Utilizing a Closed Loop Medication Management Workflow through an Engaging Interactive Robot for Older People

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***Abstract*—We describe an engaging interactive robot and the workflow design for incorporating such service robots in health care. The research is analyzing the long term usability of automated medication support for older people as they interact with a Stationary Robotic Medication Management System (StRoMMS). It delivers timely instructions and automated guidance as people take their daily medications in their independent living quarters in a retirement village. A pilot user study evaluated the hypothesized technological requirements of the robotic system and the clinical workflow requirements in the healthcare context. The novel contributions are our interactive robot and the workflow design. Following a "system of systems" design approach we determined that robots cannot work in isolation in a complex operational space such as healthcare. The value of introducing interactive robots in healthcare can be realized when the robot has interfaces with the healthcare system, which enhance the overall outcome and experience of the patient. Our research will inform the research community of the importance of the confluence of people, workflows and tools while designing healthcare robotics technology.**

I. Background and Introduction

Despite rapid advances in robotics and allied domains, there are few robots that are practically in use, especially in the healthcare context for older people. Medication errors [1] are a leading cause of hospitalization, morbidity and mortality, particularly in elderly [2]. Older people require additional support and error monitoring to improve the safety of medication use [3]. There are a number of potential dangers associated with medication errors which lead to *discomfort, adverse side effects, patient prolonged stay in hospital or change in health status* [4]. To address these issues a number of technologies and interventions have been designed. A classification and discussion of the state-of-the-art research in assistive devices to mitigate medication errors is mentioned in [5].

A. Related Work

Nursebot [6] and Pearl [7] propose functionalities to assist the elderly with service robots, however, they haven't particularly studied medication reminding for an interactive engaging robot that is collaborating in the clinical workflow. This makes our medication service uniquely different from other reminders. We want to utilize the human-like anthropomorphic form and function of robots such as **iRobiq-S**. It can be a powerful tool for engagement and persuasion, and a highly effective wellness technology for older people. The MIT Media Lab group has been developing social robots with applications related to healthcare and studies using a tabletop sociable robot have shown that behavior change pertaining to health and dieting can be achieved [8]. Virtual characters and embodied conversational agents have been proposed to promote antipsychotic medication adherence among patients with schizophrenia [9]. Table I summarizes some of the existing robots or software agents which have interactive applications for assistive purposes alongwith medication reminding.

This work was jointly supported by the R&D program of the Korea Ministry of Knowledge and Economy (MKE) and Korea Evaluation Institute of Industrial Technology (KEIT). [KI001836], Development of Mediated Interface Technology for HRI] and the New Zealand Ministry for Science and Innovation (13635). We thank the Electronics and Telecommunications Research Institute and Yujin Robot (South Korea) and our HealthBots research team.

II. Pilot study with **iRobiq-S**

1) Aims: The engaging interactive robot was designed and developed as part of a multi-disciplinary 'Healthbots' project at New Zealand Korea Centre for healthcare robotics, hosted within University of Auckland. The project provides a stimulating environment for the engineers and developers to envision futuristic robotics technology [11] while providing a platform to the healthcare experts to evaluate the technology in a real world scenario [12]. The robot used in the study is shown in Fig. 1. The **iRobiq-S** engaging interactive robot is

Fig. 1. iRobiq-S delivers timely instructions and automated guidance to an older participant

small in size, and measures 45x32x32cm. It weighs 7kg. The

Robot Name	Research Institution / Company	Robot Type	Primary Application
Pearl	Carnegie Mellon University	Interactive Mobile	Monitoring and recognizing an elder's activities
Chester	University of Rochester	Intelligent computer assistant	Dialogue systems for health communication
Waldo	UCSF Medical Center	Dispense pills to medical stations	Medication scheduling
HANC	Tevital Incorporated	Voice activated robot	Reminders for medication compliance
ConnectR	iRobot Corporation	Interactive Mobile	Visiting robot, operated by family and friends

TABLE I
EXAMPLES OF INTERACTIVE ROBOTS OR AGENTS WHICH ARE USED FOR MEDICATION REMINDER [10]

robot platform is capable of self navigation to any number of landmark targets and can intelligently avoid obstacles in its path. It has a Intel Core 2 Duo based internal computer for running its software. Physically, the robot has 2 arms which are used mainly for emotional interaction and gesturing. It is also equipped with a number of touch sensors at different locations of its body. This enables the programming of realistic responses when user, pat, tap, touch, or nudge the robot. It has a touch-screen LCD display in its body, which can be used to display menus [13]. Our aim is to investigate how the **StRoMMS** platform can facilitate safe and effective, evidence based medicine usage by older people living independently in a retirement village. The pilot study observed how people interact with an automated system in their living quarters for one week (on the kitchen bench or the dining table), how easy (or difficult) they find its use and what feedback they have to improve the design. Also of particular interest is any change in the user's knowledge and engagement with their medications, and the information collected through the regular monitoring of side-effects and therapeutic effectiveness of medication. The lessons learnt over iterations with a larger healthcare robot Charlie are documented in articles [3], [10]. Charlie is also a healthcare assistant robot and provides similar functionality to **iRobiq-S** in a larger form factor. **iRobiq-S** was used as a benchtop robot in apartments where space is a premium and so Charlie is inappropriate for 24/7 use.

2) Methodology: The robot was designed and developed as part of a multi-disciplinary team where robotics technology developers and healthcare Subject Matter Experts (SMEs) worked collaboratively to develop the technology and the experiment to validate the research hypotheses. The experiment design was based on the methodologies of Grounded Theory (GT) and Participatory Design (PD) within four Action Research (AR) cycles, the research elicited design implications and tested the design configuration addressing the unique task requirements. The methodology is described in greater detail in the paper by Tiwari [14]. The first AR cycle developed and tested a paper prototype and identified implications for software architecture and interface design. The second AR cycle observed residents interacting with a prototype and found them to be generally satisfied with it. The results informed further refinement of the prototype. A refined system in the third AR cycle led participants through a series of daily interactions, discovering a pattern of task mastery. The fourth and final AR cycle allowed older participants to independently use a robot within their apartments and is described in this paper. We performed the pilot user study in July 2011 with four participants using the robot in their apartments for one week each as shown in Fig. 2. Patients' records from computerized pharmacy systems were obtained, including the names of the prescribed drug(s), dosage, the quantity dispensed at each pharmacy fill and the dates of prescription fills. The data was entered into a web-based portal called RoboGen [10] before the deployment. These tasks were performed by qualified individuals from the School of Population Health. The **StRoMMS** system has two components, the interactive personal robot and RoboGen. RoboGen is an end-user programming tool for customizing patient medication data, personalizing the robot's dialog for medication, programming the side-effect questions as well as a portal for viewing the results [10]. The two systems communicate asynchronously. The robot application drives the interaction with the older people, whereas the web-centric RoboGen infrastructure brings in other clinical roles *to complete the loop* in the healthcare workflow.

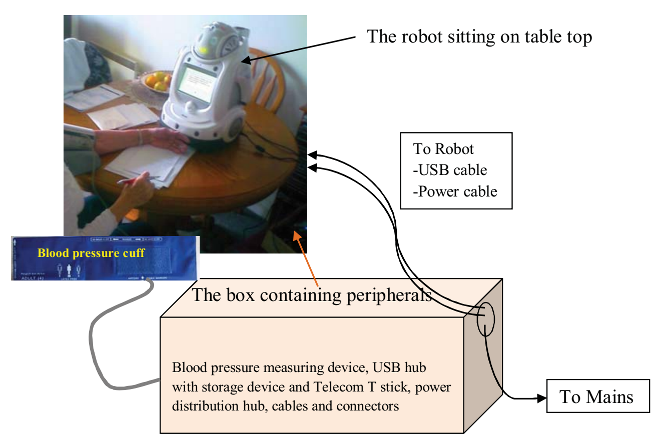

Fig. 2. Setup of the robot at older participants' independent living

III. CLOSED LOOP MEDICATION WORKFLOW

The concept of closed-loop medication workflow **(CLMW)** [15], [16] is associated with medication delivery mechanisms in hospital information systems (**HIS**). In the hospital scenario, the system comprises the following: a Pharmacy Information System (PIS), the Computerized Provider Order Entry (CPOE), bar code and the point of care dispensing device such as an automated drug dispensing cabinet. We have adapted the concept to an Aged Care Facility scenario with an interactive robot in the loop. **CLMW** in this context is defined as the actions taken by various roles in the workflow to perform tasks related to medication management to enable regular monitoring of medication intake and improve medication safety. Thus, enabling better coordination of tasks between the roles and a greater promise towards reducing medication errors while ensuring optimal compliance with medications. In an ideal medication workflow, the information flow needs to be seamless from a doctor's brain to a older patient's vein without handwriting, handoffs, or hassles [17]. However, due to real world problems which prevent such seamless co-ordination, our solution will aim at streamlining the workflow and in reducing roadblocks in the way of maintaining wellness and safety. Our system exhibits various features present in an **HIS**, and also presents extensions to support the elder-care context by enabling re-programming of the robot behavior by end users. The closed-loop system, as opposed to an open-loop stand-alone reminder was designed and applied in this study, where the robot could work in synchronization with a web-based system to enable real-time dynamic interaction with healthcare providers, caregivers and family members. With ever increasing access to web based systems, we provide multiple views of the robot's behavior to different users on different devices. As shown in Fig. 3 , the various roles in the workflow can access non-compliance alerts and updates through a visual dashboard from a portal.

Fig. 3. Various roles in the workflow can access alerts and updates through a portal across devices and remote locations

IV. Engaging Human robot Interaction

Studies at the MIT Media Lab have attempted to bring behavioral changes through human robot interaction using techniques of persuasion and engagement [18]. The studies have revealed that such interactions can bring about changes in various scenarios including healthcare. In our case, the role of the robot in the interaction is as an active agent engaging the older person while correctly scheduling the medication reminder event. As shown in Fig. 4, the robot sounds a reminder alarm bell and displays various behavioral emotional characteristics. Similar features are used in other studies with

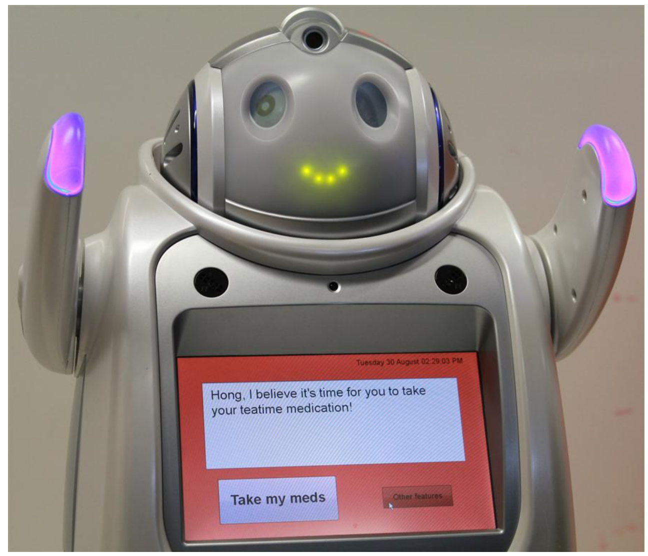

Fig. 4. An engaging interaction with body gestures of the robot

iRobiq-S for engaging children to learn [13]. We hypothesize that adding such social cues makes the overall interaction engaging for older people and encourages them to be an active participant in the interaction. The healthcare context in this interaction is patient empowerment [14]. Such engagement and ease of use will enable the patient to be a partner who has choices in any decision making about their medicines. Thus, the robot provides the advantage that the patient can manage their own health condition with remote support from healthcare providers. A systematic analysis of tasks for the robot to work autonomously in independent living quarters revealed the following requirements:

- **Refill reminders** : when to go to the pharmacy for a refill
- **Appointment reminders** : when to go to the doctor and get a new prescription
- **Customize preferences** : user should be able to change the following preferences
  - His/her preferred name (by which the robot addresses him/her)
  - Preferred clock time for ringing reminder alarm that could be different on different days of the week (e.g. to wake up later on a weekend)
  - Customize reminder dates

- **Call for assistance** : using a text messaging system to call for help if required
- **Recording medication intake video logs** : to be used as an objective verification of medication intake
- Easy user identification
- A feature so that medication education can be built into the dialogue process
- Ability for adverse drug effect monitoring/subjective symptom reporting

A part of the complex branching in the screen-flow presenting the dialogues for the interaction is shown in Fig. 5.

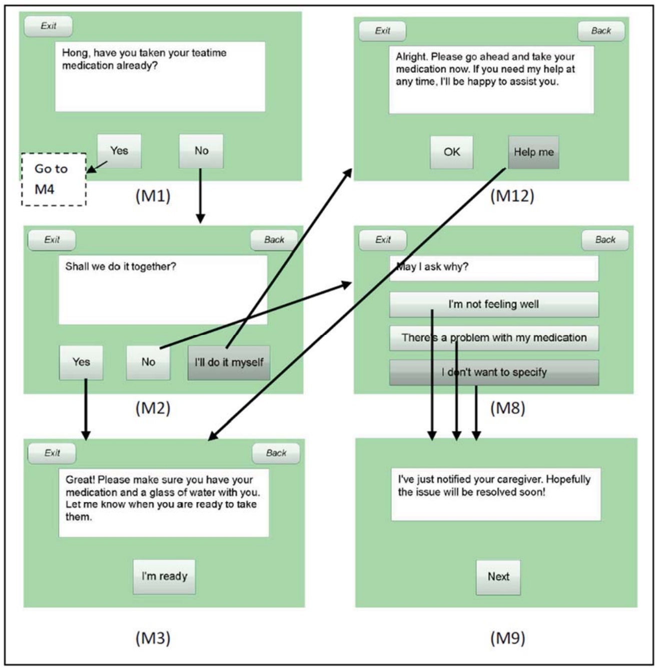

Fig. 5. Part of the complex branching in the screen-flow presenting the medication reminder dialogues

V. Formative Results

All participants completed the interaction sessions with the robot. The data from questionnaires, video records, researcher notes, and activity logs from RoboGen are being analyzed for more detailed clinical explanations of the risks and benefits found from the study and will be published later. The initial qualitative results from interviews with the participants has been positive. The low learning curve with a focus on ease of use ensures a high degree of adoptability from the older people. A dynamic and complex set of variables around medication use, possible error situations, need for personalization, need for patient education, monitoring of therapeutic efficacy and safety was unraveled. The resulting knowledge from this pilot study informed the design of a bigger trial to test clinical effectiveness of medication management support using robots in order to improve medication safety and quality use of medication in the elderly.

VI. Conclusion

There is immense potential for robotic technological innovation in healthcare and our current system design offers a clear roadmap for realizing that potential. The robot and RoboGen systems are synergistic and compliment each other extremely well. We aim to improve medication adherence, which in turn can contribute to lower healthcare costs and increased quality of life.

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