Observations From a Case Study on User Adaptive Reminders for Medication Adherence

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***Abstract*— We present the design and exploratory evaluation of a sensor-driven adaptive reminder system for home medical tasks. Our prototype implementation consists of a mobile reminder delivery device and ambient sensors for determining opportune moments for reminder delivery. A volunteer used the prototype in a residential research facility while adhering to a regimen of simulated medical tasks for ten days. Based on this case study, including direct observation of individual alert-action sequences, we make four recommendations for designers of context-sensitive adaptive reminder systems.**

Keywords-medication adherence; pervasive computing

I. INTRODUCTION

Poor adherence to medication and lifestyle guidance is a major challenge facing the healthcare community in industrialized countries. In the U.S. alone, the annual cost of nonadherence is estimated to be over $100 billion [1]. Despite extensive research into interventions for improving adherence, such as providing reminders over telephone, systematic reviews have found that even the most successful solutions have been complex, labor-intensive, and not consistently effective [2].

Many factors contribute to poor adherence, including forgetfulness, complexity of the regimen, disruption of daily routines, and, in some cases, intentional experimentation. Of these, forgetfulness could be the most common factor [3], suggesting that reminder devices might be helpful. However, existing electronic aids (e.g., [4]) issue timer-triggered alerts that could occur at inopportune moments, such as when the user is engrossed in an activity or not at home; even though most medical tasks can be completed at any time within a several hour window around the prescribed time and still be fully effective. Other medical tasks such as wound care are often even more flexible with respect to timing.

In this paper, we explore the use of context sensing to identify opportune moments for delivering ***time-shifted*** medical reminders. We report on a short case study in which a volunteer was asked to follow an intentionally complex regimen of simulated medical tasks while living in an instrumented apartment for ten days. The regimen, developed with the guidance of healthcare professionals, consisted of four medication tasks and four other health-related tasks: exercise, disinfecting hands, caring for a wound, and testing blood glucose. The volunteer received some reminders that were automatically time-shifted based on sensor data readings so as to minimize potential disruption. Other reminders were presented at fixed times during the day.

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In the following sections, we briefly describe our user-adaptive reminder system. We then summarize findings from the case study, highlighting issues that we recommend designers of adaptive reminder systems in the home consider. We also look at how these recommendations complement the state of the art in context-sensitive prompting for medication adherence – an area of increasing interest to the medical research community.

II. USER ADAPTIVE REMINDERS

Within the allowable window for completing a medical task such as taking a pill between 8 a.m. and 10 a.m., what constitutes an optimally-timed reminder? We selected three types of user context that might influence when to best present a reminder.

1) Activity. Task initiation and completion could be used to warn about a potential error or determine when to skip the reminder. Additionally, being able to recognize certain actvities of daily living, such as sleeping, waking up, going out of the house, and eating might be particularly helpful.

2) Proximity. Proximity to the location where the task must be completed could be used to delay the reminder until execution of the task is convenient based on location.

3) Changes in ambulatory state. As prior work suggests [5], time-shifting interruptions to coincide with changes in posture and mobility might reduce reminder burden.

Recent work in context-sensitive medication prompting has focused on the detection of a specific activity, often medication taking itself, as the primary contextual trigger. This has been done using hand-labeled statistical representations of typical trigger activity patterns as recorded by multimodal sensors (e.g., [6-8]). In one system, Bayesian networks representing lid, drawer and patient state were used to infer if medication had been taken, and reminders were set at predefined time-points [6]. Others have explored detection of additional activities using a variety of statistical learning methods (e.g., [7, 8]); however, reliable activity inference is a difficult problem impeded by the significant overhead of labeling data for training [8]. Detection of proximity and changes in ambulatory state may be more easily achieved, and also prove useful for reminder triggering. We are unaware of prior work in medication adherence using this type of information.

Figure 1. (a) apartment interior (b) a health task panel (c) a wireless accelerometer (worn on the wrists and one ankle) (d) a reminder on the mobile device

III. Prototype Implementation

In this work, our focus was not on selecting and optimizing sensors for activity inference from sensor data, but instead to use an existing sensor infrastructure to detect the three criteria we identified above (activity, proximity, and changes in ambulatory state) sufficiently well in order to study a user's interaction with adaptive medication reminders. We built our prototype in a 1,000 sq. ft. live-in apartment instrumented with embedded sensors and comprehensive audio-visual recording capability [9]. The facility affords a unique opportunity to observe users under residential living conditions over an extended stay. An interior view of the apartment is shown in Figure 1a. Seventy-two simple contact sensors integrated into appliances and furniture were used to detect on-off or open-closed events such as lighting of a stovetop burner or opening of the refrigerator. Flow sensors were installed in all faucets. Three miniature wireless accelerometers, continuously worn on the wrists and one ankle, registered limb motion (Fig. 1c).

A. Medical Tasks

The medical regimen used for testing the system (Fig. 2) was developed with the assistance of healthcare professionals, and consisted of 24 individual tasks per day. Although this number may seem high, patients over 70 take an average of 7 prescription medicines and 3 over-the-counter drugs per day [10], and our consultants felt that the regimen was demanding but not implausible for people recovering from a hospital stay or engaged in physical therapy. For research convenience, medical tasks were simulated, and no medication was actually taken. The tasks were designed with three goals; a) to mimic the real burden involved in completing the medical task, b) to be sufficiently difficult such that compliance for ten days would be challenging, and c) to permit unambiguous recording using sensors and video. To execute a medication task, the participant was asked to press and hold down a button on one of two panels located in the kitchen (Fig 1b) and bedroom. An additional button allowed the participant to "carry" a dose outside the apartment. For nonmedication tasks, the participant was required to complete other steps. The interaction was designed to require approximately the same amount of time it might take to complete the real task, e.g., to obtain and swallow a pill. A wireless motion sensor on a hand weight was used to confirm when the exercise task had been completed.

Do your best to complete these medication and health tasks along with the accompanying instructions

Med 1
Take three times daily, with a glass of water each time. Leave at least 5 hours between doses.

Med 2
Take once daily, before bed.

Med 3
Take once daily, first thing in the morning. No other medicines or food for 30 minutes after taking Med 3.

Med 4
Take two times daily, immediately after breakfast and dinner.

Hand Wash
Wash hands with Purell at least 8 times a day, approximately every 2 hours. Do not use more frequently than once an hour. If you are out for longer than an hour, wash hands when you return to the apartment.

Blood Glucose Test
Test four times a day, about every three hours. The first time should be on an empty stomach in the morning, and you should also test once before dinner. You will be prompted when you begin testing and prompted again when the result is available. Write down the result in the form provided to you.

Wound Care
Care for a wound after every time you take a shower and once before bed. You will be prompted to sit still for 3 minutes, and prompted again when 3 minutes are up.

Exercise with Hand Weights
Do about 20 arm curls with the hand weights, four times a day.

Figure 2. List of medical tasks from the participant instruction booklet.

B. Reminder Delivery

Prompts were issued using two mobile devices working in tandem. When one was in active use (carried in a holster), the other was being charged. The mobile devices were sufficiently loud so that auditory prompts could be heard in the apartment even if the device was put down. Ideally, such reminders might be presented using the most convenient ambient or wearable display as proposed in [11], but for this pilot, a simple approach was used.

Three types of prompts were used in our system: *task notifications*, *reminders* and *alerts*. ***Task notifications*** were presented when the user engaged in a medical task, as detected using the button panels or use of objects with sensors (e.g., weights). A task notification consisted of a soft chime and an acknowledgment message on the mobile device (e.g., "Blood glucose test started. Your result will be available in 2 minutes.", "Taking Med 3 recorded!").

Reminders (e.g., "Take Med 2 before bed.") were not usually delivered based on detection of a specific activity, but instead based on a heuristic measure of convenience computed using proximity. At the beginning of the allowable window for an uncompleted medical task, the reminder was issued only if the user moved to a location where it would be extremely convenient to complete the task, such as standing adjacent to the medication. As allowable time decreased, the proximity required to trigger the reminder was relaxed. For instance, the reminder may have been presented when the user entered the room where the task could be completed. In the sensor rich live-in apartment, it was possible to determine user position based on the usage of objects with known positions (e.g. particular cabinets, appliances). Alternatively, an indoor positioning system could have been used, were one available.

As the window of allowable time came to a close, changes in ambulatory state were also considered for reminder delivery, even if the user was not at a convenient location. For instance, the reminder was presented if the user became active after being sedentary watching television for a while. Ambulatory state was inferred through the user's limb motion, and care was taken to filter out short bursts of activity like fidgeting. Finally, at the end of the window if the reminder had not been triggered by any of the above criteria, it was presented anyway.

Alerts were issued preemptively, upon the detection of specific sensor events, to prevent overmedication or a missed task (e.g., "Just back? Disinfect hands with Purell.", "Not yet time for next dose of Med 1!"). For research purposes, each reminder or alert was followed by a multi-choice question to rate it: "I needed this message to comply", "I may have complied without it", "I would have complied anyway", or "Irrelevant or misleading." A simple touch-screen interface allowed the user to view, rate and dismiss messages.

IV. Case Study

A 50 year-old male (with an advanced but non-technical degree) in good physical and cognitive health, and who generally worked at home, was recruited for a 10-day case study. He had no affiliation with any of the researchers or their institution. Due to space constraints, we do not describe the participant screening, protocol review, and privacy protection processes here, but it is worth noting that the participant was described as *"conscientious, detail oriented and deliberate"* by a researcher who interacted with him prior to his stay. The participant had resided in the live-in laboratory for an unrelated purpose previously and was familiar with the environment. He was informed that the general purpose of this study was to evaluate strategies to assist in medication adherence and that he would be required to follow a simulated medical regimen while receiving reminders.

Half of the tasks in the regimen were associated with reminders scheduled at fixed times during the day, and half were associated with time windows within which adaptive reminders could be time-shifted. The participant's responses to a questionnaire about his typical sleeping time and meal times were used to schedule the fixed reminders and to adjust the time windows for the adaptive reminders. The two reminder strategies were used on alternate days. The participant was asked to treat the facility like a temporary home, and he was not told of the two different reminder timing strategies or how the adaptive reminders worked. At the end of the study, a debriefing interview was conducted in which the participant commented about his experience.

A complete audio-visual-sensor record of the participant's stay was made. Periods of sleep and time spent outside were marked. Subsequently, the ten-minute periods before every task execution were manually observed with these goals: to determine the participant's primary activity before executing the task, to estimate what strategy had been used to remember the task, and to gather other information based on the participant's reaction to prompts that might impact the design of the reminder system. Three objective metrics were tracked: adherence, message ratings, and time interval between the acknowledgment of each reminder and the execution of the associated task. Finally, video segments corresponding to poorly-rated reminders were viewed with the goal of determining what triggered them.

Figure 3. (a) exercise task, (b) medication task

V. Findings and Discussion

Our study captured objective (through tracked metrics) and subjective (through video and interviews) experiences during a ten day live-in trial. Here we highlight some observations that lead us to four design considerations we think others proposing context-sensitive reminder systems might benefit from.

A. *Exploit Proximity*

We observed significant day to day variation in the participant's sleep time and time spent outside the apartment. His sleep-wake schedule was erratic enough for him to note afterwards that he was uncertain how to interpret the "first thing in the morning" instruction on several days. On days when he was awake beyond 4 A.M., he completed such tasks before going to sleep. Others have proposed detection of prompting opportunities around the time the task is *usually* executed [8] however; this strategy may not be effective for users with highly variable domestic routines.

Reliable automatic detection of even simple activities (what is "eating dinner" when someone stays up until 4A.M.?) can be deceptively complex – here even the participant himself was unsure how to characterize his activity. Our system used activity detection that was tricky to implement and, ultimately, failed in some of these ambiguous instances. Proximity detection, however, is easy to implement and in our case study, led to faster reaction times. 96% of the proximity-triggered reminders were acted upon within five minutes of being acknowledged, compared to only 8% of the timer-triggered reminders. 25% of the proximity-triggered messages received the most favorable rating ("I needed this message to comply") compared to 9% of the timer-triggered ones. Not surprisingly, nearly all proximity-triggered messages received participant ratings while only 72% of the timer-triggered messages were rated and the rest ignored. Others have proposed using activity detection to trigger medication reminders [7, 8] but not the complementary and possibly simpler strategy of triggering based on proximity for reducing reminder burden.

B. *Consider the user's mental model*

As he experienced more reminders, the participant tried to understand how they were being triggered. He assumed, incorrectly in many cases, that they were "context sensitive." This phrase was introduced by the participant, not the interviewer. The participant was confused about getting reminders for bedtime tasks when he was still in the living room watching TV, and he described these as "absurd." He said he often questioned whether time alone was triggering the reminder, but he thought that the system would be more advanced (In fact, 50% of the time it was only triggering reminders based on time). The participant was building a mental model of how the system behaved, and his model did not map well onto the actual behavior of the system. The problem was especially pronounced when an activity was not detected properly.

As in prior work on medication adherence, here the context-detection system was operating as a black box, and the participant felt particularly annoyed because he assumed it should be better than it sometimes was. The participant further admitted to changing his behavior in order to "fool" the system, but since he didn't understand how it worked, this behavior was counter-productive. If users do not have an understanding of how the system works or why and how it makes errors, they are likely to create their own erroneous mental models and change behavior accordingly. These changes in behavior may further erode system performance.

C. *Let the user suggest activity detection strategies*

The participant created a "cheat sheet" for himself with personalized notes about when he would complete the different tasks relative to time of day and his typical activities. Video data revealed that this sheet was left on the dining table and referred to several times a day. This behavior is obviously not typical and even within the ten day study, compliance fell off slightly at the end of the study, as one would expect. Significantly, though, not only did the participant follow this list of activities fairly closely, he eventually added annotations such as *"Lights & (turning down) shades"* or *"Take J's call"* with which he associated some tasks and, in effect, incorporated his own activity-based reminders.

In the interview, the participant said that some of his routines had become more "front and center" in his consciousness, and he made specific recommendations for activities that could trigger reminders. For instance, he thought opening and closing the blinds and turning on and off the radio or TV were good activities around which to organize certain aspects of the regimen. Conversely, he identified specific times when he was not receptive to reminders: while in the bathroom, washing hands, or at the door leaving the house.

The ability to "attach" customized reminders to activities performed in the home seems to be useful from a user's perspective. Designers of reminder systems might consider ways in which the end users can draw on insights about their own domestic patterns to set up personalized reminders. The high variability in the participant's behavior, however, suggests that such strategies must be adaptable over time, as circumstances change.

D. *Soften prompts, use requests*

Not surprisingly, the degree of interruption acceptable to the participant generally depended on his interest and attention level for his primary activity at the time. Before his stay, the participant had asked if he was allowed to complete the exercise task more often than prescribed, and had been told that he could. On two occasions when he was awake late at night, he completed six to ten additional exercise tasks, and he remarked that the acknowledgment prompt was "fun." In the interview, the participant expressed that graduated reminders would be desirable. He said that reminders should become more frequent and "strongly worded" as the last possible time for the task approached. He expressed a desire for more softly worded (or with less strident alarm sounds) reminders for situations with less urgency to complete the task. However, the participant also indicated that he felt differently about messages that were *commands* versus task acknowledgments, which he interpreted as *congratulatory*. A recent study has shown that the degree of perceived politeness of interruptions is positively correlated with projected long-term adherence [12].

VI. Conclusion

Although prior work indicates that context-sensitive medication reminders might improve adherence levels, careful consideration of the four design observations presented here may increase the long-term acceptability of such systems. In addition to triggering reminders based on activity, designers may wish to consider triggering based on proximity and changes in state of physical activity.

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