CuePBox: An Integrated Physical and Virtual Pillbox for Patient Care

Abstract
Based on three constructs of alerts, care, and education, we describe the design and development of CuePBox, an instrumental pillbox, with a physical as well as a virtual entity, that aims to address needs for enhanced patient care, in the monitoring of medication adherence on a continuous basis. CuePBox will be facilitated by social media technologies that support patient-to-patient communities and patient-to-healthcare communities to exchange state-of-affairs information and testimonials, with advice and encouragement towards speedy recovery. The care component along with the alerts (audio, visual, and vibration) integrated within the CuePBox hopes to empower patients to manage their health conditions.

Author Keywords
Ubiquitous Computing, Patient Care, Social Media Technologies

ACM Classification Keywords
H.5.2 User Interfaces: Interaction styles, Input devices and strategies; I.4.7 Feature Measurement

General Terms
Design; Human Factors
Introduction
Observed therapy is an approach used primarily in the control of tuberculosis (TB). Health professionals or any other responsible third party (supported by a trained health professional) will provide the medication and observe the patient taking it [1]. This ensures medication adherence, which will lead to a higher percentage cure rate and reduce any drug resistance that may occur [4, 6]. There has also been the use of observed therapy for other types of diseases such as HIV and Hepatitis C [2, 3] to ensure treatment adherence.

The initial study findings [8, 5] on TB medication adherence have revealed an absence of a solution with regard to the following:
- An active monitoring and encouragement system for treatment adherence;
- A need to connect with social support groups and recovered patients; and
- A system that can allow a seamless flow of messages from (personal) doctors and healthcare authorities to patients transmitting a continuous sense of care and encouragement, with an intent to help patient complete the treatment regime.

In our study on better TB patient-care, we proposed three constructs on Alert, Care and Education [8]. Extending on-going work beyond TB patient-care, with these three constructs and objectives in mind, in this paper, we describe the design and development of an instrumented pillbox, called CuePBox, for enhanced patient-care. CuePBox provides an important platform to perform social interaction within the healthcare community, including patients, recovered patients, caregivers, and healthcare personnel by facilitating people to interact and share their experiences and send testimonials and encouragement to each other. This kind of interaction is valuable for patients who are suffering from contagious diseases, such as TB, where patients need to be isolated for some time from the general public to stop the spread of the disease or illness. Such interaction helps the patients to go through treatment with better social support, maintaining a positive well-being.

Related Work
Different kinds of pillbox devices are available in the market to assist patients with medication adherence. There are a few systems (e.g. Epill [9]; Med-Q [10], My Electronic Pillbox [11], and MedFolio Pillbox [12]) which have tried to track medication adherence. Existing methods of tracking medication adherence via electronic pillboxes suffer from a number of drawbacks, particularly in that they do not support care-focused connections with healthcare people and hospital. The widely-used Medication Event Monitoring System [13] (MEMS, Aardex Ltd.) provides a adequate information about adherence. However, the MEMS does not accommodate the use of pill boxes that are commonly used by the elderly [14], and it does not report adherence in real-time, so intervention cannot take place if medications are missed.

The CuePBox addresses those drawbacks and improves existing systems by: (i) providing mobility, monitoring and encouraging treatment adherence; (ii) connecting with social support groups, and recovered patients; and (iii) allowing messages from personal doctors and healthcare authorities to patients transmitting a sense of care and encouragement, with an interface of a 7-day physical pillbox. This system also provides a timeline for medication for patients that are meant to help them to complete their treatment regimes. Most importantly, this feature is available across the treatment ecosystem – that includes the patients,
caregivers, and healthcare personnel. This is a very important feature, especially for elderly people, who overlook their treatment regimes. Combinations of virtual and physical pillboxes provide a totally different experience for patients and caregivers. For instance, it is possible to identify when incorrect compartments are opened accidentally, which is imperative in cases where different medications are to be taken on different days. This information not only alerts the patients, but also provides awareness to caregivers. This helps both patients and caregivers to understand the situations in real-time and take appropriate actions accordingly.

**System Description**

This system has three main components, namely, the Information Management System for Patients (IMSP), Virtual Pillbox and Physical Pillbox. The overall architecture is depicted in Figure 1.

The technologies selected for the system are based on the accessibility to people in the middle of the pyramid. Thus existing GSM network which comes with the SIM card is used to communicate between IMSP, and CuePBox (virtual pillbox & physical pillbox). The virtual pillbox visualizes statistics of the treatment regime and updates the IMSP through the GSM network. Such statistical information is available for healthcare personnel who use IMSP. The Physical pillbox is also connected with IMSP through GSM network and it also visualizes statistics of the treatment regime. The connection between IMSP and CuePBox is established once the patient details are downloaded to the CuePBox. The task of IMSP and CuePBox is to track patients’ treatment regimes and give timely reminders to patients and caregivers. The physical and virtual pillboxes are also able to facilitate communication between patients and several caregivers simultaneously.

**Physical Pillbox**

The physical pillbox consists of Microcontroller, EEPROM, Realtime clock, LCD, 7 switches, 7 LEDs, navigational switches, GSM modem, and PS2 keyboard socket. The physical appurtenance of the Physical Pillbox is depicted in Figures 2 and 3 respectively. All the parameters are programmable, such as phone numbers, predefined messages, patient ID, starting date and time, time for warning messages, etc.

The registered information of the patient is downloaded to the Physical Pillbox at the hospital by the healthcare personnel and the Pillbox is handed over to the patient. When the Pillbox is powered up, it starts to operate based on the input regimen information. It is able to display care and alert messages on the 16x2 LCD panel. Seven LEDs which are allocated for each day in the week are mounted on top of the pillbox and they will be lighted up to provide visual reminders to the patient. All the messages displayed on LCD which comes from caregivers, doctors, or IMSP system. Patients can navigate the received messages by pressing the navigation button.
The microcontroller checks the status of switches continuously and updates day of week LED and compare the current time by real time clock with the preprogram time. At the morning start time, it provides a short beep sound to remind the patient to take medication. At the warning time, it provides a longer beep sound to alert the patient to take their medicine again (assuming that the patient ignored early warning). If the patient ignored all the warnings, including messages and sounds, the pillbox will send an SMS through the GSM modem to caregivers and the IMSP system. Whenever the patient opens a drawer of the Pillbox, the plunger would release a switch inside the device, sending a signal to the microcontroller indicating that the door was open. It then activates the modem, sending an SMS to update caregivers and IMSP system.

The need to collect data from the device on a frequent basis, and for the device to be portable, requires that we provide wireless connectivity. We used SMS for this connectivity because this technology can be used in developing countries where 3G networks are not available or not popular yet.

This Physical Pillbox provides following features and functionalities:

- Once the patient is registered in the IMSP and assigned to a particular treatment regime, the Physical Pillbox is updated with that particular information.
- The Physical Pillbox, composing of several containers and each container connected to a switch, triggers an operation once the container’s status is changed.
- When the patient has to take the medicine, the Physical Pillbox gives visual and auditory feedback to the patient, using LED indicators and speakers.
- Once a patient takes the medicine, it communicates the information to IMSP through the GSM network.
- If the patient does not take the medicine within the correct time period, the system automatically gives warning messages, and if the patient does not take the pills at all, it communicates these information to the IMSP and caregivers.

Virtual Pillbox
This is the virtual representation of the physical pillbox. The Virtual Pillbox is depicted in Figures 4 and 5. The Virtual Pillbox is activated when the patient information is downloaded from the IMSP system. The Virtual Pillbox connects with IMSP through the network interface and downloads the patient information in binary format encrypted under the Advanced Encryption Standard (AES) encryption standards. This is a symmetric-key algorithm where the same key is used for both encrypting and decrypting the data. When patient triggers to start operation, the application starts to simulate the patient’s treatment regime according to registered IMSP information. Currently, the treatment regime can be customized as a daily schedule and the day is further divided into three-time slots into "Morning", "Afternoon", and "Evening". This information can be customized further at the IMSP system.

The Virtual Pillbox simulates the respective treatment regime. Alertness and care messages are sent to the patients, every time they take their medication timely manner. At the beginning of each time slot, a message displays in the system, asking the patient to take the respective medicine. Interaction with the patient is enhanced with multimodal interfaces by visual and auditory messages given to patient as an additional reminder. The application is powered by the android text to speech API hence it is able to provide voice feedback in real-time. The application then monitors the patient’s response continuously. If the patient does
not respond, it feeds warning messages using visual and auditory modalities. If there is no response from the patient at all, then the application informs the caregiver(s) and the IMSP.

The information of the past seven days’ treatment is displayed in the same interface. If a patient has successfully taken the medicine on time, the schedule is highlighted in green color. The red color is used to highlight the unsuccessful slots. Pending time slots are highlighted in gray color. Inactive slots are kept in the blanks. This Virtual Pillbox provides the following features and functionalities:

- The registered patient information is downloaded to the Virtual Pillbox.
- It is connected with and continuously updates IMSP.
- It provides feedback to the patients using different modalities such as visual, auditory, and tactile (vibration)
- It provides dynamic speech feedback.
- The game engine is used in order to enhance the visual feedback and interaction. Here, visual effects are rendered using a game engine.
- Interactions are implemented using a physics joints technique between finger and display components which enhance the user experience.
- Medication history (timeline) of the patient is visualized.

**Information Management System for Patients (IMSP)**
The Information Management System for Patients (IMSP) facilitates patients’ registration at the hospital or any other authorized place where patients can register to obtain medication. Screen dump of the IMSP web interfaces is depicted in Figure 6. The health worker at the hospital enters the patient and caregiver’s details in the IMSP. The health worker enters all the patient details such as name, address, contact number, doctor’s name, medical history as well as caregiver’s name, relationship and contact number. The patient’s details are accessible through IMSP to the doctor/healthcare worker. The doctor can enter patient details after examining the patient. The doctor or his healthcare worker can enter/edit the medicine regime prescribed by the doctor. The IMSP keeps tracking each patient’s medicine regimen and sends timely reminder to each patient individually depending on his/her treatment regime prescribed by the doctor.

The prominent advantage of this system is the patient current status of the regimen can be monitored by the doctor or authorized healthcare person. In cases where it is important for patients to be directly observed, such as TB or HIV patients, the monitoring feature of this system becomes important. The IMSP system connects to a MySQL database which stores all necessary information. This information will be downloaded to both virtual and physical pillboxes for real-time interactions. The IMSP is a Web-based system which runs on Java enabled web server. It connects with a GSM network through a middleware program that facilitates sending/receive messages to/from pillboxes or any other mobile devices. This Web-based system facilitates as a platform to perform social interaction where patients, caregivers, recovered patients, and healthcare personnel can interact with their physical devices through this system.

**Concluding Remarks and On-GOING Work**
Good patient care with good social support [7] will lead to better health outcomes in terms of recovery and treatment completion rates. CuePBox is an innovative device and system for better patient care that will change how we take our medication, with a greater emphasis on using social media for alerts, care and education that may lead to better treatment adherence. Evaluation of the CuePBox system is on-going, and focus groups have been planned with three different
groups of people and with different health conditions: 1) Caregivers of elderly folks and the elderly who are more than or equal to 65 years of age; 2) Healthcare specialists and patients with chronic diseases (e.g. diabetes); and 3) Healthcare specialists and patients with stigmatized diseases (e.g. TB).

On-going work also includes applying Scenario-Based Design and Claims Analysis [15] in the conceptual design of of CuePBox and IMSP for three sets of activities: (i) information gathering developing front-end applications to gather reliable information (e.g., diseases, illnesses, location, time, climate, and geography); (ii) sense-making developing back-end applications to make sense out of information gathered through intelligent computation and algorithms; and (iii) information dissemination developing front-end applications to disseminate reliable information (e.g., forecasts of diseases or illnesses, location, and time).

To further test how useful CuePBox and IMSP are, an intervention study may be carried out in the future. Discussions have commenced with hospital partners to refine the applications of the CuePBox.

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References