End User Programming to Enable Closed-loop Medication Management Using a Healthcare Robot

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Abstract
Developments in healthcare delivery systems are focusing on improved quality of care and patient satisfaction. Automated medication management on a mobile service robot is part of our interdisciplinary Healthbots research project, and has the potential to address both areas. The robotic medication reminding system is the result of an analysis of the workflow in medication management and a systematic application of the workflow to an interactive mobile robot. The robot is being evaluated to develop a better understanding of the technology required to address the safety and adherence issues of medication management for seniors living independently in a retirement village. Medication data and instructions presented during interaction need to be programmed by end users according to the medication. Changes such as the schedule, the names of drugs, and constraints in taking the medication, are periodically updated by the caregiver after the medication is prescribed by the doctor and dispatched by the pharmacist. This paper presents an analysis of the end user tools and the software architecture essential to complete this medication workflow. Initial prototypes of the software were used in a pilot study at a retirement village. The pilot system can support the quality of care provided to the older people and prevent medication errors. The contribution the paper is a new analysis and novel design for enabling role based customization for robotic medication reminding. These contributions will assist in the technical decision making of developers involved in implementing service robots for similar tasks.

1 Introduction and related work
Medication errors are one of the leading causes of morbidity and mortality amongst older people [Sokol et al., 2005; Ryan, 1999; Higgins and Regan, 2004]. Many medication safety related issues arise due to gaps in the sharing of medication-use information amongst prescribers, pharmacists, individuals and caregivers. Interactive assistive technology can aid evidence-based safe medication administration by providing decision support to prescribers and by bringing doctors and pharmacists to the same common understanding. It can also enable caregivers and family members to monitor medication regimes and actual medication usage by elders and thus providing an opportunity to prevent potential medication errors. The medication management module in the “Healthbots” project aims to reduce non-intentional non-compliance among the older people by promoting patient-centered care, empowerment and autonomy through the use of a social robot. Social robots offer a unique opportunity to add an interpersonal element to inform, empower and support older users. The persuasive behavior of a social robot tends to promote self management of health in older people [Looije et al., 2010]. The main causes for older people not complying with their medications [Lowe et al., 2000; Ryan, 1999; Hughes, 2004] are:

- Forgetfulness, the older person does not remember to take their medication
- Change of medication schedule
- Confused by overwhelming number of instructions
- Overwhelming number of medications
- Taking medication at wrong times
- Confused by names of medication

The organization of the paper is as follows. The background and definition of the problem are presented in section 1 along with a brief literature review and existing solutions. Analysis of the context of the robot in the aged care facility is presented through the description of two field trials. The concept of closed loop medication workflow was introduced in trial 2 and is described in section 2.4. Our software architecture is presented in
section 3.1 using UML diagrams shown in figure 6 and figure 4. Finally, the resulting software prototypes are presented in section 4. The software developed is shown in figure 1 with the robot in the background.

![Figure 1: Robogen running on Ipad](image)

1.1 Related Work

Many solutions exist on the market today to tackle issues related to medication compliance [Corlett, 1996]. Medical device based solutions can be placed in categories such as pill holders, alarm based pill holders, and pill monitoring devices [Qudah et al., 2010]. Pill holders are passive solutions. They are designed as boxes or containers to carry medications. Usually they are divided into different compartments. The medication is loaded manually in the compartments. The compartments can be labeled for each dosage interval. Alarm based aids [Systems, 2011] are active solutions. Some of these devices consist of compartments to carry medication attached to a timer. When the medication is due, an alarm is triggered. Pill monitoring devices such as Med-eMonitor [Naditz, 2008] are home-based medication devices which are sealed. They dispense medication and some of them have voice and text alarms. They can be connected to the internet and alert the patient/caregiver via mobile phone if a dose is missed. The iMec dosing medication monitor [Suzuki et al., 2010] uses sensors and fuzzy inference methods for correct medication delivery.

The system is composed of an intelligent medicine case, house-embedded sensors, and a database server. By estimating present living conditions from the sensory data, the iMec can confirm the dosing [Suzuki and Nakauchi, 2009]. iMec can also recognize whether an elderly person has picked up correct medicine from its storage space to confirm the quantity of dosing. While a lot of older people still wouldn’t use PDAs and mobile phones, however mobile phone based solutions [Qudah et al., 2010] [Dean, 2005] are available to those who are willing to enter their medication manually into the mobile phone or PDA and set the dosage and reminders. Two commercial solutions are pillPAL and OnTimeRx [Torrico et al., 2005]. With these applications medication compliance data is not transmitted to health professionals to monitor patient’s compliance. They focus on improving adherence but do not attempt to measure quality use of medication in relation to its desired or undesired impact on disease and patient safety. While applications for storing, dispensing and context aware reminding have been developed, none of them brings collaboration between patient, pharmacist, caregiver and doctor.

The second kind of solutions are software based on personal health portals. Two major commercial products are Microsoft HealthVault and Google Health [Siek et al., 2009] [Steinbrook, 2008 (which has merged to HealthVault)]. Microsoft launched HealthVault [Microsoft, 2011] to provide users a centralized place to track health information, prepare for health professional visits, manage health-related devices (e.g., participating blood pressure monitors), and utilize third party health services to share information and receive personalized feedback. Its suitable when people want to manage their own medication list over a web application. Medication list management includes viewing, deleting, and adding medications. The web application also prominently displays sharing functionality.

Interactive robots have not been studied to this detail in the literature yet. Experiments presented in preliminary works [D’Este et al., 2008] [Takacs and Hanak, 2008] [Takahashi et al., 2006] [Takahashi et al., 2002] have not mentioned the clinical context which needs to be incorporated to make the deployment of the robot successful in the real world.

Table I summarizes some of the existing robots or software agents which have interactive robot applications for assistive purposes.

2 Evolution of system requirements

The development of the mobile robot medication reminding requirements is documented in this section, as it evolved from analyses and practical studies.

2.1 Field Trial 1 design and findings

Research findings [Tiwari et al., 2010] by our health informatics team at the School of Population Health, University of Auckland revealed the requirements of an autonomous robot that could facilitate medication data sharing for elderly people in aged care facilities. Following that research, a pilot field trial was conducted [Tiwari et al., 2011b] at the aged care facility. The aim was to assess the usability, feasibility and appropriateness of a medication management support system on the health-care robot system. The robot could provide the patient with reminders to take their dispensed medications and engage in dialog to collect information about any issues
<table>
<thead>
<tr>
<th>Robot Name</th>
<th>Research Institution</th>
<th>Robot Type</th>
<th>Primary Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearl</td>
<td>CMU</td>
<td>Interactive Mobile</td>
<td>Monitoring and recognizing an elder’s activities [Dishman, 2004]</td>
</tr>
<tr>
<td>Chester</td>
<td>University of Rochester</td>
<td>Intelligent computer assistant</td>
<td>Dialogue systems for health communication [Allen et al., 2006]</td>
</tr>
<tr>
<td>Waldo</td>
<td>UCSF Medical Center</td>
<td>Dispense pills to medical stations</td>
<td>Medication scheduling [Yeh et al., 2007]</td>
</tr>
<tr>
<td>HANC</td>
<td>Tevital</td>
<td>Voice activated robot</td>
<td>Reminders for medication compliance [Warner, 1998]</td>
</tr>
<tr>
<td>ConnectR</td>
<td>IRobot</td>
<td>Interactive Mobile</td>
<td>Visiting robot, operated by family and friends [Daniel et al., 2009]</td>
</tr>
</tbody>
</table>

Table 1: Interactive robots or agents which are used for assistive purposes

![Diagram](image)

Figure 2: Robot medication management field trial workflow

that may be inhibiting adherence to the medication plan. The software components to complete the workflow are shown in figure 2.

In the observational study, a small sample of residents were involved to provide feedback. The following results were concluded from a post interaction questionnaire and structured interview:

- The current state of the art for talking pill boxes or automated dispensers is not sufficient to enable engaging interaction, provide detailed instructions/education, invoke affect and social support, build trust by addressing safety, troubleshoot errors, and report and call for human help in real time, which many older people often need.

- By virtue of its mobility, anthropomorphic presence, wireless connectivity and an empowering mixed-initiative user interface, a robotic platform offers potential opportunities that were not previously possible using simple standalone reminder devices and pill management systems.

- The use of a touch screen interface supported a well structured dialogue sequence that enabled timely and personalized medication reminding.

![Diagram](image)

Figure 3: Layered software components for the medication workflow

2.2 Motivation for a portal to enable End User Programming

RoboGen [University of Auckland, 2011] is a web-based application available 24 hours, 7 days a week through any browser. RoboGen enables End User Programming (EUP). EUP trades the expressiveness of programming languages [Lieberman et al., 2006] with usability and human factors so that non-programmers can use the system. While the system ideally should execute strictly as per physician prescription, often the pharmacists changes brand names or packaging, and patients personalize medications and self prescribe nutritional supplements. Therefore adhering only to the prescription could be confusing to patients. Some degree of EUP is required, which can be done by patient or caregiver.

The motivation was to separate the clinical workflow from the robot’s software architecture, so that the users (as shown in table 2) had to access and modify only the part of the system they were concerned with. This was based on the requirements from the research summarized in section 2.3 and described in the paper [Tiwari et al., 2010]. The tiers of interaction between various software components are shown in figure 3. This form of layered design enables users, engineers and developers of the system to be isolated from each other’s domain and use the system without knowing all the system components.
2.3 Field Trial 2

The aim was to enhance the functionality from trial 1 and enable EUP of the data and dialog as per the user role definition and workflow defined in section 2.4. User role definition Research based on grounded theory was conducted at the aged care facility by our Health Informatics team [Tiwari et al., 2010]. It revealed the principal actors in the medication management workflow, their roles and concerns. The research found that the doctor and pharmacist are more interested in preventing errors and helping their patients take the medicines according to clinical guidelines for best outcomes, while caregivers are focussed on solving day-to-day problems as they help these same people with their medicines. The patients and their family members are not concerned about the processes but interested in resolving symptoms, remaining safe and healthy, and being treated well. The challenge for us was to incorporate the medical implications into our research and design the customization requirements accordingly to the provided guidelines. Table 2 shows the different users’ roles for completing the medication management workflow and the features required in the application for each group of users.

RoboGen enables EUP of the data and dialog as follows

1. main medication instructions by the doctor
2. medication names by the doctor and verification by the caregiver
3. medication timings and schedule by doctor and caregiver
4. side effects monitoring questions by the doctor
5. patient educational information by the clinicians
6. doctor appointments and refill reminders by caregiver

2.4 Closed Loop Medication Workflow

The concept of closed-loop medication (CLMW) [Cousins, 1998, Williams, 2004] is associated with medication delivery mechanisms in hospital information systems (HIS), where 56 percent of potential medication errors occur during the ordering process, compared with 10 percent during dispensing and 34 percent during administration [Brown, 2006, p.330]. The situation supports a role, such as a nurse, for maintaining medication safety [Pillow and Smith, 2007]. Closed-loop medication systems are composed of the pharmacy information system, the Computerized provider order entry, bar code and the point of care dispensing device such as an automated drug dispensing cabinet.

We adapt this concept and apply it to an automated robotic reminder system in the aged care facility setting to enable regular monitoring of medication intake as well as to enable improved medication safety. The prescribers need to know compliance as he or she needs to balance dosage in light of adequacy of symptom control and adverse drug events. Too little will not be effective and too much will cause adverse events. Often the prescriber adjusts dosage by guessing or an using an estimate based on subjective reporting that is often inaccurate.

CLMW for pilot study 2 is shown in figure 4 and explained as follows. The medication information is initially generated by the prescribing physician using his/her clinical judgement and expertise. The prescription is usually a set of coded information (e.g. Tab Per- oxetine 40 mg TID PO, mitte 90, repeats 2) that has to be decoded by the pharmacist to choose drugs and the quantities that need to be dispensed. Often the pharmacist detects potential problems and seeks clarifications from the physician, they also change brand names depending upon availability and funding eligibility and sometimes actual medication or the dose or its formulation is changed in consultation with the physician. The patients then need to convert these multiple medications and instructions to their daily routine and try their best to comply with the instructions given. This issue is minimized by customizing the medication instructions and medication details using RoboGen. Patients have their own way of assigning meaning to the medication instructions and calendaring the regimen. The cognitive challenges of old age make it difficult to manage this complex task, often compounded by apathy and shifting clinical status that demands frequent change in medications [Morrow and Leirer, 1999, Park, 2000]. The problems faced by patients in day to day adhering with the regimen, adequacy of symptom control or appearance of side effects are rarely conveyed to physicians with the level of granularity that can influence clinical decision making [Waitzkin, 1984, Ong et al., 1995]. To tackle these issues RoboGen enables tailoring of the medication schedule and timings. As the robot does the medication reminders, it logs the medication activity and then uploads the data to RoboGen, so that doctors, family and caregivers can track the proper medication intake. This feedback in form of analytics is visualized in a dashboard. It is very helpful to the doctors to quickly review the patients following the medication regimen. This is discussed in more detail in section 3.

3 “RoboGen” design

Since users in the healthcare sector have limited knowledge of advanced devices and the ability to use state-of-the-art technologies, we tried to simplify the workflow
Table 2: User role definition for robotic medication management

<table>
<thead>
<tr>
<th>Physician</th>
<th>Care-giver</th>
<th>Older Person</th>
<th>Pharmacist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generate Prescription</td>
<td>Customize user preferences</td>
<td>Personalize name</td>
<td>Review and edit prescription</td>
</tr>
<tr>
<td>Define Monitoring Parameters</td>
<td>Enter reporting parameters</td>
<td>Personalize dosage timings</td>
<td>Enter medication education information</td>
</tr>
<tr>
<td>Evaluate Compliance</td>
<td></td>
<td></td>
<td>Respond to robot</td>
</tr>
</tbody>
</table>

Figure 4: Closed Loop Medication Workflow (CLMW)

by limiting the functionality of the **EUP tools** to the specific items required by each role as described in section 2.3. Different roles have access to their data and can collaborate in innovative ways. For doctor, pharmacist and care-giver roles, who are not always with the robot, there are benefits in having customization over a web application:

- **Cross-platform support** Most web-based applications are far more compatible across platforms than desktop installed software. Typically, the minimum requirement would be a web browser which are usually installed in most systems and even portable devices. The web browsers are available for a multitude of operating systems and so whether the users use Windows, Linux, Mac OS or iOS, they can still run the web application.

- **Manageability** Web-based systems need only be installed on the server placing minimal requirements on the end user workstation. This makes maintaining and updating the system much simpler as usually it can all be done on the server. Client updates can be deployed via the web server with relative ease.

- **Easy deployability** Due to the manageability and cross-platform support, deploying web applications to the end user is far easier. They are also ideal where bandwidth is limited and the system and data are remote to the user.

- **Security of older people’s data** Typically,
in larger more desktop-oriented systems data are stored and moved around separate systems and data sources. In web-based systems, these systems and processes can often be consolidated, reducing the need to move data around. Web-based applications also provide an added layer of security by removing the need for the user to have access to the data and back end servers.

3.1 RoboGen components

The software design for the CLMW in section 2.4 is shown in figure 5. The design is further explained by the UML sequence diagram in figure 6 and UML collaboration diagram in figure 7. Unlike the sequence diagram, the collaboration diagram shows relationships among component roles and does not express time as a separate dimension. Therefore, the messages in the collaboration diagram are numbered to indicate their sequence. The proposed web-based tool’s architecture is sketched in figure 7. The user’s browser on a PC or mobile device connects to the web server using an HTTP request. The web server hosts the web application on the IIS (Internet Information Server) web server, which receives and sends HTTP requests. The web application is a Microsoft ASP.NET application that handles these requests. The application data are stored in one or more databases. The application can access the database using SQL commands or a web service. The ASP.NET application dynamically creates HTML pages, which IIS posts to the users’ web browser. The browser then displays the page for customization. A request for medication dialog and associated medication data from the Healthbot framework returns the customized information for the particular older person interacting with the robot.

4 Results and RoboGen Prototype used in Field Trial 2

The implementation of the requirements discussed in section 2.3 was evaluated in a user study conducted at Selwyn Village, a residential aged care facility housing over 300 older people in March 2011 [Tiwari et al., 2011a]. We conducted a formative study to access patient acceptance and feasibility of our design. Following an ethics approval from the institutional committee, six participants were recruited by a random selection and expression of interest in participation. Their personal health records were obtained from their General Physicians and designated pharmacies. The trial was conducted for a two week period. During this period the researchers took the robot to the participants’ apartments. The medication information was entered into RoboGen prior to conducting the interaction with each participant. At the end of each interaction, a semi-structured interview was conducted. Clinical data was collected from questionnaires, video recordings of interactions, researcher notes and activity logs in RoboGen.

The age of participants ranged from 83 to 92 years with a mean of 86.6, out of which 50% were male and 50% female. Half of the participants used pill boxes to organize their medication, while others used loose pills. The participants did not receive personal assistance from the care-giver for supervising the robot interaction or medication administration. Table 3 shows the results of interactions with the robot, extracted from the recorded videos. The participant could interact with the robot everyday. The total number of interactions logged was 45, out of which 42 were successfully completed. In the other 3 instances, the participants had already taken their medications without waiting for the robot to arrive.

The closed-loop medication system along-with the robot was intended to tackle the following distinct causes of medication error:

- Forgetfulness and missed doses
- Confusion about timings and quantity of medications
- Complex medication regimes demanding different medications on different days
- Changed prescriptions on hospitalization and acute episodes of illness

These issues were addressed by incorporating the following in our system design:

- Timely reminders of medication as per patient preference
Figure 6: UML Sequence Diagram for CLMW

Figure 7: UML Collaboration Diagram for CLMW

- Precise dialog and instruction detailing names, doses and method to take each medication
- Simplification of the medication regimen where the cognitive burden of handling complexity has been handled using the robot and RoboGen
- Changes in prescription translates into an accurate reminder dialog helping the patient to cope with the change

An interaction screen showing the participant receiving an accurate instruction from the robot is depicted in figure 8. The results which enable the other stakeholders in the workflow to minimize the error and delivery higher quality of care is shown in figure 9.

A summary of the formative study is as follows:
- The intended goal was achieved in 42 out of a total of 45 interactions: successful intake of medication
Table 3: Result of the interactions with the robot from the recorded videos

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Total No. Interactions</th>
<th>Success of intake</th>
<th>Correct Prompting/appropriate dialog</th>
<th>Instances needing researcher help</th>
<th>Yes to side effects</th>
<th>Non-tech. errors (if any)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>9/9</td>
<td>8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>day 1</td>
<td>no</td>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>5/5</td>
<td>4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>day 1, 2, 3</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>8/8</td>
<td>8</td>
<td>day 1</td>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>8/8</td>
<td>8</td>
<td>0</td>
<td>no</td>
<td>1&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>6/7&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7</td>
<td>0</td>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>6/8</td>
<td>8</td>
<td>day 1</td>
<td>no</td>
<td>1</td>
</tr>
</tbody>
</table>

<sup>a</sup>Taken medication without robot
<sup>b</sup>Loose medication was arranged mistakenly in the pillbox
<sup>c</sup>Unclear when to swallow pill
<sup>d</sup>Missed supplements
<sup>e</sup>Taken medication without robot
<sup>f</sup>Taken medication without robot

Figure 9: Medical Compliance Summary on RoboGen accessed by a physician

- While being prompted by the automated dialogue system, in turn driven by the Robogen database.
- Moreover 43 of 45 prompts were correctly delivered while being sequentially relevant and contextually appropriate.
- Medication side effect monitoring dialogues were delivered 11 times, and one was reported positive.
- The intended goal of increasing participants medication knowledge, by providing detailed medication information as an option, was not successful in the current design. Despite being made available as an option and being demonstrated in the beginning the users neither accessed it nor remembered it.
- RoboGen correctly collected and displayed the session outcome logs as intended at each instance in real time. No errors were recorded during the trial.
- Overall the users rated their experience positive. After the initial days the ratings ranged from good to excellent. At the end of the study the users gave similar ratings.

These results show that the new role based analysis of end user tool requirements, the software architecture, and initial prototype can support the medication management workflow required for quality of life for older people, and prevent medication errors.
5 Conclusion

This paper presents our mobile healthcare robot medication management system based on an analysis of the medication management process in an aged care facility, along with the customization tools and the software architecture essential to complete a medication management workflow. The main objective of improving medication compliance with an interactive robot and the software tools is to reduce mortality and morbidity rates and reduce the cost and burden on the health system, due to preventable hospitalizations. The integration of the medication management module into the robot suite of software services allows for collecting valuable medication compliance data and side effects responses. As a result, we hope to see health improvement and better patient awareness with respect to their medication and also the other healthcare professionals involved in the workflow to be better informed about their patients.

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References


