

SmartMATES for Medication Adherence Using Non-intrusive Wearable Sensors

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Abstract. According to the National institute on Aging, 8% of the world's population is over 65 or older. There is a need for a long term care and a remote home-care environment for the aging population using smart technologies as this number expected to double by 2050. With the advancement of embedded sensing technologies, wireless sensing technologies have been used to monitor user's activities and maintain a healthy lifestyle. In this paper, we develop a Smart Medication Alert and Treatment Electronic Systems (SmartMATES) using a non-intrusive wearable sensor system to detect and prevent a home-based patient from missing his or her medication. The sensor collects and processes both the accelerometer and radio signal strength measurement on the left and right wrist. Based on the data collected, SmartMATES correlates the left and right wrist accelerometer reading to model the action of taking medication. If SmartMATES detects the patient is not taking the medication within a time-frame, it will be send an alert to the mobile phone to remind the users to take their medication. We have evaluated the SmartMATES on 9 participants. The results show that the SmartMATES can identify and prevent missing dosage in a less intrusive way than existing mobile application and traditional approaches.

Keywords: Medication adherence · Body sensor networks · Activities recognition · Hand gesture

1 Introduction

Medication adherence is known to be a problem for patients especially elderly who experience forgetfulness and suffers from a number of medical conditions that require different medications. Studies have shown that 26% of the hospitalization were caused by non-adherence of medicine therapy which involved elderly patients above 75 years of age due to fall, postural hypotension, heart failure and delirium [1]. According to the World Health Organization [2], medication adherence is defined as “the degree to which the person's behavior corresponds with the agreed recommendations from a healthcare provider”. When the patients begin to deviate from their recommended prescription, it is known as non-adherence. There are two types of non-adherence namely primary and non-persistence [2]. Primary non-adherence occurs when healthcare providers

prescribe the medicine but is never filled or started. Non-persistence occurs when the patients accidentally miss or stop taking medication after starting it without the advice from a doctor. Non-persistence is usually unintentional and occurs when there is a misunderstanding between the patients and healthcare providers. It may also happen for elderlies who suffer from a decline in functional abilities, such as cognitive, vision and/or hearing impairment, that prevent them from executing their decisions to follow treatment [3]. Hence, there is a need for an assisted Internet based technology to detect and alert the patient to take miss dosage or realignment of medication adherence.

Advancement in electronic technologies and smart mobile applications have helped in medication adherence. Electronic monitoring chip, such as the Medication Event Monitoring Systems (MEMS) [4], has been inserted into medication bottle cap to record the date and time the patient opens and closes the bottle. This system can detect single opening and closing for a single dose but may result in inaccuracy for multiple doses [4]. The device also only records the prescription intake and does not provide any reminder or alert for missing dosage. It is necessary to alert the patients to take the missing doses using device such as CompuMed [5] and mHealth [6]. CompuMed is a medication dispenser that emits an audible tone to remind the patients. It can be programmed at regular to alert the patients to take their medication, with an option to call the patient. Although experimental results from Winland and Valiente have shown fewer missed doses with CompuMed compared to MEMS pill box [5], constantly sending alert at regular interval can be very annoying to the patients. There is also a probability that the patients may miss their medication when they are outdoor as they cannot take the CompuMed with them. The price of CompuMed is also significantly higher than MEMS pill box.

In this paper, we develop a non-intrusive wearable Smart Medication Alert and Treatment Electronic Systems (SmartMATES) and test SmartMATES on 15 participants. SmartMATES uses two 3-axis accelerometer to track the left and right hand gestures and identify the motion of taking a medicine from its packaging and consuming it. Based on the measurement of the accelerometers and the radio signal between the left and right wrists, SmartMATES will detect and only alert the user if he or she forgets misses a medicine prescription. Existing smart phone applications use pre-defined interval to remind the user to take the medication. However, constantly sending alarm to the users can be intruding when the users have already taken the medication. The main contributions of the paper are:

- A real time smart medicine adherence systems system only alert the user if they have not taken the medicine within the prescription time.
- An non-intrusive wearable sensor system that can identify and differentiate between the action of taking medication from other Activities of Daily Life (ADL). These sensor systems can be attached to cardigan or other clothing materials.

The remaining of this paper is structured as follows. In Sect. 2, we present the architecture of the system and the component of the SmartMATES. We describe

the experimental scenario to analysis SmartMATES in Sect. 3. The results from the experiment are discussed in Sect. 4. The paper concludes by highlighting the future works in Sect. 5.

2 System Design

Fig. 1 shows the overall architecture of SmartMATES consisting of three units namely: M-App (A mobile Application), Left MATES Sense (LMS) and Right MATES Sense (RMS).

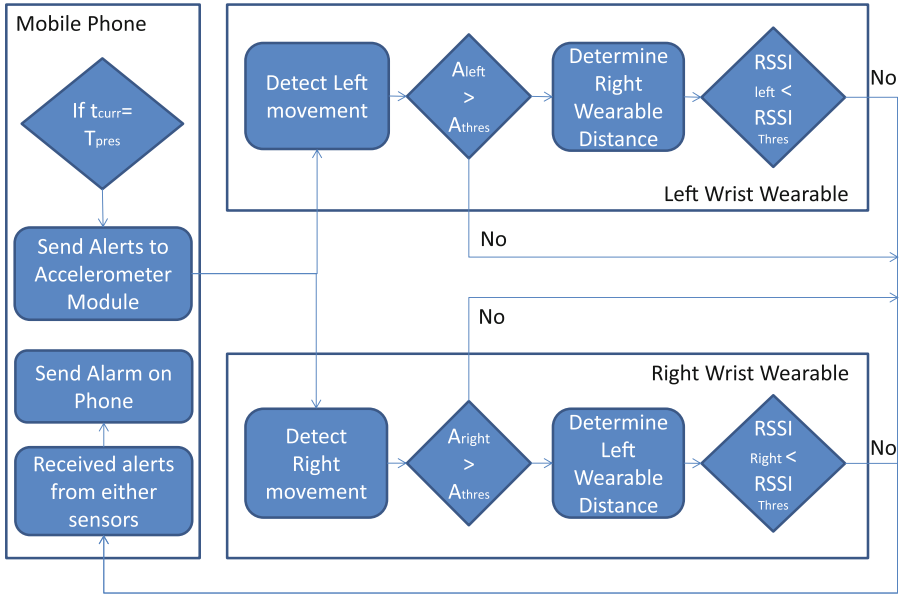


Fig. 1. SmartMATES system architecture

SmartMATES operates on the assumption that *medication intakes generally occur within the same time of day or at a recommended interval*. This assumption is usually true for most medications such as hypertension medication or antibiotics. In SmartMATES, an accelerometer sensor is attached to patient's wrist to monitor the ADL and identify the action of consuming a medication when it is time for a patient medication. Accelerometer is commonly used for gait analysis to detect walking pattern [7] and fall detection [8] using Wireless Sensor Networks [9]. Using the same approach, SmartMATES uses accelerometer to detect non-medication adherence by applying gait analysis on the accelerometer x, y, z to determine the specific pattern feature of consuming the medication. The algorithm used to detect the pattern is an extension of our previous work

in [10]. The system generates an alert on the user's mobile phone if the feature is not observed within the time frame.

The LMS and RMS track the hand movement using the FLORA Accelerometer/Compass Sensor (LSM303) and a bluetooth module. The M-App is a medication management and alerting application installed on the mobile phone. M-App manages and stores the patient medication history and schedule information. When an user first installs the SmartMATES, he or she needs to enter his or her personal and medications details including user name, age, weight, drug name, type, strength, frequency of doses per day, doses intake times, number of doses per intake, and before or after meals. Currently, M-App does not verify the prescription instructions and assumes that all the information entered by the users are accurate. M-App can be extended to check and verify the instructions against a drugs database available in the Internet to ensure that the correct doses are consumed. Once the M-App is configured, the SmartMATES is ready to communicate with LMS and RMS.

3 Experimental Setup

The evaluation of SmartMATES consists of two stages: (i) Identifying the groups of participants and (ii) Deploying in homes with real patients. Our main goal is to demonstrate the reliability of SmartMATES to detect and prevent medication non-adherence and the non-intrusive feature of SmartMATES amongst the users.

3.1 Preliminary Study

We conducted an online survey to identify users had problem in adhering medication schedule. From 155 online participants, 86 respondents have medication adherence problem. 87.2% of non-adherence were caused by forgetfulness while the remaining 13.8% had disability problems that hinder them to take the medicines on time.

3.2 SmartMATES Case Study

From the preliminary study, we randomly selected 9 participants from the 86 respondents. Each participant wore a wrist strap, attached with an accelerometer sensor, on the left and right wrists to track the movement of the hands as illustrated in Fig. 2. The LMS and RMS began to sample the accelerometers at a sampling rate of 100 Hz when the systems received a notification from the mobile phone M-App via the bluetooth. The M-App is configured to trigger the tracking systems on the LMS and RMS five minutes before the patient medication time.

The participants were divided into 3 groups for three experiments. The first experiment was the control group where the participants did not use any tool and rely on oneself to take the medications. To check if the participants missed a medication, a carer was assigned to call and check on the participants remotely daily, five minutes after the prescription time for the patient. In the second



Fig. 2. A wearable accelerometer to track movements RMS

experiment, the participants were asked to install the PillBox, a medication and pill reminder mobile application to help the patients to track and remind their medications. The third and final group of participants wore and used the SmartMATES. The experiment ran for 3 days continuously. The participants were given the prescription to take the medication three times a day.

4 Results

As shown in Table 1, SmartMATES and PillBox have managed to prevent the patients from missing their medication and have achieved 100% adherence compared to manual intervention. In manual, one of the patients has forgotten to take his medication within the five minutes interval after the prescription time and was requiring reminder from the carer to take the medicine in day 3 (Table 1). Although the Mobile App and SmartMATES have achieved 100% adherence, SmartMATES had only triggered an alert to the patient as he has forgotten to take the medication on time (Table 2). Users with SmartMATES have also reported they felt less intrusive as SmartMATES did not raise any alarm if the user have taken the medication compared to PillBox.

Table 1. Medicine adherence for 3 days

Group	SmartMATES	My Pillbox	Manual
Day 1	100%	100%	100%
Day 2	100%	100%	100%
Day 3	100%	100%	50%

Table 2. Number of alerts

Group	SmartMATES	My Pillbox	Manual
Day 1	0	3	2
Day 2	0	3	3
Day 3	1	3	1

5 Conclusion

In this paper, we developed and tested a non-intrusive wearable medication adherence systems, SmartMATES. Although SmartMATES has only been tested for a small sample in short duration, SmartMATES had achieved the same reliability rate with a mobile application. In the future, we would like to test SmartMATES for long term clinical used.

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