Continuous Activity Monitoring and Intelligent Contextual Prompting to Improve Medication Adherence

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***Abstract*—Poor medication adherence is a serious medical problem, particularly in older adults. Various solutions have been developed to remind people to take their medications, but these systems are usually simple time-based alarm systems that are not particularly effective. We describe a system that is context aware, and that utilizes information about past patterns of behavior plus the current context to provide prompts at the appropriate time and place. A case study from our initial deployment of the system to eleven older adults illustrates the possibilities and advantages of context aware prompting systems.**

I. INTRODUCTION

It is widely known that the difficulties of adhering to medication regimens is a serious medical problem[1]. Several researchers have identified a constellation of reasons why adherence is difficult[2]. Certainly, one of the primary challenges is simply remembering to take medications at the proper time. This is especially true in older adults who may have memory problems combined with complex medication regimens.

Our research has focused on the problem of older adults who frequently forget to take their medications. Although many studies have been conducted to assess the degree of non-adherence in this population, most of these studies rely on self-report or periodic pill counting. These methods have been somewhat unreliable, and therefore more recently researchers have used technology to more accurately assess adherence, e.g., Cramer et al[3].

While these technology-based studies have provided more reliable evidence of the adherence problem, there exists very little research regarding why people might forget to take their medications on any given day. Thus, we have developed an activity sensing system for deployment into the homes of elders to attempt to investigate this issue.

This system also addresses another problem. Although many technology-based medication reminding systems have been developed, they have not been adopted by many patients. We hypothesize that most reminding systems, which usually rely on a simple time-of-day rule to trigger an alarm, are not very effective because the reminder is generated whether or not it is an opportune time or place to take the medication. In addition, these time-based reminders may be irritating if the user has already taken their medications.

To investigate these issues, we have developed a system called CAMP (Context Aware Medication Prompting) to explore two hypotheses:

1. Medication adherence as measured by a medication tracking device correlates with patterns of activity in the home that can be detected via sensors.
2. Context-aware prompting can improve medication adherence over simple time-based prompting, and patients will prefer the context-aware prompting.

By context-aware prompting, we mean prompting that takes into account a person's typical behaviors, as well as an understanding of the current situation such that prompts can be delivered most effectively. Two common situations in which time based prompting devices would fail are:

- The person is not at home when the prompt is delivered, and thus never hears it.
- The person is occupied with some other activity when the prompt is delivered, and forgets to take the medication by the time they are finished.

II. EXPERIMENTAL METHOD

To assess the effectiveness of the system (described in the next section), we recruited eleven "poor adherents" from a previous study of medication adherence where volunteers were asked to take a 250 mg vitamin C tablet twice a day[4]. We defined poor adherence as missing at least 20% of the prescribed doses. Participants were all single, living alone in one of two retirement communities in Oregon. All signed written informed consent (OHSU IRB #1682). There were ten females and 1 male, with a mean age of 83.3. Subjects were screened to exclude depression and dementing illnesses with standardized cognitive and behavioral tests. Participants were asked to take a low dose vitamin C tablet twice daily, as they had in the previous study. During the initial interview, we asked subjects to select the two times during the day that they would take their vitamin (these were always 12 hours apart, e.g., 7am and 7pm). We defined

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"adherence" as taking the vitamin within a 3 hour window around the selected time – 90 minutes before the time and 90 minutes after the time.

During the baseline phase, participants received no reminders. The baseline phase lasted an average of 89.5 days. During the intervention phase, we first turned on *time based prompting* (described below). Time based prompting lasted for an average of 78.5 days. Next we enabled context based prompting, in which location-aware prompting occurred only when the system inferred that participants were likely to miss taking their vitamin (described in more detail below). Context-based prompting lasted for an average of 55 days.

At the end of the baseline phase of the study, participants were given a battery of cognitive and health related tests, plus a sleep disturbance symptom questionnaire[5]. The cognitive tests were the same tests given to participants in the original adherence study about a year prior to the current study. This allowed us to compare changes in cognitive ability and correlate this with changes in adherence level.

III. System design

In designing our system, several factors and requirements were considered. First, it was important to consider carefully which activities were most important to track, and use appropriate and reliable sensors to track those activities. Second, the system had to operate in real time, so that reminders could be administered to the participants based on their current location and activity. Third, the system had to be simple and non-intrusive – we did not want to use more sensors than were necessary, as each additional sensor adds complexity and potential intrusiveness to the system. Fourth, the system had to be flexible in its ability to prompt; it should prompt participants only when they needed prompting, and remind them in the place they were located, e.g., the bedroom or the bathroom. Fifth, the system had to be easily installed and maintained in existing homes.

A. Defining relevant activities

Branin et al describe methods people use to remember their medications[6], but this gives little information as to the situational factors involved in forgetting. We hypothesized that disruptive or unusual activities that occur just before or during the time one would normally take their medications might be a reason for forgetting. We conducted a brief study in which 10 participants took vitamins twice a day and recorded the conditions under which they took their medications, and the conditions in which they did not[7]. From this data, and from interviews with elders, we created a list of activities that were likely causes of forgetting:

- Having to leave their home shortly before their normal time to take medications
- Telephone calls during the medication time
- Visitors to the home during the medication time
- Lack of sleep or unusual nighttime activity the prior night
- Unusual activity in the home during the medication time. This might indicate non-routine behaviors that could distract participants from remembering to take their medications

B. System Description

From the system requirements and the activities, we developed a system with three major components – the sensor system, the inference engine, and the reminding system.

1) The sensor system.

The sensor system consists of the following:

- A laptop computer connected to the internet via broadband with a wireless antenna for receiving messages from the sensors
- A wireless motion sensor in each room of the house
- Wireless sensors located on the refrigerator and front door to detect door open/close
- A wireless sensor connected to the phone line that detects 'off hook' or 'on hook'
- A watch worn by the subject, which is used to identify where the subject is located in the house.
- A wireless bed sensor, which is placed underneath the subject's mattress to detect movement in the bed
- A MedTracker, which is similar to a day-of-the-week pillbox. The tracker detects when a door has been opened on the device and wirelessly sends the information to the computer.

2) The inference engine

The inference system was designed to "learn" an individual's activities and then to make a decision to prompt based on those activities. The input data comprised events from the sensor system. The inference, including temporal reasoning, was performed by a simple Dynamic Bayesian Network trained by hand labeled data. The details of the inference process are described in Vurgun et al[8].

3) The prompting system

The prompting system consists of the Med Tracker and one or more *Activity Beacons* shown in figure 1. The Med Tracker uses three modalities for prompting. First, it emits a beeping noise. Second, the display reads "It's time to take your vitamins", and third, a light blinks inside the translucent door corresponding to the correct day of the week.

Activity beacons are small wireless devices that can be placed in different rooms of the house. Activity beacons also prompt in three modalities: beeping noise, flashing lights, and an audio message that can either be triggered automatically or can be played by the user by pressing a button. For this study, the beacon would play a voice recording that repeated "It's time to take your vitamins."

Figure 1. The Activity Beacon and the Med Tracker

a) Time based prompting system

Time based prompting was enabled on this system so we could test hypothesis #2. In time-based prompting, the Med Tracker would prompt for three minutes at the times selected by the participants.

b) Context aware prompting system

We define context aware prompting as prompting that only prompts when it is likely that a person is going to miss taking their medications, based on individual patterns of activity. Furthermore, the system prompts at the appropriate location, and withholds prompting if the participant is engaged in an activity that might prevent them from taking their vitamin (e.g., the participant is on the phone).

The following rules were established to define the prompting system:

1. Never prompt outside the adherence window (90 minutes before and after the time to take the vitamin).
2. Don't prompt if the vitamin has already been taken within the current window.
3. Don't prompt if the participant is not home. Resume if the participant returns home before the window ends.
4. Don't prompt if the participant is in bed. Wait until they are out of bed to prompt.
5. Don't prompt if participant is on the phone. Wait until they are off the phone to prompt.
6. Don't prompt before the time the user usually takes the pill (estimated from their baseline data). The only exception to this is if the participant appears to be leaving prior to their regular pill taking time.
7. Prompt at the closest location to the participant, using either the Med Tracker itself or the closest activity beacon.
8. If it is less than 20 minutes left until the adherence window expires, start prompting, disregarding all other rules (except 1-3).

IV. COMPARISON WITH OTHER SYSTEMS

Our system resembles some other systems that have been developed. Mihailidis et al have described a system that uses a similar approach to use location to find the nearest prompt available[9]. However, this latter system does not attempt to identify activities or address interruptions in activity, and we are not aware of this latter device being deployed in the community. Nugent and others have developed a medication organizer that functions in a similar way that the Med Tracker does[10]. However, this system relies on time-based prompting only. In this study, we are attempting to discover activity correlates of forgetting and modify the prompting strategy accordingly, plus utilize location in a similar way as Mihaildis et al.

V. DATA ANALYSIS - CASE STUDY

We are currently in the process of analyzing the data from this study. We present a case study and preliminary data from this case to illustrate the potential of this sensor system and prompting system.

Case Study

"Jane" is an 83 year old female who lives in a one-bedroom apartment. In the initial interview, she reported that she frequently has difficulty sleeping, and gets up several times a night. She also reported that she usually goes to bed at 11pm and gets up at 5am. She takes her medications at morning and night, but says she is "much worse" in taking her medications at night. She selected 7am and 7pm as the time she would try to take her vitamin.

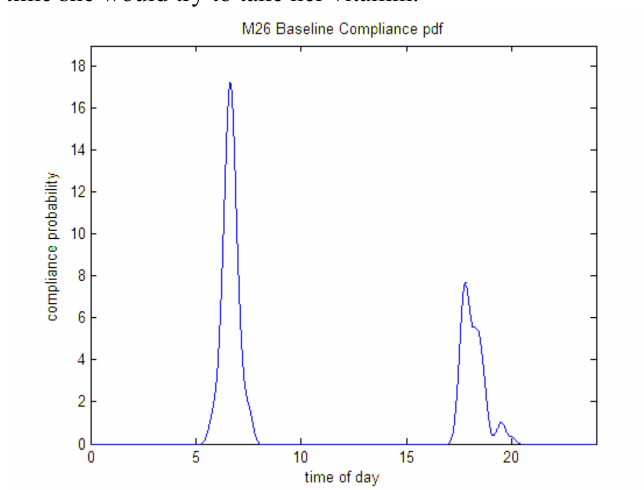

Figure 2. Adherence during the baseline phase

Jane's compliance rate was 66% during baseline, 71% during time-based prompting, and 81% during context based prompting. In figure 2, we can see that in the baseline phase (without prompting), the vitamin taking times are evenly distributed around the average in the morning, with lower adherence in the evening. During time based prompting (figure 3), the morning times are slightly skewed, as if she is often waiting for the prompt before taking her vitamin. Her adherence in the evening has not improved, possibly because she was often out of her home at 7pm. Finally, in the context based prompting (figure 4), note that adherence is much better in the evening, although the distribution is uneven. This is because the system was sometimes able to anticipate Jane leaving her apartment, and reminded her before she left. Other times, it would remind her after she returned. Figure 5 shows an example of context based prompting that occurred on a night that Jane left before the adherence window, but the prompter turned on and reminded her when she returned home.

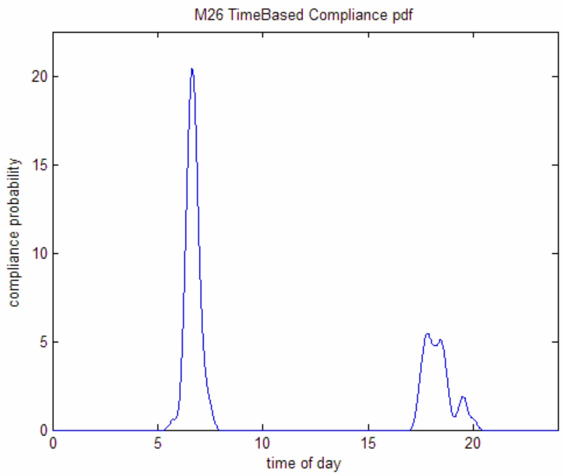

Figure 3. Adherence during Time Based Prompting

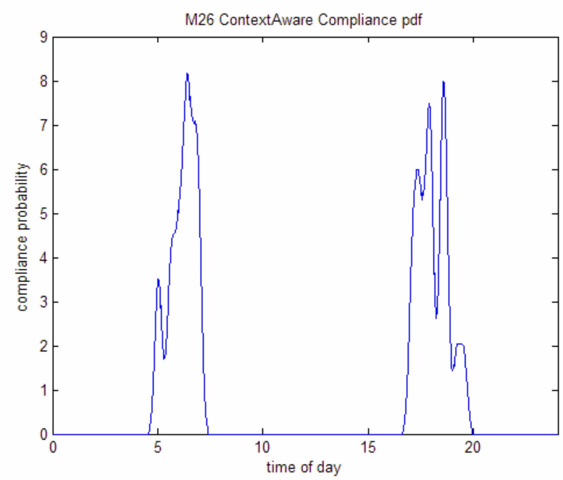

Figure 4. Adherence during Contextual Prompting

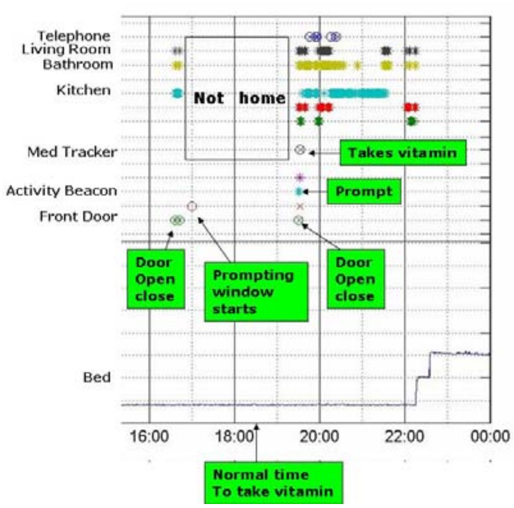

Figure 5. The inference engine waits until returning home before prompting.

VI. Conclusions/Future Work

The preliminary conclusions from this pilot study suggest that unobtrusive monitoring of elders' activities combined with statistical inference could comprise an effective system for medication prompting.

It is likely that the effectiveness of the system will be enhanced by improved assessment of the activity of the elder and by more accurate estimation of the position of the elder.

Future work will include statistical analysis of the correlations between patterns of activity and adherence during the baseline phase of the study, and both quantitative and qualitative analysis of the effects of time-based and context-based prompting.

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