MedRem: An Interactive Medication Reminder and Tracking System on Wrist Devices

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Abstract— **Medication adherence is pivotal for effective health outcomes. One of the main reasons behind poor medication adherence is forgetfulness, and reminder systems are often used in addressing the problem. This paper presents MedRem, a novel medication reminder and tracking system on wearable wrist devices. The system is handy and interactive, and it is enriched with several useful features. To address the limitations of the tiny display size of the wrist devices, MedRem incorporates speech recognition and text-to-speech features along with clever interface design. Users interact with the system using voice commands as well as using the display available on the device. A dictionary based training approach is used on top of the state of the art speech recognition systems to reduce the errors in recognizing the commands from the users. The system is evaluated for both native and non-native English speakers. The error rates for recognizing voice commands are 6.43% and 20.9% for the native and the non-native speakers, respectively, when a off-the-shelf speech recognition system is used. MedRem reduces the error to nearly zero for both types of users through a dictionary based training approach. On average, only 1.25 and 15 training commands are required to achieve this performance for the native and the non-native speakers, respectively.**

I. Introduction

Proper adherence to prescribed medications is a fundamental requirement for effective health outcomes. The possible consequences of poor medication adherence include reduced effectiveness of treatments, deterioration of health conditions, longer recovery time, increased cost, irrecoverable damages to health, hospitalization, and even death. Despite the severe consequences, the medication adherence rate among patients is significantly low [1] [2] [3]. According to the World Health Organization (WHO), "Adherence to long-term therapy for chronic illnesses in developed countries averages 50%. In developing countries, the rates are even lower" [1]. Poor medication adherence is a public health problem, and WHO identifies it as a worldwide problem of striking magnitude. It causes about 33-69% of all the medication associated hospital admissions in the U.S. [4].

One of the main reasons for poor medication adherence is forgetfulness. People often forget to take medication at appropriate time, and even sometimes take wrong dosages. Though forgetfulness is more prevalent in people with reduced cognitive ability such as the elderly, it is also very common to healthy and young people due to factors like daily routine, habits, and changes in medication regimen. For example, irregular use of contraceptive pills increases the risk of unintended pregnancy, nonetheless 68.1% of the participants of a study reported missing at least one pill and 48.9% reported missing more than one during a 3-month period [5]. In the study, the average age of the participants is 20.9 years, and forgetfulness is listed as one of the main reasons for missing taking the pills. Several studies show that medication adherence is improved significantly with the use of automated reminder systems [6][7][8].

A number of smart phone applications for medication reminder and tracking are available in app stores [9] [10]. Researchers have also designed, developed and evaluated reminder systems using smart phones [11][12]. However, smart phone apps are not convenient and effective enough for medication reminder and tracking. Though smart phones can be used by one hand when it is laid on or hung against some surfaces, most of the times users need to hold the phone by one hand, and use it by another. Occupation of the hands for using the phones, and the attention required to use the apps justify that smartphone based systems are significantly intrusive, and are not convenient, particularly for long-term and complex medication regimens. Also, smart phones provide limited effectiveness in different contexts as shown in [13]. A user is very likely to miss a reminder at home when the phone is far enough from his/her location at the time the reminder is given. For instance, a user may miss a reminder when he/she is busy in the kitchen, but the phone is in the bedroom far away from the user. Moreover, remainders may be missed while listening to songs, TVs or videos even if the phone is located near the user. In many situations like in meetings and classrooms, smart phones typically need to be kept silent, and users often forget to return the devices back to the non-silent mode when silence is not required any more. It is very likely that a user misses some reminders in such scenarios.

This paper presents MedRem, a novel medication reminder and tracking system on wearable wrist devices. As the device is placed on wrist, it is free from the above mentioned limitations of smart phones. However, one of the major challenges in developing interactive systems for the wrist devices is their form factor. The touch screens available on these devices are tiny and much smaller compared to smart phones and tablet computers. MedRem enables user interactions by incorporating speech recognition and text-to-speech features along with clever interface design. The tiny display of the device is used for minimal inputs and outputs, while a user can retrieve and provide more information from/to the system through voice commands. Personalized models are built and

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updated over time to reduce errors in recognizing users' voice commands, and thus better user experience is provided.

The contributions of this paper are:

- A novel medication reminder and tracking system on wrist devices that is more handy and less intrusive compared to existing systems.
- User interactions are enabled by incorporating text-to-speech and speech recognition features along with clever interface design.
- It is a general purpose medication reminder and tracking system that can be customized according to the patients' needs.
- A novel dictionary based training approach is used on top of the state of the art speech recognition systems to reduce the errors in recognizing the voice commands from the users.
- The technical accuracy of the system is evaluated for both native and non-native English speakers in controlled experiments.
- The dictionary based training approach reduces error to nearly zero for both the native and the non-native speakers with only 1.25 and 15 training commands on average, respectively. In contrast, the error rates of using the off-the-shelf speech recognition systems with no training are 6.43% and 20.9%, respectively.

II. Related Work

To avoid missing important tasks, people use different kinds of reminders, ranging from traditional methods like notes to technology enabled systems like text messages and smart phone apps. With the ubiquity of mobile phones, the use of these devices for medication alerts and tracking has received significant attention from different stakeholders including patients, caregivers, developers, and researchers. Text messages are used for health intervention in several studies [14][15][16]. The text message based systems are not convenient for user interactions and therefore inflexible in re-scheduling reminders and tracking medication. Most of the limitations of the smart phone based systems, as mentioned earlier, are also applicable for the text message based systems.

A number of smart phone applications with different features are available in app stores for providing medication reminders and tracking intakes [9] [10]. A functionality review of 229 of the apps, as reported in [17], shows that many of the apps lack important features like re-scheduling, medication pictures, and data export. For example, only 17% of the apps offered an option to re-schedule or postpone a reminder. Researchers have also designed, developed, and evaluated smart phone based reminder and tracking systems. Wedjat [11] is such a system that provides potential drug-drug/drug-food interaction information to the users in addition to medication reminder and tracking features. UbiMed [12] presents a solution that incorporates smart phone apps to provide reminders, and to support the tracking of prescribed medication for the aging and disabled population. As described earlier, smart phone based systems for medication reminder and tracking come with a number of limitations. A feasibility study [13] reveals some of the limitations.

Smart wearable devices like smart watches and wrist bands are usually enriched with many features like touch screens, microphones, sensors, BlueTooth and Wi/Fi. These devices are being used widely in healthcare applications including activity tracking, wellbeing monitoring, and reminders. Harmony [18] is a hand wash monitoring and reminder system that uses inertial sensors of the smart watches in detecting hand wash activities of the wearer, and Bluetooth beacon based localization technique to trigger reminders when required. A diary like system for diabetes patients is presented in [19] that uses both smartphones and smartwatches to log information from, and provide reminders to diabetes patients. SPARK [20] is a framework that combines smartphones and smartwatches together in monitoring symptoms of patients with Parkinson Disease. It also supports physicians in providing tele-interventions to the patients. Fabian et. al. [21] proposes to show pictures of the drugs on the display of the wrist device to reduce confusion of the patients when multiple drugs need to be taken. Some smartphone apps also synchronize reminders with smart watches [22]. However, these systems use only the small display of the wrist device, and therefore can not provide detailed information related to a reminder using the wrist device only. Also, wrist devices used in the existing systems do not support rescheduling the reminders. Most of these reminder and tracking systems are aimed for specific group of patients or users. In contrast, MedRem is a general purpose medication reminder and tracking system that can be customized according to the patients' needs. It combines speech recognition and text-to-speech technologies with intelligent interface design in providing reminders and tracking intakes.

III. System Description

MedRem is a highly flexible, customizable, and automated system where the wrist devices are connected with a cloud platform. Configurations and updates from the cloud are automatically downloaded to the wrist devices, and data from the devices are also uploaded to the cloud platform automatically. The uploaded data can be used by the caregivers, physicians and other legitimate stakeholders for different purposes including monitoring medication adherence.

A. Operating Script

The core of MedRem is the Operating Script (OS) that contains the list of reminders for a user along with necessary settings and information. When required, the OS is updated in the cloud by the patient or other stakeholders, and the wrist devide fetches the updates automatically. There are two components of the OS, general settings and reminder list. General settings include OS identification number, last date and time the OS was updated, user name, and user preferences that are applicable to all the reminders. Each of the entries of the reminder list contains details of a reminder

```
{
    "id": 1,
    "type" : "daily",
    "time": "2:00 pm",
    "display symbol": "pill_X",
    "message": "Please take a pill of X ",
    "details": "Take the pill after eating. Report your
    physician immediately if there is any side effect.",
    "repetition interval": "00:20:00",
    "repetition period": "05:00:00",
    "repeat message": "Have you taken a pill of X?"
}
```


Fig. 1. Example of a reminder entry in the Operating Script (OS) in JSON format

with fields such as id, type, time, and message. Reminder specific settings are also available in the corresponding entry, and the number and values of the fields in an entry depend on the specific reminder. An example of an entry in the reminder list is shown Figure 1. The "type" and "time" fields indicate that the reminder is provided daily at 2:00 pm, and the "display symbol" field indicates the symbol that is displayed on the wrist device when the reminder is given. The "message" field contains the message that is provided for the reminder, and the "details" field contains more information about the medication. Some other fields from this example reminder entry are discussed later in this paper.

B. Reminder Life Cycle

MedRem allows the users to reschedule or postpone a reminder. When a reminder is provided, if the user doesn't respond or doesn't confirm that the medication is taken, the reminder for that medication is rescheduled at a later time according to the settings of the reminder. In case the user explicitly asks the system to reschedule the reminder at a later time of his/her preference, it is rescheduled according to user's preference instead of the default settings.

A reminder is rescheduled again and again until any of the following occurs:

- The user confirms that the medication is taken
- The user explicitly asks the system to stop rescheduling the reminder
- A predefined period of time is elapsed from the original schedule time of the reminder.

For example, the repetition interval and period of the reminder of Figure 1 are defined as 20 minutes and 5 hours, respectively. So, the reminder is given first at the specified time at 2:00 pm, and it is repeated periodically with a 20 minute interval for up to 5 hours. If the user confirms that the medication has been taken, or he/she asks the system to stop the repetitions, the reminder is not repeated any more. The default repetition interval for the reminder is changed according to user's preferences, if there is any. As an example, consider a scenario when the user is driving and a reminder is provided, but the user needs one more hour before he/she can take the medications. In this case, the user can ask the system verbally to remind him/her after one hour instead of the default interval. This feature allows the user to avoid unnecessary reminders. The life cycle of a reminder is illustrated in Figure 2.

The repetitions of a reminder help the user not to forget the medication, as well as being useful for tracking medication intakes through the confirmation from the user. Stopping the repetitions after a certain period, which is configurable, ensures that a reminder is not repeated irrelevantly or unnecessarily. For instance, the medication that is supposed to be taken at 2:00 pm may be ineffective after 7:00 pm. So, providing reminder of the medication after 7:00 pm is irrelevant. The repetition period as well as the repetition interval can differ among the reminders.

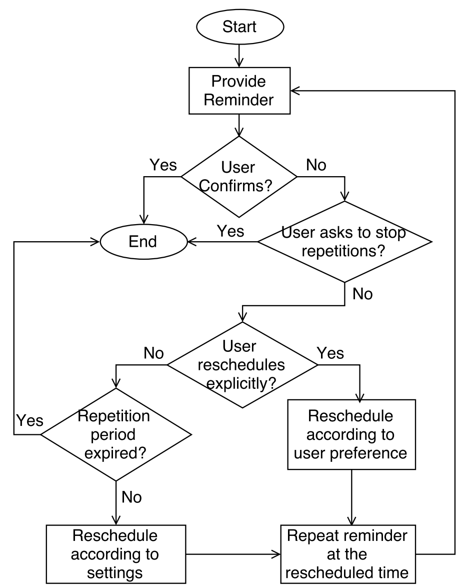

Fig. 2. Life cycle of a reminder

C. Reminder Session

A reminder session starts when the system provides a reminder alert to the user, and ends when the interaction between the user and the device is finished for the reminder. If a user doesn't respond within some time period after the reminder alert is given, the session terminates automatically. Responses from the device are given using speakers only when a user uses voice commands for interactions.

D. System Architecture

MedRem uses a microphone and a speaker along with the touch screen of the wrist device for taking inputs from and providing outputs to the user. The microphone and the speaker work as input and output media, respectively, and the touch screen works as both. MedRem is composed of several modules namely I/O Manager, Network Manager, Schedule Manager, Session Manager, and Storage Manager. The architecture of the system is shown in Figure 3.

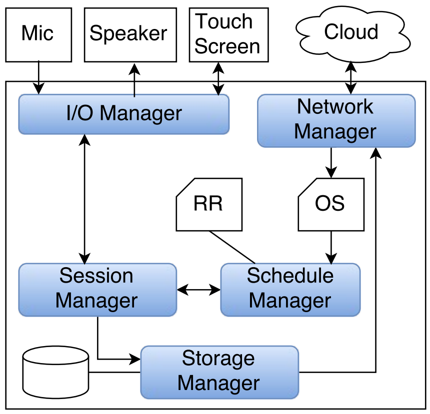

Fig. 3. System Architecture

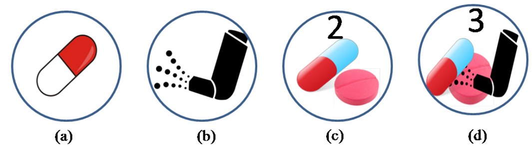

Fig. 4. Some example symbols for a reminder (a) one pill (b) inhaler (c) two pills (d) two pills and the inhaler

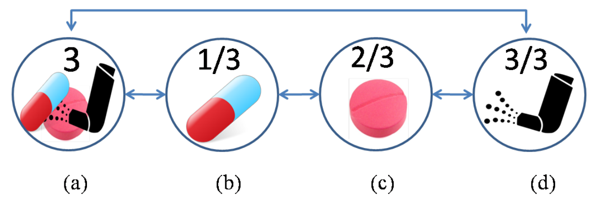

Fig. 5. Example of navigation between pages for a multi-pill reminder.

The Schedule Manager is responsible for scheduling the reminders. It maintains a dynamic list of Repeated Reminders(RR) that contains information about the reminders which need to be repeated. Using the OS and the RR, the Schedule Manager schedules the next reminder session, and details of the next reminder session are sent to the Session Manager that starts the next session according to the schedule. The Session Manager manages the whole workflow of a reminder session, including the recognition of the voice commands. It stores necessary information like medication intake confirmations. Data is stored temporarily on the device, and the Network Manager uploads the data to the cloud periodically. The Network Manager is also responsible to look for and download the updates available in the cloud. The I/O Manager takes inputs from and provides outputs to the user. The Storage Manager helps to organize, store and retrieve data to/from the storage.

IV. Solutions

A. Alerts

To provide an alert, MedRem vibrates the device. Since the device is attached to the wrist, the user gets the alert while the device is worn. The duration of the vibration is a configurable parameter with the default value of two seconds.

B. User Interaction

1) Interactions through Touch Screen: Due to the form-factor of the wrist devices, MedRem displays very few symbols and words on the screen so that they are bigger in size and require very little attention or effort from the user to understand and interact. Different symbols and texts are used for different types of reminders. For example, a symbol of a pill is shown when the user is reminded to take a pill. Customized symbols for the reminders of different kinds of medications help the user to better comprehend about why the reminder is given, particularly when the user needs to take multiple types of medications with different dosages. Examples of reminder symbols are shown in Figure 4. If a reminder is provided for multiple medications, the total number of medications is also displayed on the screen, as shown in Figures 4(c) and 4(d). When a user needs to be provided with critical information like changes of medicine, dosage or schedule, the display is blinked so that the user can easily understand that some important information is available there.

MedRem not only provides reminders, but also tracks medication intakes. Whenever a reminder is provided, either a fresh or a repeated one, the user can confirm medication intake just by clicking the display. It ensures medication tracking with minimum intervention. If the user hasn't taken the medication, the reminder session can be closed by double clicking on the display, or just by leaving as it is. For the later case, the system automatically closes the reminder session as well as the display after some predefined time period. In case the medication intake is not confirmed, the reminder is rescheduled at a later time, as described earlier.

In cases where a reminder is given for multiple medications, a display page for each of the medications is available in addition to the combined display (Figure 5). Users can navigate between different pages through sweeping the display to the left or to the right. If the user has taken all the medications when the reminder is provided, he/she confirms it just by clicking on the combined display (Figure 5(a)). However, if the user has taken some of the medications, that can be confirmed by navigating to and clicking on the corresponding pages. This navigation feature enables easy tracking of partial medication intakes.

Although limited, the interactions supported in MedRem through the device screens are very useful when the users do not need or prefer voice interactions. Most of the times, the user understands the reminder by just getting the vibration and/or looking at the display.

2) Interaction through Voice Commands: There are cases when the touch screen is not feasible for exchanging information between the user and the system. MedRem addresses the limitation of the touch screen through enabling voice interactions. Listed below are some of the scenarios when voice interactions are used.

- When the display flips, the user understands that there is some important information there. The user can command the system to provide the information.
- The user needs more information about a reminder beyond what is displayed on the screen.
- The user needs to reschedule the reminder at a later time of his/her preference.
- The user needs to record some information related to the medication.
- The hands of the user are occupied, and the user wants to confirm medication intake.

To ensure that MedRem doesn't talk in the contexts where the user doesn't prefer it to, voice interaction is started during a reminder session only when the user provide some specific commands, known as 'session initiators'. For example, users can use any of the words of "$System$", "$Reminder$" or "$Device$" as session initiator. After providing a reminder, if the system recognizes any of these session initiators, it starts talking with the user. Words like "Hi" or "$Hello$" can be added in front of the session initiators to reduce the possibility of starting voice interaction during natural conversations in the user's environment where the user does not intend to start voice interaction with the system, but he/she or someone else nearby utters the session initiator keywords.

MedRem doesn't require strict format for any voice command except the session initiators. Users provide voice commands with more natural expressions, but including the required keywords. For example, if a user wants to reschedule a reminder after half an hour, possible command expressions include, but not limited to:

"$Remind\ me\ after\ half\ an\ hour$"
"$Remind\ after\ thirty\ minutes$"
"$Please\ ask\ me\ after\ half\ hour$"

Here, the command expressions need to include any of the keywords "$remind$" and "ask", as well as it should include a specific interval. In cases when the user provides some information or instructions to the system like medication intake confirmation or about rescheduling a reminder, the system repeats what it recognizes to make sure that the information is not recorded incorrectly. If the system does not recognize the command properly, the user can repeat the command. A user can also ask for the same information repeatedly during a reminder session.

It should be noted that 'Command' or 'Voice Command' in this paper denotes the word or the sequence of words that a user speaks to the system. For instance, the sentence "$I've\ taken\ medicine$" is also considered to be a command. Examples of command keywords, their purposes, and some possible voice commands associated with the keywords are listed in Table I. The command keywords along with their purposes are configurable in MedRem. Even the session initiator keywords can be changed. This feature allows customized options for any user or user group.

C. Voice Command Recognition

MedRem uses off-the-shelf speech recognition tools like the Android Speech Recognizer [23] that are available on the smart wrist devices. The actual commands provided by the users, and the words generated by the speech recognition system often differ significantly, particularly for the non-native speakers. Though the problem is less severe for the native speakers, the errors reduce usability of the system and result in poor user experiences. Here, the actual text representation of a voice command, and the text output of the speech recognition system for that command are denoted as Actual Command Text (ACT) and Recognized Command Text (RCT), respectively.

To support the users in providing voice commands in a more natural way, regular expression based techniques are used in the system. A set of regular expressions are defined corresponding to the command keywords. Table I shows some command keywords along with the corresponding regular expressions. An ACT or a RCT is valid if it matches with one and only one of the regular expressions defined in the system, otherwise it is invalid. The voice command recognition process in MedRem is depicted in Figure 6. Whenever a user provides a voice command to the system, the speech recognition tool is used to retrieve the RCT for that command. If the RTC is valid, i.e., it matches with one and only one of the regular expressions defined in the system, the command is recognized, and the corresponding action is carried out. Otherwise the RCT is searched in a dictionary that maps invalid RCTs to ACTs. If the RCT is found in the dictionary, the command is recognized using the corresponding ACT. If it is not found, the user is requested to train the dictionary. The voice command or dictionary training process is described in the following subsection.

D. Voice Command Training Process

MedRem uses a personalized dictionary for each of the users where a dictionary for a user is empty when the user starts using the system, and it is populated over time with RCTs and ACTs from the user. When a command is not recognized by the system, i.e., when a RCT is invalid, the user provides the corresponding ACT to the system as text. Since the screen of a wrist device is not feasible for text inputs, a device with larger display like a smartphone or a desktop computer is used for the ACT inputs. The watch is connected to the larger device using Bluetooth and/or WiFi. The ACT provided by the user is tested for validity first, and if the ACT is valid, the RCT and the ACT are entered into the dictionary. This pair of RCT and ACT is used consequently to recognize a voice command from the user that generates the invalid RCT. Thus, the errors in recognizing voice commands are reduced over time. It is not necessary for a user to train the system immediately after a command is not recognized, rather the system can be trained later at a time convenient to the user.

TABLE I
EXAMPLES OF COMMAND KEYWORDS, THEIR PURPOSES, REGULAR EXPRESSIONS AND RELATED COMMANDS

Command Keywords	**Purpose**	**Regular Expression**	**Example Commands**
System | Reminder | Device	Session initiation	(Hi|Hello)? (System | Reminder | Device)	System Hello Reminder
detail | more	To get more information about the medication.	.* (detail | more) .*	Details please Give me more information Tell me details
repeat | what | say again	To ask the system to repeat what it just told.	.* (repeat | what | say .* again) .*	Say it again please Please repeat it What?
done | taken	To confirm that the medication is taken.	.* (done | taken) .*	I've taken it I'm done
yes | no	Answer to a yes/no question from the system.	(yes|no) .*	yes yes, I've taken no
okay | ok | thank	To terminate a reminder session.	.* (okay | ok | thank) .*	Okay Thank you Okay thanks
remind | ask + later | after specific time	To ask the system to remind later (after a predefined time interval) or after the interval the user prefers.	.* (remind|ask) .* (later | after TIME) .* TIME → NUM hour (and)? NUM minute | NUM hour | NUM minute NUM→ number (and half)? | half	Remind me after half hour Ask me after one hour and thirty minute Please remind me later
don't remind	To ask the system not to remind again.	.* (don't remind) .*	Don't remind again Please don't remind

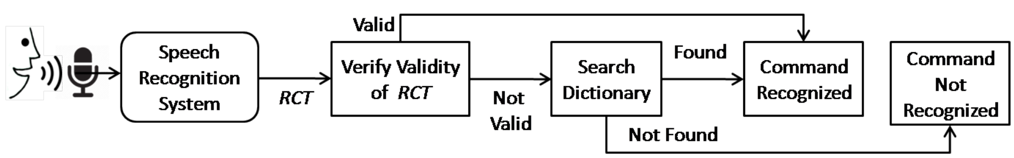

Fig. 6. Voice command recognition process

E. Cloud Connectivity

The wearable devices used in MedRem are equipped with Bluetooth and Wi-Fi capability. In cases where Wi-Fi access is available, MedRem uses it to connect to the cloud. Otherwise, the wrist device is connected to a smartphone using Bluetooth, and then the system connects to the cloud through the smartphone.

F. Energy Efficiency

Due to the form factor of the wrist devices, the capacity of the batteries available in the devices is typically very low. So, any system for these devices needs to be energy efficient. MedRem uses the display, the microphone, and the speaker only during the reminder sessions. A reminder session typically runs for very short time, usually less than a minute. As stated before, if a user doesn't respond to a reminder within a predefined time period after the reminder is given, the reminder session terminates automatically. The time period is a configurable parameter with a default value of 10 seconds. When a reminder session ends, MedRem schedules the next reminder, notifies the underlying operating system of the device about the schedule, and moves to hibernate state. The underlying operating system wakes MedRem up according to the schedule. So, the energy consumption by MedRem depends upon how many reminders need to be provided within a time period, and how long the reminder sessions run. The total time MedRem runs per day is likely to be few minutes, and so it doesn't consume significant energy.

To save energy, automatic upload or download of data to/from the cloud is carried out very sparsely, only once a day by default. However, the frequency can be configured according to the need of the users. If a user needs MedRem to transfer data immediately, that can be done just by pressing a button available in the MedRem app in the wrist device. This approach of data exchange between the wrist device and the cloud platform ensures that very little energy is consumed without compromising the needs of the users.

V. EXPERIMENTS

An application has been developed using the ASUS Zenwatch2, an Android powered smart watch that comes with a microphone, a speaker, and a 1.63 inch touch screen. The application converts the voice commands into texts using the speech recognition engine available in the Android platform, and then verifies the validity of the recognized command texts (RCTs) using the regular expressions defined in Table I. If a command expression is valid, a predefined response corresponding to the command is provided to the user. For a command that is invalid i.e. that is not recognized by the regular expressions, the application informs the user that it can not recognize the command. The watch provides the responses verbally using the speaker as well as by showing information on the display of the watch.

A. Data Collection

Data has been collected from 4 native and 6 non-native English speakers. The native speakers are from U.S., and the non-native speakers are from Bangladesh and China. The participants in the study include undergraduate students, graduate students, faculty and a housewife. The participants are provided with mock reminders on the smart watch, and they interact with the system using voice commands. The experiments are carried out in a semi-controlled environment where the actual voice commands provided by the users to the system (the ACTs) and the command text generated by the Android Speech Recognizer (the RCTs) are recorded by a second person. There is no constraint on the number or order of commands to be used for each of the reminders. A total of 292 reminders are provided to the participants, and a total of 1142 commands from the participants are recorded for the reminders. 182 of these commands can not be recognized by the application that uses the Android Speech Recognizer only with no training or dictionary. It should be noted that the participants use several commands in a reminder, on average, for the purpose of the experiment. Also, similar commands are repeated during many of the reminder sessions. In real deployments, the average number of voice commands used during a reminder session is likely be smaller.

B. Analysis

The performance of the system in recognizing the voice commands is evaluated for two types of training approaches: leave one person out ($LOPO$) training and personalized training. Here, error rate is defined as the ratio of the number of commands the system fails to recognize and the total number of commands given.

In the $LOPO$ training, commands from each subject are tested using a dictionary that is trained by the unrecognized commands (the invalid RCTs) of the other subjects. Figure 7 shows the error rates both when only the speech recognizer is used and when the dictionary built from the $LOPO$ training, called the $LOPO$ dictionary, is used on top of the speech recognizer. As shown in the figure, the error rates are 6.43% and 20.9% for the native and non-native speakers, respectively, when no dictionary is used. Using the $LOPO$ dictionary with the speech recognizer reduces the error rates to 2.96%, and 12.88%, respectively. As several of the invalid RCTs of a subject do not match with those from the other subjects, it is manifested that many of the errors are not generic, rather they are person specific.

For the personalized training, the dictionary for a user is built and updated with the unrecognized commands from him/her in the temporal order the commands are provided. Figure 8 illustrates how errors are reduced with the average number of commands used in training the system. The error rates are reduced to nearly zero after using 1.25 and 15 commands, on average, for the training of a native speaker and a non-native speaker, respectively. Once the system is trained for an unrecognized command, the command is recognized later if the same RCT is generated even though the RCT is invalid. So, the error rate reduces over time by the training process. The required training effort from a user depends on the variety of command expressions used by the user as well as factors like his/her pronunciation and accent that are associated with speech recognition accuracy. The average number of training commands required to achieve nearly zero error is small due to the fact that a limited number of command keywords are defined in the system, and the varieties of the command expressions used by the users are generally not large.

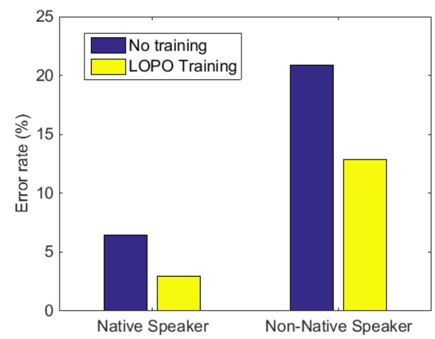

Fig. 7. Error rates in recognizing intended voice commands using speech recognizer only (No training) and using speech recognizer with leave-one-person-out (LOPO) training

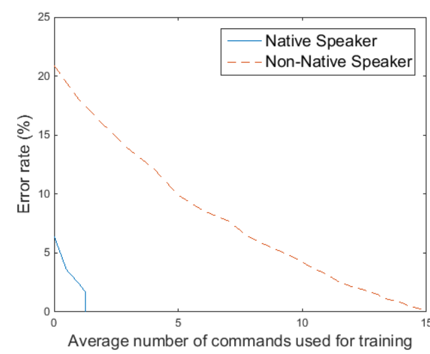

Fig. 8. Reduction of error rates with personalized training

VI. Discussion

As expected, the error rate of speech recognition by the state of the art system is much higher for non-native speakers compared to native speakers. The performance of the speech recognizer also differs for native speakers with different accents. The dictionary based training approach enables MedRem to be robust in recognizing command even from non-native speakers. Though the system is evaluated using English language only, the design of the system is language independent. Beyond the purpose of a medication reminder and tracker, MedRem can be used for other purposes like providing reminders for exercise and other daily activities, and for tracking well-being of the users. For instance, MedRem can be configured to ask the users periodically about their physiological conditions and to record the feedback.

One of the limitations of our experiments is the lack of real world deployment. Previously unseen problems along with new issues are often observed when a system is used in real world settings. The effectiveness of MedRem in improving medication adherence has not been explored in this study. However, studies show that automated reminder systems are effective in improving medication adherence, as mentioned before. Considering that MedRem comes with several useful features, and it overcomes many of the limitations of the existing automated systems, it would be more effective in improving medication adherence compared to the state of the arts. MedRem can be extremely useful for people with visual impairment, Essential Tremor, Parkinson Disease, and/or other disabilities. In the future, different aspects of MedRem like its effectiveness and usability will be studied through long term and real world deployments.

To reduce interventions in tracking medication intake, automatic medication tracking features can be integrated into the system. The sensors like the accelerometers and the gyroscopes embedded into the wrist devices can be used to monitor medication intake through tracking the hand movement of the users. Automatic tracking of the medication using the wrist device will be explored in future endeavors.

Smart wrist devices can be used for multiple useful purposes beyond just as a timepiece, and so the use of these devices has proliferated in the recent years. MedRem can be installed as an additional application on these devices with no/very low additional cost.

VII. Conclusion

This paper presents MedRem, a novel medication reminder and tracking system on wrist devices. State of the art speech recognition tools are combined with novel approaches that makes the system very usable and robust. Experimental results show that with very little efforts from the users, only 1.25 and 15 training commands on average for native and non-native English speakers, respectively, MedRem achieves nearly zero error in recognizing users' voice commands. As literature shows that medication adherence is improved significantly with the use of automated reminder systems [6][7][8], and as MedRem overcomes many of the limitations of the state of the art, this system would be very effective toward improving medication adherence.

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