed, in completing their ADL. Such help will be delivered in the form of audio/video prompts or a combination of both to

*This work was supported by a catalyst grant from the Canadian Institutes of Health Research (CIHR)

The authors are with the Intelligent Assistive Technology and Systems Lab (IATSL), University of Toronto and Toronto Rehabilitation Institute, Toronto, Ontario, Canada e-mail: Momotaz.Begum@uhn.ca

978-1-4673-6024-1/13/$31.00 ©2013 IEEE

describe the way to perform a certain subtask in an ADL. There exists a number of smart home technologies and a handful of assistive robots to help OAwD (section II provides a brief discussion of those systems) but an assistive robot to provide guidance especially in ADLs of OAwD, to the best of our knowledge, is the first of its kind. Design of such a sophisticated intelligent robot is already a challenging task (from a technical point of view), but the vulnerability of the target population makes it even more challenging. Our research, therefore, adopts an user-centered design approach where the target users (OAwD and their caregivers) will be actively involved in the design and development process of the assistive robot. As a first stage of this multi-stage design approach we have developed a prototype mobile robot to tele-operate to different places inside a home and to interact with people through natural speech. We have implemented a prompting system (similar to the COACH prompting system) in the robot for an ADL task which is making a cup of tea in the kitchen. An online survey with 106 familial caregivers identified this ADL as one of the important tasks to incorporate in future smart home systems for OAwD [14]. We conducted a pilot study with a group of OAwD and their caregivers using the prototype assistive mobile robot in order to investigate the *feasibility* and *usability* of the system.

The rest of this manuscript is organized as follows. Section II describes the related work, section III provides the detailed setting for the pilot study (the study procedure, evaluation method, robot, subjects, and tea-making task), section IV presents an analysis of the data, section V provides the future work and finally section VI provides some concluding remarks.

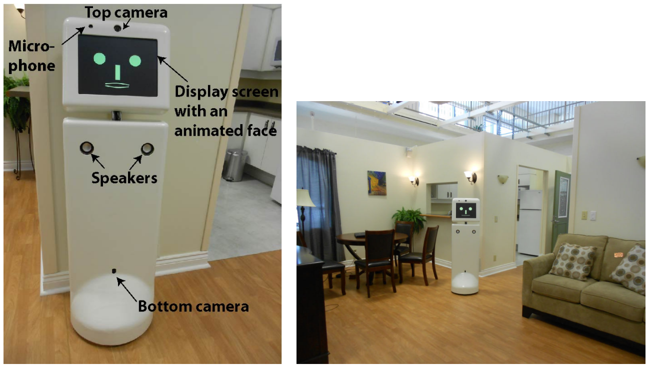
## II. ASSISTIVE ROBOTS FOR THE CARE OF PEOPLE WITH DEMENTIA

Assistive robotics is a fairly new research domain and there are only a few works which deal with people with dementia or other forms of cognitive impairment. The Nursebot [15] (also known as 'Pearl') is a mobile robot with a custom-designed actuated head, several on-board sensors (e.g. laser, camera, sonar), a touch-sensitive screen, speech recognition, and speech synthesizing ability. The robot uses auto reminder technology described in [2] to remind older adults about events and schedules. Also, it provides indoor navigational support through the use of intelligent mobility platform (IMP) introduced in [1]. The Care-O-bot [16] mobile robot is equipped with a manipulator arm, adjustable walking supporters, a tilting sensor head containing two cameras and a laser scanner, and a hand-held control panel. The robot is capable of performing basic pick-and-place operations on simple objects commonly found in home environments. The goal of Care-O-bot is to serve as a service robot for the elderly and people with physical disabilities. The robotic seal 'Paro' [17], [18] is probably the most clinically tested robotic technology designed to help people with dementia. This companion robot is able to respond to touch, sound, sight and temperature. Several studies show that 'Paro' has the potential to improve the mood of OAwD and to help reduce the dependency of OAwD on their caregivers. The 'Bandit' robot [19], [20] is an anthropomorphic upper-torso humanoid robot mounted on a mobile base. The robot was employed in a number of studies where it served as a social companion for the users (through executing a number of social cues e.g. pointing, prompting, asking, playing music, and reciting/reading books and newspapers), played a custom-designed simple game with the user and finally, provided motivation and encouragement to perform mild physical exercise. The result of these studies, although conducted on a small sample, shows the potential of using robots as a cognitive companion for people with dementia. The European Union (EU) is currently funding a large research initiative led by several universities and industries to design assistive robots for elderly aging in place [21], [22], [23], [24], [25]. Although many of these projects are not specifically targeting OAwD, due to the nature of the target population all of them are considering the fact that the elderly will require assistance in remembering events and actions. Among these EU funded research initiatives the ROBADOM project [21], [22] aims at developing a socially assistive robot for OAwD. The services expected to be offered by the robot include reminders for appointments and medications, management of shopping lists and cognitive stimulation. A prototype robot has already been developed based on interview-based feedback from 15 older adults with and without cognitive impairment. Work is currently being done to automate different human-robot interaction (HRI) modules of the robot as reported in [26]. Any study involving the robot and peoples with dementia, however, has not been reported yet.

The majority of the assistive robotic research for people with dementia is focused on companionship and cognitive stimulation. But assisting OAwD in their ADLs is an overwhelmingly stressful task for caregivers of OAwD and, therefore, is an area where assistive robots can significantly contribute. None of the current assistive robotic research, however, to the best of our knowledge, focuses on providing need-based step-by-step guidance for OAwD to carry out their ADLs.

## III. EXPERIMENTAL DESIGN

Our prototype robot "Ed" (figure 1(a)) provides need-based step-by-step guidance to OAwD while they perform the tea-making task. The study was conducted in the iDAPT HomeLab at Toronto Rehabilitation Institute (figure 1(b)). HomeLab is a fully equipped lab resembling a typical single-storey dwelling. The indoor navigation of the robot as well as the delivery of the prompts were tele-operated by one of the co-authors of this manuscript. The tele-operator was located in a remote location in the HomeLab during the experiment. The tele-operated robot initiates a verbal interaction with OAwD by introducing itself and then accompanies them to the kitchen to make a cup of tea. When the task is finished, the robot guides them back to the living area.




(a) (b)

Fig. 1. (a) The prototype robot "Ed" to assist OAwD with ADLs (b) Ed in the HomeLab

### A. OBJECTIVES

The objectives of this pilot study are to investigate the *feasibility* and *usability* of using an assistive robot to assist OAwD to perform their ADLs. The information we gather will help us to improve our system for future research. The definition of *feasibility* and *usability* in the context of our work and the way we perform quantitative and qualitative evaluation are described below.

- Feasibility: *Feasibility* indicates the overall viability of the idea of assisting OAwD in their ADLs through a mobile robot. This pilot study allows us to investigate the following issues.
  - Whether delivering ADL prompt through a mobile robot is a feasible idea,
  - The strengths and weaknesses of the new method of prompt delivery,
  - The hardware, software, and environmental resources required to implement the new system, and finally
  - The possible directions of future research.

  The measure of *feasibility* is mostly qualitative, although a quantitative idea is achieved through the measure of usability.
- Usability: *Usability* evaluation includes effectiveness, efficiency and satisfaction, however, only the data for effectiveness and satisfaction are reported in this manuscript. Analysis of the efficiency data will be included in a forthcoming article. The metrics used and the methods of data collection for effectiveness and satisfaction are summarized in table I.

### B. SUBJECTS

Subjects were OAwD aging in their own homes as well as their caregivers. They were recruited through Toronto Memory Program (TMP), a community-based medical clinic specialized in the diagnosis and treatment of Alzheimer's disease and related disorders in Canada. The caregivers were family members who had clear ideas about the abilities of the OAwD. A Mini-Mental State Exam (MMSE) [27] was performed on each OAwD before the study to screen their level of dementia. The demographics of the subjects and caregivers are summarized in Table II (OAwD and caregivers are termed by OA and C, respectively).

TABLE I
USABILITY INDICES AND THEIR DATA COLLECTION METHODS

| Effectiveness | Satisfaction |
|---|---|
| Completeness of task<br>*-from behavioral observation*<br><br>Adherence to robot prompts<br>*-from behavioral observation*<br><br>Engagement with robot<br>*-from behavioral observation* | Emotional response: acceptance, usefulness, ease of use<br>*- from interview and questionnaire* |

TABLE II
DEMOGRAPHICS OF THE SUBJECTS AND CAREGIVERS

| Subject | | | | Caregiver | |
|---|---|---|---|---|---|
| Subject | Gender | Ages (years) | MMSE | Caregiver | Relation to subject |
| OA1 | F | 76 | 9 | C1 | Son |
| OA2 | M | 86 | 24 | C2 | Wife |
| OA3 | M | 88 | 25 | C3 | Daughter |
| OA4 | F | 77 | 25 | C4 | Daughter |
| OA5 | F | 59 | 18 | C5 | Husband |

### C. ADL, COACH PROMPTS, AND HUMAN-ROBOT INTERACTION

ADL tasks chosen for this study were hand washing in the washroom and tea-making in the kitchen. For efficient prompting each ADL task is broken down into different steps or subtasks. For instance, we identify seven essential steps and three optional steps for a tea-making task. The essential steps are: *go to kitchen*, *turn water faucet on*, *fill kettle with water*, *boil water*, *put teabag into cup*, *pour hot water into cup*, and *put teabag into garbage bin*. The optional steps are: *spoon sugar into cup*, *retrieve milk from fridge*, and *pour milk into cup*. Accordingly, we record the required video and audio prompts for each of these steps. The audio prompt is a speech-based description of a subtask while the video prompt is an example display of how a specific subtask can be performed. For each subtask the prompts have three different levels of assistance: minimal (MN), maximal (MX), and maximal with video (MXV). The MN prompt is a high level speech-based instruction to complete a subtask. The MX prompt provides more directive instruction (rather than suggestive) about how to complete a subtask and is delivered along with the subject's name in order to attract his/her attention [28]. The MXV prompt is essentially the MX audio prompt which is executed along with a corresponding video display. Table III shows two example subtasks and the corresponding prompts. Figure 2 shows the robot executing a MXV prompt of how to use the kettle to one of the OAwD during the tea-making task.


Fig. 2. The robot showing a video prompt to an OAwD during the tea-making ADL

The static COACH system in our previous research [11] uses a POMDP model to autonomously detect missed steps and provide prompts accordingly. In the current study as the robot is tele-operated, the operator continuously monitors the camera images and audio data to identify a missed step and provides prompts accordingly. The tele-operation follows a set of rules to ensure that the human-robot interaction is smooth and consistent for each subject. The rules are as follows.

- The robot allows the OAwD to initiate steps in each task and waits for them to initiate a step as they wish.
- If an OAwD looks around or asks about directions, the robot delivers the appropriate prompt.
- If an OAwD replies that (s)he does not do things that way and does not do it, the robot agrees with that as long as the OAwD does not skip an essential step.
- If an OAwD asks a question about the location of an item specific to the task, the robot provides a full-body gesture by physically orienting itself toward the 'sought for' item. If the OAwD still can not locate the item, the robot then delivers the MXV prompt.
- During water boiling, the robot asks them to put sugar or milk or tea bag in the cup. If that is done or they do not want it, and there is more time, the robot engages in a social conversation with the OAwD, e.g. asking about the weather.
- If an OAwD asks a question where the prerecorded prompts do not work, the robot either responds by giving the correct answer (through the operator using a text-to-speech (TTS) platform) or says "I don't know", depending on the question.

TABLE III
SOME OF THE ESSENTIAL STEPS AND PROMPTS FOR TEA-MAKING ADL

| Steps | Prompt |
|---|---|
| Turn water on | MN: *Can you turn the water on now?*<br>MX: *Try pulling the silver lever toward you*<br>MXV: MX + Video (Model turns on the water) |
| Fill kettle with water | MN: *Can you fill the kettle with water now?*<br>MX: *Try filling the kettle under the water.*<br>MXV: MX + Video(Model picks up kettle and fills kettle with water) |

If an OAwD cannot complete an essential step despite the delivery of MXV prompt, then a researcher intervenes to assist to move on to the next step. The video file "OATea-Making.mp4" attached with this manuscript contains video clips showing different OAwD performing various steps of the tea-making task while following the guidance of the robot. To comply with the research ethics board (REB) protocol the identifiable features of the OAwD (faces, voices) have been removed from the video.

### D. ROBOTIC SYSTEM AND CONTROL SOFTWARE

*1) Hardware:* The prototype robot "Ed" is built on top of an *iRobot Create* platform and is equipped with a tablet computer for on-board processing (as shown in Fig. 1(a)). The robot is 40 inches high, has one microphone to record all audio data, two speakers to deliver speech (ADL prompts and other conversations), a display screen that shows an animated face and video prompts, and two cameras (one above the screen and the other near the bottom). The top camera uses a fisheye lens and covers a wider view of the subjects and their surrounding. The bottom camera is used to help the tele-operator for obstacle avoidance and safe navigation. All camera images and audio data are transmitted to the tele-operator for efficient delivery of the prompts as well as for safe navigation.

*2) Software:* The control software is designed as a server-client model, where the robot PC hosts the server and the operator PC hosts the client side of the software. The client software provides a graphical user interface (GUI), as shown in Fig. 3, for the operator to remotely control the robot and to deliver prompts. The server transmits real-time camera images and audio feedback to the client with a transmission delay of less than 0.5 sec. The feedback images are shown on the right panel of the operator's GUI. The server also controls the *iRobot Create* platform using motion commands sent by the operator. The robot control interface as shown on the left panel of the GUI includes *Go Forward*, *Go Backward*, *Rotate Left*, *Rotate Right* and *Stop* motion commands. The operator can also use a combination of the motion commands to generate curvature in robot trajectories. The maximum speed of the robot is 0.5 m/sec.

The middle panel of the GUI shows a list of prerecorded audio/video prompts for the ADL tasks. It includes a set of general audio prompts together with task dependent audio/video prompts (see Section III-C for further discussion on prompts). This panel also includes the TTS field to generate additional online context-dependent audio prompts.

### E. INTERVIEW AND QUESTIONNAIRE

Each OAwD and caregiver was interviewed just after the two ADL tasks were completed. The interview was semi-structured and was intended to gather feedback on the following:

- Overall impressions of the system (e.g. how useful the prompts were).
- Engagement with the robot and prompts.
- Reliability of the system.
- Effectiveness of actions taken by the system, including movements, etc.

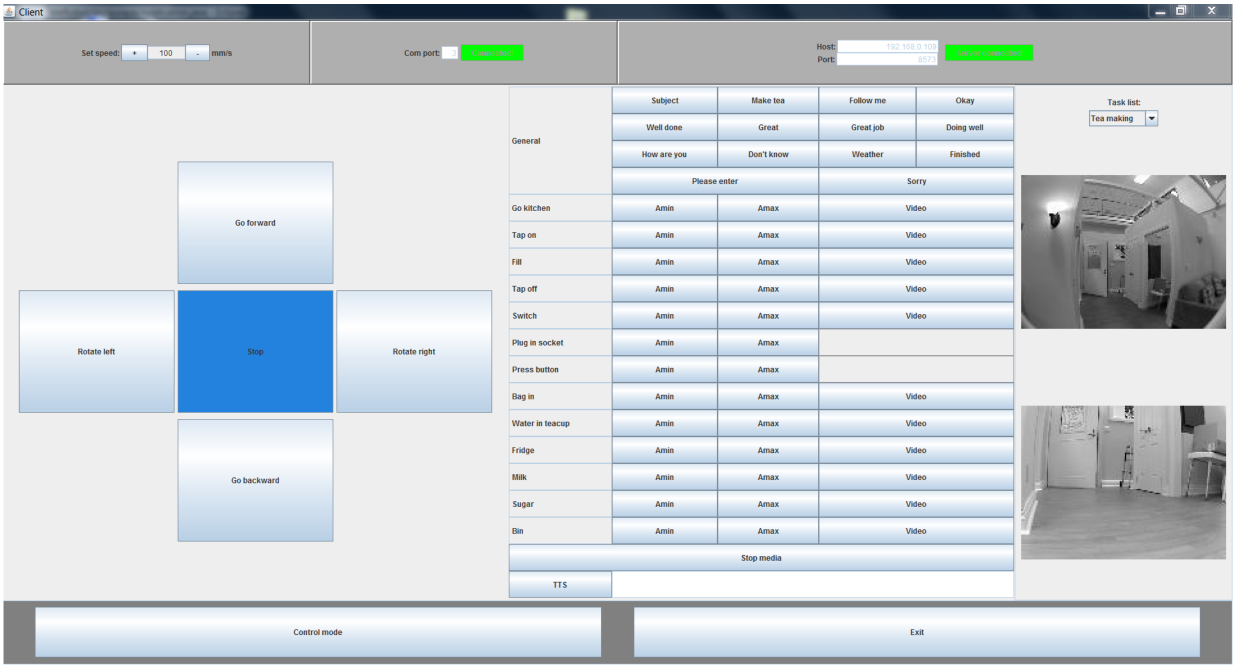



Fig. 3. Graphical user interface of the control software for the operator

- Other activities and tasks that could benefit from the system

The questionnaire consisted of eight Likert-scale type questions and was based on questions from the Almere Model Toolkit for measuring acceptance of assistive social robots [29].

## IV. RESULTS & ANALYSIS

Each experiment took approximately $2-2.5$ hours to complete. The videos of the experiment were manually analyzed by two of the co-authors to make *behavioral observations* (in reference to Table I) of OAwD during the tasks. The *behavioral observations* provide us with some quantitative measures of usability of the system. We also analyzed the interview videos of OAwD and caregivers to gain their feedback on the overall system. Using all these *usability* data we conducted a feasibility analysis which involves forming a knowledge-base regarding the following research issues.

| |
|---|
| *Feasibility of using a robot to help with ADLs* |
| *Overall acceptance of the robot* |
| *Physical attributes of the robot* |
| *Users' expectation from an assistive robot* |

### A. USABILITY ANALYSIS

*1) Effectiveness:* The metrics used for the quantitative measure of effectiveness, as introduced in Table I, are defined as follows (with respect to the tea-making ADL).

- Completeness of task: This indicates the percentage of the steps essential to make a cup of tea the was performed by the OAwD. A step is not considered to be completed by OAwD if he/she requires someone else's assistance (in addition to the robot prompts) to perform that step.
- Adherence to robot prompt: This is the percentage of the prompts delivered by robot that were followed correctly.
- Engagement with the robot: This indicates the number of times an OAwD interacted with the robot while performing the tea-making task. Examples of such interactions are looking at the robot's screen, smiling at the robot, talking to the robot, making hand gestures to the robot, and touching the robot.

Table IV summarizes the metrics for effectiveness of the assistive robot during the tea-making task.

TABLE IV
EFFECTIVENESS OF THE ROBOT DURING TEA-MAKING

| Subject | Total no. of steps | Total no. of prompts | Completeness (%) | Adherence % | Engagement |
|---|---|---|---|---|---|
| OA1 | 7 | 7 | 14 | 14 | 19 |
| OA2 | 7 | 3 | 100 | 100 | 5 |
| OA3 | 10 | 9 | 90 | 89 | 38 |
| OA4 | 10 | 4 | 100 | 100 | 28 |
| OA5 | 7 | 2 | 71 | 0 | 9 |

*2) Satisfaction:* We focused on the following three factors related to the satisfaction of the subjects with the robot: Ease of use (how easy the robot was to work with), Usefulness (was the robot helpful/useful to carry out the tea-making task?), Acceptance (would they use the robot again?). Two of the co-authors reviewed the questionnaires and recorded interviews of OAwD and their caregivers to collect information about these factors. Table V provides key examples of their responses. Depending on the level of dementia, some of

OAwD were unable to understand the questions and provided answers which were not relevant to the questions. In such cases the authors analyzed the interview as well as the videos of the tea-making task to extract their impression about the robot. Such an interpreted opinion regarding an issue is marked within parenthesis in Table V. A more detailed analysis of their general opinion about an assistive robot will be discussed in the following section.

TABLE V

A SUMMARY OF THE SATISFACTION RELATED TO USING THE ROBOT

| | Ease of use | Usefulness | Acceptance |
|---|---|---|---|
| OA1 | *[Not easy]* | *No* | *We do not need it* |
| C1 | *Very easy* | *Prompt is helpful* | *Will try again* |
| OA2 | *Very easy* | *Yes* | *Not now, may be in the future* |
| C2 | *Not difficult* | *Yes, good help* | *Sure, yes* |
| OA3 | *Pretty straight-forward, simple, easy to follow the instructions* | *Yes, clear instructions on how to do it* | *Capable of doing own ADLs, but for others it could be necessary* |
| C3 | *Good design* | *I think so* | *Yes, Absolutely* |
| OA4 | *Did not have to do much to use it* | *Yes* | *Oh, yes. later on I would like to have it* |
| C4 | *Easy* | *Yes* | *Yes* |
| OA5 | *Anybody can use it* | [Does not need help] | *[Liked the robot very much]* |
| C5 | *Easy* | *Yes, but the OAwD was not paying attention to it* | *Yes* |

## B. *FEASIBILITY ANALYSIS*

*1) Feasibility of using a robot to help with ADLs:* The tele-operated assistive robot was generally able to deliver the appropriate prompts to assist OAwD to complete the tea-making task. As the robot is at a very early stage of its development, it faced a number of technical difficulties throughout the study (e.g. interrupted communication between the server and the client). There were also operator errors while driving the robot and delivering the prompts. Apart from these technical glitches the system worked collaboratively with OAwD. Table V shows that most OAwD (three out of five) and all caregivers found the robot prompting to be helpful or useful. This is one indication of feasibility of this new method of prompt delivery. The HomeLab, where the study was conducted, resembles a regular home, which implies that use of such an assistive robot does not require any special environment. The robot used its mobility to suitably position itself for an improved perception of the subject's work area. Additionally, it used full body gestures to provide directions to the user. These functionalities are absent in static ADL prompting systems. Based on the experience gathered from this pilot study we can safely state that using an assistive robot to help OAwD for their ADL is feasible.

*2) Overall acceptance of the assistive robot:* Feasibility is merely the first criterion required for an assistive robot to be employed to assist OAwD in real life. The next most important factor is the acceptance of the assistive robot to the target users. This study provided us with some very fascinating facts about the acceptance of an assistive robot (in general as well as for the prototype robot) by the target user group. Usability data (Table IV) shows that three of the five OAwD had high adherence to robot prompts which is a clear indication of their acceptance of the robot as a helper during the task. Besides, almost all OAwD had some sort of interaction with the robot during the tea-making task. Three OAwD (OA3, OA4 and OA5) even engaged in a social conversation which was initiated by the robot. These serve as positive cues regarding the acceptability of the robot to OAwD. Apart from the numeric data of usability, the interviews with OAwD also show their positive attitude toward the assistive robot. Four OAwD (OA2 to OA5) personified the robot and mentioned that they treated the robot the way they would treat another person. OA5 even refers to the robot as her friend. Three OAwD (OA2 to OA4) mentioned that they trusted the prompts provided by the robot and thought that the robot could be reliable. All of these subjective observations made us believe that OAwD had some degree of general acceptance of the robot. When asked if they want such a robot at home, OAwD, however, showed interesting responses. OAwD (OA2, OA3, and OA5) who are living with a spouse thought that they do not need an assistive robot as they can perform ADL on their own. The caregivers of these OAwD, however, said that they help with ADL such as dressing or reminding for appointments. But OAwD did not rule out the possibility of using such a robot down the road if their dementia becomes more severe. They also expressed that the assistive robot could be helpful for persons who have physical disabilities and require more assistance. The only OAwD in this study who lives alone is OA4 and she showed a strong preference to have an assistive robot at home as she thought that a robot might help her to age-in place rather than move to an elderly-care facility. It is important to report that OA1, who had the lowest MMSE score among the participants, could not respond to most of the questions during the interview. She, however, expressed her opinion that she did not want a robot at home.

All of the caregivers were highly enthusiastic about the concept of an assistive robot and expressed their appreciation for this line of research. They appreciated the way the robot provided step-by-step guidance and thought that the video prompts can be very useful for OAwD. All of them were open to employing an assistive robot at home for the care of their loved one if a fully functional automated version is available. This complies with the fact that assistive technologies for OAwD have more chances of adoption if they focus on caregivers' needs in addition to the need of OAwD [30].

*3) Physical attributes of the robot:* During the interview we asked for the opinion of OAwD and their caregivers regarding the physical appearance of the robot (size, shape, face, and voice) and we received some valuable suggestions. OA1, OA4, and OA5 found the size of the robot too big while others did not comment about the size. The caregivers generally did not have any comment regarding the size. Three OAwD (OA3, OA4, and OA5) found the overall appearance of the robot very gentle and not aggressive. OA5 preferred the current animated face of the robot and OA4 found the animated face funny. The other OAwD did not have any comment about the face. Among the caregivers C3 suggested a very expressive baby-like face but C5 thought the animated face was a "happy face for a machine". Other caregivers did not have any specific disliking or suggestions about the face. The voice of the robot drew some criticism from both OAwD and their caregivers. OA1 found the voice noisy and her caregiver also suggested a softer voice. OA3 found the voice "clear and easy to understand" while his caregiver suggested a "more authoritative female voice with more emotion". OA4 as well as her caregiver also had a preference for a female voice. Caregiver C5 found the voice "comforting and not scary".

*4) Users' expectation from an assistive robot:* All the OAwD and their caregivers except OA1 expressed their desire to receive more services from an assistive robot in addition to prompts during ADLs. Although a majority of OAwD (OA2 to OA5) personified the robot, their expectations from an assistive robot were very realistic and geared to the needs of day-to-day living. For instance, a common expectation of OAwD as well as the caregivers was that the robot should provide automatic reminder of events (e.g. doctor's appointment, medication, garbage collection day, daughter's wedding) and activities (turning off the tv, closing the door, flushing the toilet, proper clothing sequence, etc). These are reasonable expectations given the nature of cognitive impairment in OAwD. Some of the participants expected different kinds of services from the robot. For instance, OA5 expressed her desire to have a robot that can perform household activities (cleaning, making a cup of tea, etc), OA3 talked about breakfast preparation by a robot, and finally C3 suggested that walking support from a robot could be a great help for people who have difficulties in walking. OA4 thought that the robot could be good company for her as she lives alone. Generally all of the participants (except OA1) liked the interaction capacity of the robot and OA4 enjoyed the humor of the robot. Most of the caregivers (C2, C3, and C4), however, found that the robot was slow in responding and should be able to match the interaction abilities and speed of the OAwD. C3 and C4 also emphasized that an assistive robot should have some sense of humor as demonstrated by the robot.

## V. DISCUSSION AND FUTURE WORK

It is recognized that the sample size for this pilot study is not large enough to make any final conclusion regarding the efficacy of the system but analysis of the data obtained from the study helped us to believe that assistive robots, if designed based on the users' needs, have enormous potential to contribute to the daily lives of OAwD and help them to age-in-place. It is also worthwhile to mention here that due to the special nature of the participants, it is hard to recruit participants for this kind of study. Almost all of our participants were positive about the overall idea of building an assistive robot to support ADLs of OAwD. They also provided us with valuable feedback. We will conduct the same study with five more OAwDs and caregivers. Based on the study data we will start the second stage of the design of the assistive robot. The next stage of development will focus on the following.

*Artificial intelligence:* Automatic delivery of ADL prompts (instead of tele-operation) is the first step of our future development. This involves designing highly sophisticated intelligent perception (step-by-step activity recognition for any particular ADL), planning and decision making modules (automated reasoning to trigger appropriate prompts based on recognized activity) for the mobile robot. We will modify our existing AI modules for the static COACH system to comply with the mobile robot.

*Human-robot interaction:* A human-robot interaction module will be designed to recognize the emotion of the user (e.g. facial expression, gesture) and to interact with them accordingly in a more human-like fashion. Our study data suggest that a socially interactive robot might have a higher degree of acceptance by OAwDs.

*Physical appearance:* Based on the users' feedback we intend to perform a few changes to the overall appearance of the robot which include using an animated avatar for speech delivery and using a low pitch female voice.

## VI. CONCLUSIONS

This paper describes a pilot study on the feasibility and usability of using a mobile robot to help OAwD in ADLs. Older adults have a strong preference to age in their own home but that is especially difficult for the people who have dementia. Different kinds of smart-home technologies are currently being developed to assist OAwD to age-in-place. No research, however, has been reported which uses assistive mobile robots to provided need-based step-by-step guidance to complete ADLs of OAwD. We adopt a user-centered design approach to develop this new piece of technology where we involve the end users (OAwD and their caregivers) from the very early stage. The pilot study described in this paper is the first stage of this user-centered design approach. We build a prototype mobile robot and tele-operate it to provide guidance, when needed, to a group of older adults while they prepare a cup of tea in the kitchen of a simulated home. Caregivers were requested to observer the whole process. We later interviewed OAwD and the caregivers separately to obtain their feedback regarding the current system and their expectation from such an assistive robot. Preliminary analysis of the study data made us believe that an assistive robot to help in ADLs of OAwD has enormous potential. Currently we are conducting the same study protocol with more OAwDs and their caregivers.. Our future goal is to automate the prompting system of the robot as well as incorporate the changes in the robot's software and hardware as suggested by OAwD and their caregivers.

## ACKNOWLEDGMENT

We wish to thank Colin Harry and Yani Ioannou for their technical assistance, Jennifer Boger and Dr. Goldie

Nejat for contributing to the design of the study, and Vara Parameswaran and Dr. Sharon Cohen at the Toronto Memory Program for their assistance in recruiting subjects.

## REFERENCES


[1] A. Morris, R. Donamukkala, A. Kapuria, A. Steinfeld, J. Matthews, J. Dunbar, and S. Thrun, "A robotic walker that provides guidance," in *Proceedings IEEE international conference on Robotics and Automation*, 2003, pp. 25–30.

[2] M. E. Pollack, L. Brown, D. Colbry, C. E. McCarthy, C. Orosz, B. Peintner, S. Ramakrishnan, and I.Tsamardinos, "Autominder: An intelligent cognitive orthotic system for people with memory impairment," *Robotics and Autonomous Systems*, vol. 44, no. 3-4, pp. 273–282, 2003.

[3] K. Z. Haigh, L. Kiff, J. Myers, V. Guralnik, K. Kirschbaum, J. Phelps, T. Plocher, and D. Toms, "The independent lifestyle assistant (ILSA)," Honeywell Laboratories, Minneapolis, MN, Tech. Rep. ACSPO3023, 2003.

[4] C. Kart, J. Kinney, L. Murdoch, and T. Ziemba, "Crossing the digital divide: Family caregiver's acceptance of technology," Scripps Gerontology Center, Miami University, Oxford, OH, Tech. Rep., 2002.

[5] M. Chan, H. Bocquet, E. Campo, T. Val, and J. Pous, "Alarm communication network to help carers of elderly for safety purposes: A survey of a project," *International Journal of Rehabilitation Research*, vol. 22, no. 2, pp. 131–136, 1999.

[6] M. Ogawa, R. Suzuki, T. Izutsu, T. Iwaya, and T. Togawa, "Long term remote and behavioral monitoring of elderly by using sensors installed in ordinary housing," in *Proceedings of International IEEE-EMBS special topic conference on Microtechnologies in Medicine and Biology*, 2002, pp. 322–325.

[7] T. Lee and A. Mihailidis, "An intelligent emergency response system: Preliminary development and testing of automated fall detection," *Journal of Telemedicine and Telecare*, vol. 11, no. 4, pp. 194–198, June 2005.

[8] J. Chan and G. Nejat, "Promoting engagement in cognitively stimulating activities using an intelligent socially assistive robot," in *Proc. IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM'10)*, Montreal, QC, Canada, July 2010, pp. 533–538.

[9] I. Siio, J. Rowan, and E. Mynatt, "Peek-a-drawer: Communication by furniture," in *ACM Conference on Human Factors in Computing Systems*, 2002, pp. 582–583.

[10] H. B. Jimison, M. Pavel, and J. Pavel, "Adaptive interfaces for home health," in *Proceedings of Second International Workshop on Ubiquitous Computing for Pervasive Healthcare Applications*, 2003.

[11] A. Mihailidis, J. N. Boger, T. Craig, and J. Hoey, "The coach prompting system to assist older adults with dementia through hand washing: An efficacy study," *BMC Geriatrics*, vol. 8, no. 28, Nov. 2008.

[12] H. Pigot, D. Lussier-Desrochers, J. Bauchet, S. Giroux, and Y. Lachapelle, *A Smart Home to Assist in Recipe Completion*. The Netherlands: IOS Press, 2008.

[13] S. Klemmer, B. Hartmann, and L. Takayama, "How bodies matter: five themes for interaction design," in *Proceedings of the conference on Designing Interactive systems*, 2006, pp. 140–149.

[14] S. Czarnuch and A. Mihailidis, "The design of in-home assistive technologies: Assessing the needs of older adults with dementia and their caregivers," *Gerontechnology*, vol. 10, pp. 165–178, 2011.

[15] J. Pineau, M. Montemerlo, M. Pollack, N. Roy, and S. Thrun, "Towards robotic assistants in nursing homes: Challenges and results," *Robotics and Autonomous Systems*, vol. 42, no. 3-4, pp. 271–281, 2003.

[16] B. Graf, M. Hans, and R. D. Schraft, "Care-o-bot ii - development of a next generation robotic home assistant," *Autonomous Robots*, vol. 16, no. 2, pp. 193–205, 2004.

[17] T. Shibata, "Robot assisted activity for senior people at day service centre," in *Proc. International Conference on Information Technology in Mechatronics*, Istanbul, Turkey, 2001, pp. 71–76.

[18] ——, "An overview of human interactive robots for psychological enrichment," *Proceedings of the IEEE*, vol. 92, no. 11, pp. 1749–1758, Nov. 2004.

[19] A. Tapus, C. Tapus, and M. J. Mataric, "Music therapist robot for people suffering from dementia: Longitudinal study," in *Proceedings of International Conference on Alzheimer's Disease*, 2009.

[20] A. Tapus, J. Fasola, and M. J. Mataric, "Cognitive assistance and physical therapy for dementia patients," in *ICRA Workshop on Social Interaction with Intelligent Indoor Robots*, 2008.

[21] M. Chetouani, Y. H. Wu, C. Jost, B. L. Pevedic, C. Fassert, V. Cristancho-Lacroix, S. Lassiaille, C. Granata, A. Tapus, D. Duhaut, and A. S. Rigaud, "Cognitive services for elderly people: The ROBADOM project," in *Proceedings of the European Conference on Cognitive Ergonomics, Workshop on Robots That Care*, Delft, The Netherlands, 2010.

[22] A. Tapus and M. Chetouani, "ROBADOM: the impact of a domestic robot on the psychological and cognitive state of the elderly with mild cognitive impairment," in *Proceedings of the Second International Symposium on Quality of Life Technology Intelligent Systems for Better Living*, Las Vegas, USA, 2010.

[23] A. R. A. Renteria, L. Martinez and J.F.Veneman, "Socially assistive robotics for welfare," in *euRobotics workshop on Robots in Healthcare and Welfare*, 2012.

[24] E. Lucet, "Social mobiserv kompai robot to assist people," in *euRobotics workshop on Robots in Healthcare and Welfare*, 2012.

[25] A. Bley and F. Wallhoff, "Alias - adaptable ambient living assistant," in *euRobotics workshop on Robots in Healthcare and Welfare*, 2012.

[26] Y. Wu, M. Chetouani, V. Cristancho-Lacroix, J. Matre, C. Jost, B. Pevedic, D. Duhaut, C. Granata, and A. Rigaud, "ROBADOM: an assistive robot for the elderly with mild cognitive impairment: System design and users' perspective," in *5th Companion Robotics Institute Workshop AAL User-Centric Companion Robotics*, France, 2011.

[27] M. F. Folstein, S. E. Folstein, T. White, and M. A. Messer, *Mini-Mental State Examination user's guide*. Odessa (FL): Psychological Assessment Resources, 2001.

[28] R. Wilson, E. Rochon, A. Mihailidis, and C. Leonard, "Examining success of communication strategies used by formal caregivers assisting individuals with alzheimers disease during an activity of daily living," *Journal of Speech, Language, and Hearing Research*, vol. 55, pp. 328–341, Apr. 2012.

[29] M. Heerink, B. Kröse, V. Evers, and B. Wielinga, "Assessing acceptance of assistive social agent technology by older adults: The almere model," *International Journal of Social Robotics*, vol. 2, pp. 361–375, Sept. 2010, doi: 10.1007/s12369-010-0068-5.

[30] S. Thielke, M. Harniss, H. Thompson, S. Patel, G. Demiris, and K. Johnson, "Maslows hierarchy of human needs and the adoption of health-related technologies for older adults," *Ageing International*, 2011.