Toward Naturalistic Self-Monitoring of Medicine Intake

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ABSTRACT

Since drug actions are dose- and time-dependent, adherence to prescribed medications is essential for the effectiveness of therapies. Unfortunately, several studies show that when patients are responsible for treatment administration, poor adherence is prevalent. Hence, it is necessary to devise effective methods to remotely assess medication compliance and support self-administration of drugs. Existing methods include electronic reminders such as short message service reminders and pill reminder apps. Although those tools may help increasing adherence, they interfere with the normal routine of patients by providing unnecessary reminders, or providing the reminder at an unfortunate time. More sophisticated solutions include the use of smart packaging and ingestible sensors to quantify and monitor drug intake. While those solutions do not interfere with normal routines, currently they are restricted to patients involved in a few clinical studies. In this paper, we introduce a novel system to support self-administration of drugs without interfering with the patient’s routines. The system is based on a combination of cheap sensors and a smartphone. Tiny Bluetooth low energy sensors attached to medicine boxes communicate motion data to an app running on the patient’s smartphone. Thanks to a machine learning algorithm, the app detects intake events, and reminds the user only when needed. Active learning is used to improve recognition rates thanks to the user’s feedback. Preliminary experiments with a dataset acquired from volunteers show that the algorithm can detect most intake events with a few false positives. At the time of writing, we have developed a working prototype of the system, and we are beginning an experimental evaluation with a group of patients of an Italian hospital.

CCS CONCEPTS
• Human-centered computing → Human computer interaction (HCI); Ubiquitous and mobile computing systems and tools; Ubiquitous and mobile devices;

KEYWORDS
Medicine intake monitoring, e-health, activity recognition, pervasive computing

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1 INTRODUCTION

Accurate adherence to medical prescriptions is a prerequisite for the effectiveness of therapies based on pharmaceutical drugs [17]. Unfortunately, several patients experience difficulties in complying to the medical prescriptions. For instance, around 50% of patients with cardiovascular disease have poor adherence [11]. This problem is particularly relevant for patients with chronic illnesses, and can lead to increased use of healthcare services and detriment of life quality [13].

When non-adherence is unintentional, one of the main reported reasons is forgetfulness [1]. Consequently, different tools have been proposed to remind the patient about the medications to take. A simple solution is the use of “medication reminder packaging”, where the medicine box incorporates the prescribed date and time of drug intake. However, those solutions showed a modest improvement of adherence on the long term [12]. RFID tags were used in [15] to let the patient manually register the medicine intake. Other tools actively remind the user, using pagers, custom devices, short message service and, more recently, smartphone apps [6, 16]. Those tools proved to be quite effective on the short term; however, the effects on the long term are unclear [18]. Moreover, existing reminders are context-oblivious: the patient is notified with a reminder at each scheduled time of intake.
Hence, such reminders may interfere with the normal routine of users, since they are issued even when patients have actually taken the prescribed drug at the prescribed time. Ideally, the patient should receive a reminder only when he/she actually forgets to take the prescribed medicine.

More recently, different sensor technologies have been proposed for monitoring medicine intake, based on smart packaging, or ingestible sensors. Smart packaging solutions integrate conductive tracks on medicine blisters; their rupture is interpreted as an intake action, and communicated to a remote server [7]. Ingestible smart sensors integrated in pills are activated by gastric acids and emit a weak wireless signal, which is amplified by a tiny device stuck on the user’s skin, and transmitted to a remote server to store the drug’s identity and the time of intake [8]. Those solutions do not interfere with the patient’s routine. However, at the time of writing they incur high costs, and they have been used only in a few selected clinical studies.

In this paper, we address the challenging issue of devising a system to support self-administration of drugs, which does not interfere with the normal routine of the patient. We introduce a novel system based on a combination of cheap wireless sensors, a smartphone app, and cloud infrastructure, to monitor medicine intake and provide reminders only when actually needed. Tiny accelerometers stuck to medicine boxes communicate motion data through a Bluetooth low energy interface to the patient’s app. The app preprocesses accelerometer data to extract features of interest, and uses machine learning (ML) methods to detect intake actions. Detected intake actions are compared with the scheduled therapy. In case of missed intake, the app notifies the user with a reminder. The patient is asked to confirm or refute the detections of the app. The app’s feedback is exploited by the app to fine-tune the prediction algorithm to the user’s habits, using an active learning method.

With respect to “traditional” reminder apps, our system reduces the number of unneeded reminders, since the user is actively notified only when the app detects a missed intake. With respect to solutions based on smart packaging or ingestible sensors, our system has the advantage of being readily applicable to existing therapies, since it does not require changes in manufacturing of medicine blisters, or integration of sensors in drugs.

The use of adhesive accelerometers was proposed in [3] to monitor different activities, including medicine intake. The goal of that work was the detection of activity components at a fine-grained level in order to recognize early symptoms of cognitive impairment. In our work, we pursue a different goal: recognizing intake actions at a coarse-grained level in order to support self-administration of drugs. Moreover, differently from [3], our system is integrated with a smartphone app to notify the patient, and with a Web dashboard for the practitioner to evaluate the patient’s adherence.

We have implemented a working prototype of the whole system, and conducted preliminary experiments with a dataset of intake actions acquired from a small set of volunteers. Results show that our algorithms can detect most intake events, producing a small number of false positives. Moreover, our active learning method improves detection rates. At the time of writing, we are beginning to experiment our system with a group of patients of an Italian hospital.

2 SYSTEM OVERVIEW

The system is depicted in Figure 1, and includes a smartphone running the smart reminder app, tiny Bluetooth sensors (named tags) attached to medicine boxes, and communication with the cloud to acquire data about tags and to process the data at the server side. The app exploits user feedback to fine-tune medicine intake recognition to the patient’s habits. A Web-based dashboard is available to clinicians for inspecting the history of medicine intakes of their patients.

As in normal pill reminder apps, the patient manually fills his/her therapies and the prescribed times of intake. However, as shown in Figure 2(a), through the smart reminder app, the patient also associates each therapy to a colored tag, which is actually a tiny Bluetooth low energy (BLE) beacon with an integrated accelerometer.

The app queries the cloud to get tags information, including the color and the kind of image depicted on its surface, in order to facilitate tag identification. After the association, the patient sticks the tag to the medicine box (Figure 3).

When moved, the tag broadcasts packets containing its identification number and tri-axial acceleration. Those packets are acquired by the app and analysed by a ML algorithm, which is in charge of classifying the movements of the medicine box in either “intake action” or “other action”. When the app detects a medicine intake action at the prescribed time, it discreetly displays a pop-up message asking the patient to either confirm or refute the intake, and to fill a mood and pain scale. For the sake of this project, mood

![Figure 1: System overview.](Image)
and pain values are important to understand why the patient is taking or not the prescribed medicines. If the app does not detect the intake of a prescribed medicine within a time threshold, it vibrates, emits a sound and displays a reminder. The patient can either confirm that he/she forgot to take the prescribed drug, or may report a misprediction of the app, indicating the actual time of intake.

The app has a calendar function showing the prescribed medicines to be taken in the current time of the day, as well as a “performance” function, shown in Figure 2(b), displaying the rates of correct intakes and average mood and pain values in the current day, week and month.

The app is part of the DomuSafe research project1, and can be used both by patients participating to the project’s experimental evaluation, and by other users. The app data (therapies, motion data, medicine intakes, mood and pain values) are periodically communicated to a server in the cloud. The server provides a Web-based dashboard through which clinicians can evaluate the adherence to prescriptions of patients participating to the evaluation, and inspect the trends of pain and mood. Communication with the cloud is done through an encrypted channel. The data are stored on the server in an anonymous form. Each patient participating to the experiment is identified by a unique code; the association among codes and identities is known by the clinician only.

The app has been developed for the Android platform, using the Weka [9] libraries for implementing the ML algorithms. In the current implementation, we adopt Estimote2 stickers as our tags. Sticker, as the one shown in Figure 3, have an adhesive side that makes it easy to stick to medicine boxes. Their communication range is sufficient to cover most apartments. Stickers are disposable and have a life time of approximately one year. At the time of writing, their cost is ten US dollars each. The Web dashboard is implemented in PHP and HTML5.

3 REMINDERS AND USER FEEDBACK

As explained before, the mobile application introduced in this paper allows the patient to receive a reminder for taking his or her medicines only when he/she actually forgot to do it. When the app detects the intake of a prescribed drug at the prescribed time (i.e., within a one hour interval from prescribed time), the patient receives an unobtrusive screen notification (the lowest notification shown in Figure 4(a)) that produces a vibration of the smartphone but no sound. That notification reminds the patient to confirm or refute the detection, and to fill the scales of pain and mood. On the contrary, when the app detects that the intake was skipped, the patient is alerted with both a vibration and a one-time ring, in order to immediately draw his/her attention, and the upper notification shown in Figure 4(a) is issued. Therefore, when the patient takes the drug at the right time, the notification is much less invasive than when he/she misses the intake. Of course, if the phone is too far from medicine boxes, the app would detect a missed intake in any case.

Clicking on the notification will open a form containing the intake data (shown in Figure 4(b)). The form is divided into 4 sections: “Summary”, “Mood”, “Pain” and “Intake”. The patient will be able to fill this form only after receiving the notification. The medicine intake summary contains:

1http://sites.unica.it/domusafe/

2https://estimote.com/
4 DETECTING INTAKE THROUGH MEDICINE BOX MOTION

The basic requirement for detecting intakes of a certain medicine is the presence of an association between the medicine and a tag. As explained before, if a user wants to set up a new drug treatment, he/she must complete the appropriate section of the application by entering the information needed to describe the therapy. After that, he/she has to apply the tag to the medicine box, using its adhesive side. When the smartphone is in the communication range of the tag, the app is able to detect the movements of the box during the scheduled time, and consequently it can determine whether the medicine has been taken or not.

Intake monitoring is performed by analyzing and processing motion data packets sent by sensors. The process is composed of four main phases:

- stream data processing of accelerometer packets;
- feature extraction;
- application of the ML algorithm;
- update of the ML model based on user’s feedback.

A manipulation represents a continuous movement of the medicine box. It can be classified as either “intake action” or “other action”. If motion data in the stream are considered continuous and temporally close based on certain thresholds, the app aggregates them into a unique “manipulation event” and extracts two features: total duration of the manipulation, and duration of the movements within the manipulation. Each manipulation event will eventually be processed by the ML algorithm to determine whether it resembles the parameters of intake actions or if it can be considered as a different action.

The intake detection algorithm is set up for adapting itself to the habits of the user and to the characteristics of the specific therapy. Manipulation events are categorized thanks to the feedback provided by the user through the app. Through feedback, the app can identify false detections (false positives and false negatives) and positive detections (true positive and true negative). Consequently, the app can re-train the ML model in order to adapt detection to the specific patient and therapy. As long as there are less than 10 samples of intake actions or less than 10 samples of other actions, the app uses a basic technique based on pre-set thresholds that were chosen empirically. Once the required number of samples is obtained, the system applies a ML algorithm for training a generic model valid for every therapy. When a sufficient number of samples is obtained for one therapy, those samples are used to train a model specific to that therapy.

The choice of the classification algorithm was based on preliminary experiments carried out on a sample of 200 manipulation events by three volunteers, which used the app for a few days simulating the intake of different therapies.
The used dataset contains 102 samples of intake action and 98 samples of other action. Different algorithms have been compared in order to select the most accurate one: Random Forests [2], RIPPER [4], Bayesian Networks [10], Support vector machines (SVM) [5] and Neural networks [14]. Those algorithms cover several of the most prominent approaches in supervised learning. The experiments were executed through a Java program using the libraries provided by Weka [9].

Results are illustrated in Figure 5. The plot shows the accuracy achieved by the different algorithms using a growing number of samples for training (from 10 samples to 50 samples). The other samples were used for testing. In these experiments we used two-folds cross-validation. The baseline threshold algorithm achieves an accuracy of about 89%, which is constant since threshold values are fixed and do not depend on training. The other methods show a variable trend of accuracy. The one achieving the best result for our application is Random forests. Indeed, it achieves the highest accuracy (90%) with the smallest dimension of the training set. Moreover, accuracy tends to grow with the size of the training set, even if the improvement is limited. Hence, we adopted that algorithm for our app.

5 CONCLUSION AND FUTURE WORK

While adherence to medical prescriptions is a prerequisite for the effectiveness of pharmacological therapies, most patients experience difficulties in following the prescribed treatments, especially on the long term. A major reason for poor adherence is forgetfulness. In this paper, we proposed a novel system to support self-administration of medicines through context-aware reminders that do not interfere with the normal routine of the patient. The system is based on a smartphone app and cheap wireless sensors to be attached to medicine boxes. We implemented the system and conducted a preliminary experimental evaluation. Results show that our system can recognize most intake actions with a small number of false positives.

Future work includes experimenting our system with real patients. We are beginning an experimentation with patients of an Italian hospital to evaluate both the utility and usability of our system. We also plan to investigate more advanced active learning methods, in order to fine-tune the prediction model to the patient’s context and habits while reducing the effort of providing feedback to the app.

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