Comprehensive Support for Self Management of Medications by a Networked Robot for the Elderly

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Abstract

Quality use of medication by older people is becoming an important challenge with the demographic shift and increasing burden on our healthcare system. There is a significant emphasis on improving medication adherence as well as safety. We developed an automated dialogue system for residents of an Aged Care Facility (ACF) who were on multiple medications to help them manage their medications better. The dialogue was delivered spoken as well as via a written display over a touch screen mounted on a robot. Each session assisted the identified users in finding the right medication, and taking the right dose at the right time through the right route. It also included dialogues on side effects monitoring and other essential drug information. The data on the robot were exchanged wirelessly with a remote health record (called Robogen) in real time. The sessions were video logged, researcher notes and semi-structured interviews were conducted to elicit acceptance and usability information. Six participants interacted over a two-week period. Most users found the system easy to use and helpful and demonstrated evidence of task mastery by the 3rd or 4th sessions. We conclude that such a system can be used to enhance quality of use of medication by the elderly, but we need to better understand and address user behaviour while designing such system.

1. Introduction

Improving adherence to prescribed medications has received wide attention in recent years. A Cochrane review on interventions for helping patients to follow prescriptions for medication claimed: “increasing the effectiveness of adherence interventions may have far greater impact on the health of the population than any improvement in specific medical treatment” [1, 2]. However, the issue becomes more complicated in elderly populations, where many suffer from more than two chronic conditions and are on 5-15 long term medication at any given point in time [3]. Factors including larger numbers of medications, complexity of regimen, declining cognitive abilities and sensitivity to medications not only makes it difficult for the elderly to adhere but also makes them prone to adverse drug events [4]. Studies have shown that a large number of older people are admitted to hospital every year as a result of problems with the use of medicines, including adverse reactions [5]. Many national policies around safe medication use, assert upon building a base of informed consumers that can actively share responsibility for quality and safety, instead of exclusively relying upon healthcare providers [6].

Taking medication typically involves the use of prospective memory where an intention to perform a certain task in future is encoded, followed by an action at an appropriate time [7]. With erosion of memory the intention to take medication can be supported by external cues in the forms of calendar charts, reminders and alarms [2]. Such reminders may achieve higher adherence to a regimen but still fall short on safety issues. Enabling older consumers with an ability to appreciate proper use of medications, over the counter medications, nutritional supplements, occurrence of side effects, adequacy of symptom control and reporting them in a timely and appropriate manner – remains to be resolved. Unsurprisingly, standalone adherence-improving interventions for older people, have failed to offer any significant improvement on hospitalization and mortality [8].

Therefore, promoting quality use of medication requires a multidisciplinary approach that should ideally include not only reminders targeted at adherence, but also address medication safety, provide motivation, build skills and improve communication between patients and their providers [9]. A wider approach could have an incremental influence for improving outcomes for this vulnerable population. Existing interventions that are predominantly alarm based reminders or one-off sessions with a healthcare provider fail to provide this comprehensive support, leaving scope for exploring innovative approaches to medication management.

Incremental burden of care, in face of shrinking health workforce, supports the case of process automation. Automating communications in healthcare has received some attention; and building of automated dialogue engines that deliver healthcare messages over phones, as text messages and variety of other platforms, has been well researched [10, 11]. However, there has been little research on use of such systems to assist older people to execute complex self-care tasks such as medication management. Moreover, an ideal platform to deliver these messages has not yet been established. Recently social robots have been suggested as a possible information delivery platform for the elderly [12]. The mobility, anthropomorphic presence and physical capabilities of the robot could add further enhancement to the overall user experience with healthcare assistance [13].

The authors have been developing a robot mounted interactive automated dialogue system targeted towards older users that takes advantage of human robot interactions to present an intelligent reminder with safety protocols. Earlier studies have looked at wider implications, and analyzed the development and testing of the system, the design details and results of which that have been presented elsewhere [14-16]. This paper presents the results of the third action research cycle in an ongoing study. This study crafted the medication management module to include medication safety dialogues (side effect monitoring and medication education) and programmed it to sit alongside other services (those included tele-monitoring of vital signs, cognitive training exercises, entertainment and video communication modules).

2. Methods

This mixed method qualitative study leaned upon Action Research paradigm supported by Participatory design and Grounded Theory principles to triangulate data from multiple sources like questionnaires, transcribed interviews, field notes and video records to arrive at conclusions. Action Research is a research paradigm that involves iterative cycles of planning, action taking, evaluating and reflecting to arrive at successively refined learning [17]. It permits use of qualitative and quantitative tools that assist the researcher in arriving at a comprehensive understanding of the situation and design implications in the real world. AR has been useful in exploratory phase of research where establishing the validity of design prototype is sought in early stages [18]. Once the design gets validated, then in later stages, it might be exposed to a quantitative positivist analysis including controlled trials. The design principles and observations made during evaluation of design are presented below.

2.1. Design of the Medication Management Module

A novel system was designed to enable role based end user programming and complete a Closed Loop Medication Workflow between prescriber and consumer. Contrary to standalone medical devices or software agents, we contribute an architectural style based on a set of constraints towards a complex system which is web centric and fits a more heterogeneous clinical environment comprising of clinicians with different requirements from the robot. We envision that in doing so, we would be able to keep the Closed Lops Medication Workflow, agnostic to any particular robot or hardware per se, and our style of design will enable seamless integration between the platform software and the robot's interaction software. A more detailed description of the closed loop medication workflow and software platform design including a video demonstration has been submitted elsewhere [19, 20].

Figure 1 below shows the design overview of the networked robot where the touch screen on the robot served as the user interface hosting the Medication Management Module (MMM), developed in a previous action research cycle of a large health robotics project. This communicated over the web with a secure server, hosting the medication information repository and prompts to guide robot behaviour (The web based service engine is called Robogen). An automated dialogue system using the touch screen served as a backbone for delivery of a comprehensive multi-component support for self management of medications, namely:

- Medication administration prompt
- Querying symptoms and side effects

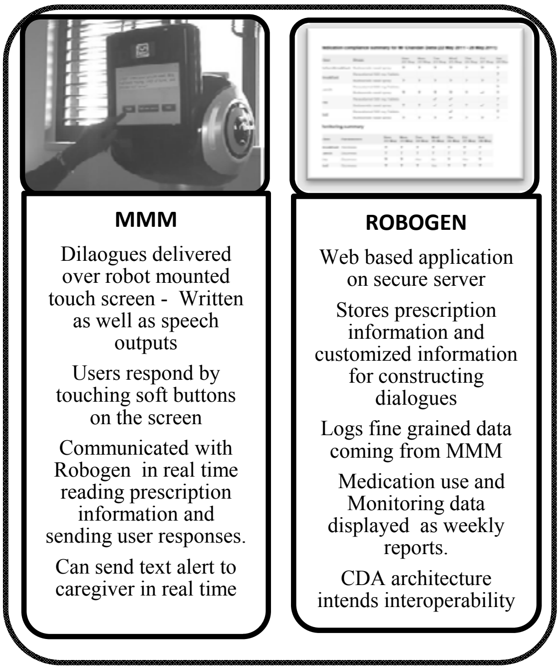

Figure 1 - Conceptual Design

- Drug information & tailored education
- Alerts and call for assistance
- Vital signs monitoring
- Cognitive training

The robot self-initiates at a clock time programmed as a preferred reminding time. Thereafter it seeks user attention and identifies the user by face recognition or asking the user to identify themselves. On successful establishment of identity the MMM is invoked which contacts the Robogen server to upload the list of medications scheduled for that time (Breakfast, Lunch, Tea or Bedtime) and initiates a reminder dialogue.

The system could elicit and report users' absences, skipped doses, and choices of taking or not taking medications, associated symptoms or occurrence of adverse events. MMM sends this information through a wireless connection to Robogen in real time. Robogen's reporting screen is able to automatically populate patient compliance records and other critical information in an easy to view tabular format. Simultaneous display of weekly logs along with symptom and monitoring data intends to support appropriate clinical decision making. In instances of the patient not responding or deliberate non-adherence, adverse event reporting or failure to follow the dialogues, the system gives feedback to the patient and notifies the selected caregiver through an instant mobile text message.

The complexity of converting a plain prescription into a meaningful dialogue in the language that a lay patient can understand was a complex task. Figure 2 below attempts to briefly illustrate our efforts in designing Robogen that could achieve this objective to a great extent.

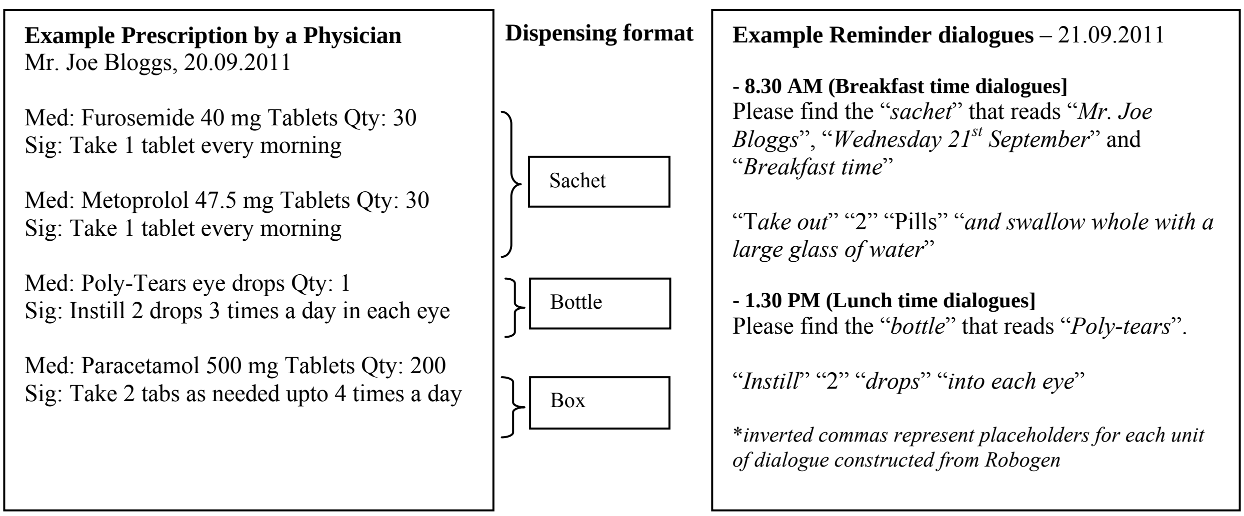

Figure 2 - Converting prescription into meaningful dialogues

Figure 3 - Dialogue sequence

Prescription data including patient's NHI is populated into Robogen and missing fields relevant to utterance of meaningful and correct dialogues are completed. Thereafter the users can see the same on their personal robot's screen, where they can confirm the medication list and alter their preference for reminder timings and appointments with doctor and/or pharmacist. The known side effects of prescribed medications are listed and prioritised according to severity, expected frequency and interactions with other medications and/or clinical conditions or co-morbidities. The side effects can be queried in different ways at a desired interval. The medication education module was designed as per WHO guidelines [21] and the information was simplified to improve ease of understanding. At each instance of interaction, the medication related dialogue set consisted of sequential display of information shown in Figure 3.

2.2. Evaluation of the Medication Management Module

This study was conducted at Selwyn Village, a residential care facility in Auckland housing over 300 elderly residents. Ethics approval was obtained from the institutional committee. To address issues related to this patient population, we conducted a formative evaluation to assess patient acceptance and feasibility of the application. Independent living residents at Selwyn Village were invited to participate according to theoretical and convenience sampling. Six residents consented to participate. Robogen was tested over a two-week period, according to the following steps.

1. After consenting to participate, residents completed a questionnaire about medication management.
2. Participants' health records and latest prescription information were obtained from their GPs and designated pharmacies and their facial images were recorded for the purpose of face recognition.
3. The robot and the researchers visited the participants' living apartments each morning at a time selected by the participant, for 5-7 mornings. The first visit consisted of a demonstration and familiarization session, in which the participants were encouraged to learn to use the robot with minimal assistance.
4. At each session the robot offered medication assistance, monitored vital signs and allowed them to use other features.
5. At the end of the trial period, the participants were asked to complete a second questionnaire and participate in a semi-structured interview.
6. Throughout the trial period, the researcher video-recorded each medication session and made field notes. Robogen activity logs were recorded for analysis.

The data from the interviews, questionnaires, video records, researcher notes, and activity logs from Robogen were analysed.

3. RESULTS

Participant profile: The age of participants ranged from 83 to 92 years with a mean of 86.6, out of which 50% were males and 50% females. Half the participants used pill boxes to organise their medications while others used loose pills. One participant who did not complete the study was on sachet based compliance packaging. None of the participants received personal assistance from a caregiver for supervised administration of medications.

Table 1 shows the results of video analysis. The users could interact with the robot on an everyday basis including the weekends. However most participants opted out during weekends or on the days when they had other social commitments, logging 7-9 days of interaction out of a total of 14 possible. This could be because of the formal nature of the trial where two to three researchers would approach their apartment at a scheduled time, making them feel obliged to interact; however, we are not sure how events would have turned out if the robot stayed within their apartments. One participant discontinued the trial after 5th day due to aggravation of a health condition, which was unrelated to the intervention. Out of a total of 45 interactions logged, 42 were successfully completed. In 3 unsuccessful instances the participants had already taken their medications as usual without waiting for the robot to arrive in the morning. On assessing the relationship of displayed instructions to user behaviour, 43 out of 45 instances of interaction, the users interpreted instructions correctly and responded appropriately. On one occasion the participant felt confused between "*take your medication*" (took them in hand) where the instruction was meaning 'swallow the medications'.

Table 1 - Results of video analysis

User No.	Total No. Of Interactions	Success of medication intake (out of total no of interactions)	Appropriateness of dialogue to actual activity	Backtracking, getting stuck or needing help	Response to side effects question	Medication information accessed / demonstrated	Non-technical errors observed at any point
1	9	9/9	8 †	day 1		1	1‡
2	5	5/5	4§	day 1, 2,3	1	1	
3	8	8/8	8	day 1		1	
4	8	8/8	8	0		1	1‖
5	7	6*/7	7	0		1	
6	8	6*/8	8	day 1		1	1¶

**Had taken medications before our arrival*
†Error in capturing "before breakfast" medication
§Unclear instruction when to swallow pills

‡ Loose medication was found in the pillbox,
‖ We missed to record supplements,
¶Prompted name of brand was different

On another occasion, the participant had taken some morning medications 'before breakfast' on an empty stomach, whereas the instructions on the robot assumed that all morning medications are always to be taken 'after breakfast'. The participants had some difficulty in the first day of interactions where they were not sure how or which button to press and the researcher had to prompt them, but they were able to use it successfully without prompting from the next day onwards, except one participant who struggled due to physical limitations (severe arthritis of fingers) and lack of confidence and prematurely dropped out of the trial. Out of 45 interactions, queries for side effects were raised 15 times (as it was programmed to ask every 3 days) and only one instance of side effect was reported (in the patient who was struggling). This person with an unstable clinical condition might have benefitted from closer monitoring but unfortunately was finding it too challenging to use this technology.

While mapping the correctness of medication information shared with the participant during the trial we observed that people change their medication organisation: sometimes keeping them in the bottles, and putting them in pill box at other times; brand names of dispensed medication change; and people start and stop nutritional supplements on their own, making it difficult to automate dialogues correctly every time.

Analysis of psycho-motor performance during the trial showed that most participants progressively improved the speed of task completion, except the one that continued to have problems and dropped out of study. 5 out of 6 participants showed a sign of task mastery, by anticipating instructions and jumping ahead of task by pressing the response button even before the dialogue was finished. It took them anywhere from 2-4 sessions to master the task and predict the behaviour of technology. This could be explained by our selection of relatively capable participants, whereas the system was designed to take cognitively challenged people into account. However, in further iterations of the design we would need to offer brief and crisp version to suit octogenarians who are still sharp and easily master basics.

The participants were served a questionnaire at the end of the trial and an interview conducted. The table 2 summarizes the response to questionnaire. At the end of each session the participants were asked to rank the experience as one of four options displayed on the robot screen (1= Poor, 2= Average, 3= Good and 4 = Excellent). In Figure 4 it can be seen that user ratings improved as the task was mastered and people felt more confident and comfortable using the system after 2 - 4 interactions.

During a brief interview the participants shared their enthusiasm and concerns about the robotic reminder system. Most of them were very positive and supportive of the idea, however some expressed concern about abilities of their colleagues who are cognitively challenged, to be able to use such a system. On being informed about the medication education available as a choice, one participant said:

> *"I have enjoyed it immensely-cannot speak too highly of its wide applications, and am desirous of having one myself. For me a brief reminder would be sufficient, but I am not sure if Mrs. …. Living next doors would make much sense of it".*

Other participant expressed regret having missed out on medication education module:

> *"I thought it was quite well done- but I missed to find out more about the actual medications, that would have been helpful if I knew it was there".*

Table 2 - Questionnaire responses

Question	Yes	No	Not sure	Other	Researcher Comments
Was your prescription information on the robot correct?	5	0	1	0	Participant on Sachets have many pills packaged together and find it difficult to remember and correlate
Did you access educational details about your medications on the robot?	0	6	0	0	None of the participants remembered having accessed medication education module despite being demonstrated in the beginning and therefore unsurprisingly did not find it useful.
Did the robot have correct educational information about your medications?	1	0	5	0	Most participants did not access the details despite being available as an option, hence unsure about it.
Did the robot help you to remember your medications	0	6	0	0	When one is prepared to receive visitors and a robot, little chances that they will forget. Anyways, the participants were independent living people who were managing themselves without reminding.
Did the robot ask you about the side effects of your medications?	1	5	0	0	Despite being asked on multiple occasions participants did not remember it. Perhaps because we did not specify this was a side effect question.
Did you find the side effect monitoring questions helpful?	1	0	5	0	Since most of the participants did not acknowledge remembering it they were not sure about its helpfulness, but the one who remembered it found it helpful
Would you like to change the number of steps or instructions being given in medication management module?	0	6	0	0	The participants thought this was an appropriately delivered content

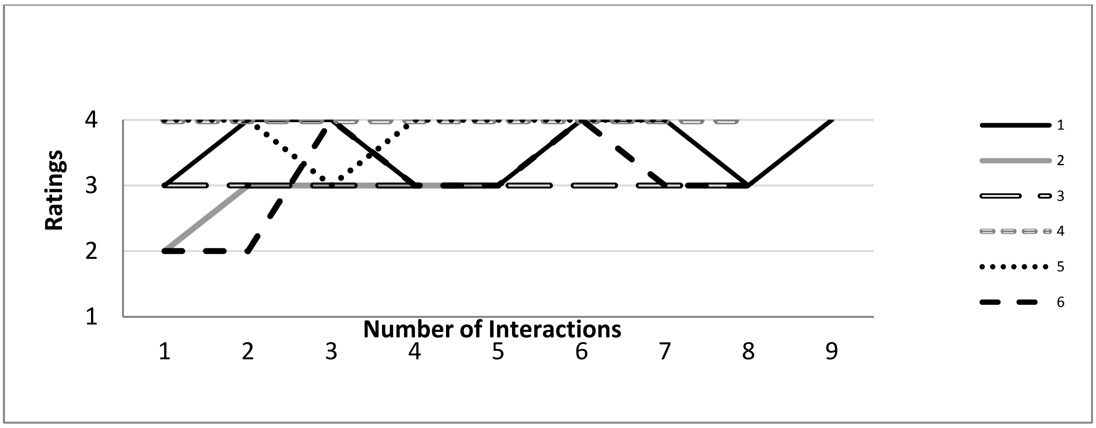

Figure 4 - Graph of user experience rating (1= Poor, 2 =Average, 3 = Good, 4 = Excellent)

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The physical limitation poses a challenge while expecting older users to perform challenging tasks like typing on a virtual keyboard. Sometimes users needed to identify themselves by typing their names in case facial recognition failed. But in this trial we learnt that it was not a good idea to offer face recognition in varying light conditions indoors.

> *"Entering my name was hard on the robot as my hands are shaky".*

The participants appreciated the fun and novelty of an interesting gadget that temporarily took away their monotony of living in a rest home. However how long this novelty factor would last is subject of future research.

> *"My grandsons think it's a hoot that grandma's doing robot research. I found it quite entertaining, and looked forward to the visit each morning".*

4. Discussion

The use of medications is a highly personalised activity. In contrast to the doctor's precise instructions on the prescription, the patients discover their own way of internalising those instructions and personalise their medication administration behaviour around their lifestyle and capabilities[22]. Moreover, the medications keep changing with progression of chronic conditions and their complications, and people's capabilities change and the way they organise their medications changes as well (e.g. pill boxes or sachets or loose). Medications have different forms (tablets as strips or in bottles, as drops, patches, inhalers, liquids and so on), they have different doses at different time of the day, and may have preconditions (e.g. after meals or on empty stomach) to name just a few variables. Mapping these variables onto an automated system and introducing a complex technology in that environment with an assumption of matching prescriber's instructions and predicting patients' behaviour could be extremely frustrating. Despite multiple iterations earlier we further discovered new issues that need to be corrected in our design. It may not be difficult to envisage how any attempt to directly transfer prescribed information from CPOE or PHR to patient compliance system, ignoring this complexity, would bear a high risk of failure. In the system presented here the two aspects of patient instructions and physician prescription were separated into two interdependent modules to handle the complexity. MMM that was hosted on the robot's touch screen mapped the user preferences allowed users to customise the instructions according to their preferences. Whereas 'Robogen,' which was on a remote server, coded the healthcare provider domain of mapping the prescription, drug information etc. such that the patients could see but could not change.

This study represents an early phase of iterative development and testing of a novel intervention. It explored whether such a system could: (a) successfully match the prescribed information entered in Robogen with patient activities on ground and (b) can the patients actually use the robot featuring an automated dialogue system. The results positively supported these expectations. The prompts were correctly delivered while being sequentially relevant and contextually appropriate, and most participants with an average age of 86.6 years successfully completed interactions with the robot mounted touch screen presented to them. The web based Robogen component correctly collected and displayed the session outcome logs as intended.

Generally the user liked the system and enjoyed interacting with it; and the time to complete the module drops indicating building of skills and task mastery. One user who was struggling from the beginning found it harder to cope because of her worsening clinical condition. She prematurely dropped out from the study. This observation could indicate that clinically fragile patients would probably need longer support and encouragement to gain enough confidence and skills to be able to use the modules successfully and independently.

We also learned more about the participants' inclination to access medication education and essential drug information: which is not actively sought after by patients, and there is scope for making it more expressive. The assumption that older patients tend to have more symptoms and side effects and that asking them about symptoms and side effects could overwhelm them was not held valid in the study, possibly because the participants in this study were more self-reliant and proactive, but that needs to be studied further.

The results of this research are limited by lack of baseline data about user's capabilities and performance of self-medication management. The study is also limited by its small sample size and lack of control group, because the intention was qualitative evaluation focusing more on eliciting implicit requirements rather than establishing efficacy. Moreover, most of these participants were capable enough to handle themselves even without the intervention. The next action research cycle examines longer-term use of the robot without as much direct supervision by the researchers. The next cycle would incorporate lessons learnt here and include more participants that are challenged cognitively.

5. Conclusions

In context of collaborative medication management, separating the patient interface from the provider interface, yet keeping them linked, seems to be a good way to reconcile flexible user preferences with the prescribed regimen. Ability to complete the interaction and reporting high user friendliness of the system supports our hypothesis that older people can successfully navigate through a touch screen based system to assist them with a complex self-care task such as medication administration. There has been a debate as to whether to inform patients about side effects or medication details. In this study we showed that is possible to unobtrusively query clinically relevant symptoms and side effects to gauge adequacy of symptoms control or early identification of adverse drug event, without raising patient's anxiety. However, we learnt that merely providing an option to access drug information may not be the best way to build medication knowledge and skills in older people. They seemed to be interested in knowing more about their medications, and could be helped by personalised dialogues more effectively than being given option of reading generic leaflets.

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