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Design of a Context-Aware Model to Enhance Medication Adherence

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Abstract— **Medication adherence is important to patients who suffer from chronic disease. Regular medication activity reduces the cost of caring disease and prohibits the worsening of disease condition. To support patients taking medicine correctly, we developed a medication assistance system which alarms medication situation through multimedia messages and help patients to take a medicine. To enable the system copes with various situations related to a medication service, we designed a medication context model and implemented a state based context aware application. We also applied our system to patients and saw a little improvement in medication adherence.**

I. Introduction

DUE to the advancement of medical technology, aging society is becoming a worldwide issue. As the population of the elderly grows, people who suffer from chronic disease - hypertension, diabetes, heart disease, and etc - increases rapidly. In caring them, managing medication is an important factor to improve their status. In the research of Sokol[1], concerned about medication, assisted that improper medication of patients causes the society to exhaust uncountable healthcare cost. So just taking a medicine in proper time can improve the condition of a disease.

People sometimes make little of taking medicine and they intentionally don't take medicine, but mostly, they tend to forget to take medicine. The situation is occurred more frequently among aged persons. For this reason, there needs to be a method of assisting them to take medicine in proper time with proper ways. In doing such a work, context-aware application can be a solution responding to requirements related on medication service.

Following the requirement, we developed a system which supports patients to take medicine properly based on a context-aware approach. The system manages the medication schedule and, if it is time to take medicine, alarms the patient to take medicine. The system also recognizes whether he takes a medicine or not by using sensors in the pillbox and records the medication history for a later analysis of a medication pattern by the doctor. Moreover, it alarms using SMS when the patient is going out. We devised a smart medication pillbox to store the package of pills and dispense it to the user.

In earlier commercial products of medication assistants are mostly a kind of simple plastic case. They just deposit the medicine at several holes of the case. Medication time is set up using timer and the case alarms when time is on. This type of device is simple, but the user hardly expects the valuable services and there's no way to recognize whether the user takes a medicine or not. Due to increasing interests about medication assistance, a lot of systems have been researched and developed[3][4][5][6]. Among them, S. Vurgun et al.[5] developed a smart medical system to monitor the user and handle the medication. They used several sensors such as ultrasonic and PIR to monitor the user's action and location, and indicated the reminding message through PDA or mobile phone. To analyze the medication status, they used Bayesian network based reasoning engine. The system recognizes the user's status and infers the service based on the situation. But the inference model is based on the learning algorithm, training data have to be made before the operation.

In this paper, we suggested a context model for the medication service and a context management method to interpret situations and provide a service corresponded with each situation. Usually, the inference method, which recognizes the situation and decides the service related on the context in a context-aware application, can be made up of rule based method, for example, using inference engine like Jess, or various machine learning algorithms, such as HMM and etc. In our previous research[2], we developed a rule based inference method using Jess inference engine. It was sometimes complex in describing situations and relation models using rules, and had difficulty in tracing the situation by examine numerous facts in the model. In a case of a medication service, the situation and context is simple and clear, so there needs more simple method to describe and interpret the situation. So, we designed the situation as a state model and expressed the related services as a state transition diagram.

In the section 2, we explain the concept of our system and describe the context model. We show the implementation result and evaluate the system in the section 3. Finally, we summarize our work and discuss about the future work in the section 4.

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II. METHODS

A. Medication Monitoring System

The service concept of our medication assistance system, PROMES (PROactive MEdication System), is presented in Figure 1. Using the pillbox and the display, medication service is provided by the user followed by the current situation. The system is composed of a smart pillbox, medication assistance application, and digital display.

Smart pillbox plays roles of a medicine dispenser and message indicator. It is composed of 4 medicine containers, buttons with LED, infrared sensors, and a LCD. It deposits medicines which are packed in a paper bag; most pharmacies fill a prescription in a kind of paper bag in Korea. As it is usually prescribed in long term periods to the patients with chronic disease, the pillbox is designed to deposit more than 30 bags in each container. When it is time to take medicine, the pillbox alarms by displaying simple message to the LCD and lightening the button LED assigned to each container. If the user pushes the button to take medicine, the pillbox discharges the medicine bag to the user. It recognizes whether taking a medicine or not by sensing whether the bag is discharged or not.

Medication Assistance Application carries out two core functions. First, it manages patient information and their medication schedule. It also manages a pillbox and assigns the schedule to the pillbox. It summaries a medication pattern of a user and displays a medication status of him. Second, it gathers sensor data from the pillbox and the display and recognizes the situation of medication status. By organizing the button, sensor, and time of the schedule, the application infers the medication context and prepares a service proper to a given situation. If it is needed to send a short message to a mobile phone, the application sends an alarm message through a SMS server. The application is executed in PC.

Digital display acts as a graphical message provider. It displays various types of messages in a user-friendly view and informs the current medication status. It displays images of user's interests when there isn't any particular message and, if there is a message to inform, the application pops up and displays the message.

Based on the system, usage scenarios can be summarized as next:

If there is a medication schedule at 10:00 am and time is on, the display alarms to take a medicine. It directs a container to use and turn on the LED of that container. When the user presses wrong button, the display alerts that wrong container is selected. If the user presses the correct container button, the pillbox discharges the medicine bag and shows the instructions about taking medicine, and the system record the schedule is finished normally. If it is not a time to take medicine and the user presses a button, the system alerts that it is not a time to take medicine. If the user presses the same button again, then the system treats the situation as the user is willing to take out the medicine for outgoing purpose, so it discharges the medicine and record the schedule as outgoing state. When time comes, the system sends a short message to user's mobile phone to alarm to take.

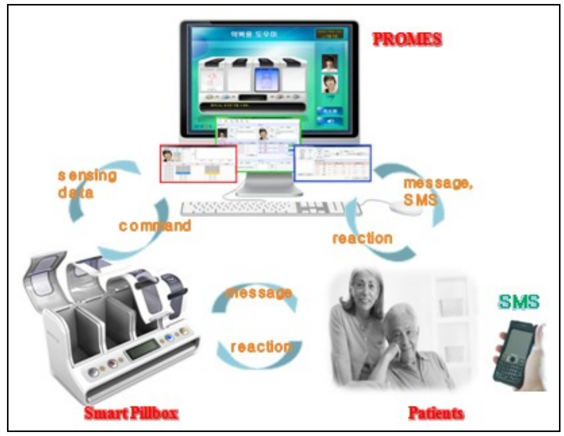

Fig. 1. Concept of a Medication Service.
Pillbox deposits the medicine and the application recognizes the medication situation and generates services. Alarm messages can be provided to the user through a pillbox, display, and mobile phone. Patients can push a button or touch display to get a medicine or to see the schedules, and so on.

The architecture of the system simply can be defined as showed in figure 2. The system monitors the pillbox and touchable display as thread. Sensed data are merged and delivered to the context inference step. When the situation is identified, actuation step is processed to organize messages and output them via related devices.

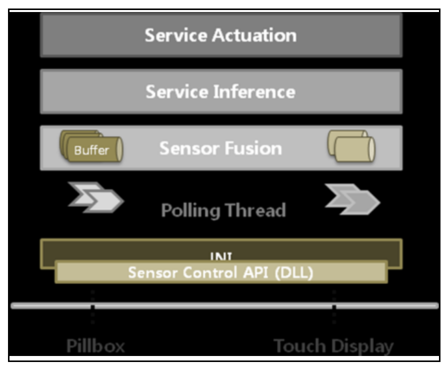

Fig. 2. Architecture of the system

B. Context Model

In designing the context model, we first identified the service to be provided. To be helpful the system to the user, we thought our system has to provide functions below:

Notifying The system has to inform the notification related on medication. For example, the system notifies to take a medicine when it is time to take medicine.

Warning The system has to catch up the wrong actions by the user. When user doesn't take a medicine, the system has to report that to the family or caregiver.

Recording The system has to record the medication status. To analyze the medication pattern and find out whether the medicine is effective or not, the system has to record whether the medicine is taken or not, and when it is done, and etc.

Error Reporting There may be problems in the pillbox, for example, no medicine is in the pillbox or fails to discharge medicine due to jam of medicine bag. The system has to inform it to user and lead to the problem is being solved.

We identified the 13 service situations of the medication in the basis of these requirements. First, the state of the final medication schedule condition can be defined as 4 states – *Taken*, *Not_Taken*, *Outgoing_Done*, and *Unknown*. *Taken* is a state that user takes the medicine normally. *Not_Taken* means that user didn't take the medication in time. *Outgoing_Done* is a state that the system notified to take medicine on an outgoing schedule. *Unknown* is a state that the system is off and it cannot know whether medicine is taken or not. The system judges the final state of the schedule as one of them.

Before the final state is decided, there are several temporal states. *On_Time* is a state that it is time to take medicine. *Discharge* represents a state that the pillbox is discharging the medicine. If the medicine is discharged, *Taken* or *Outgoing* is transited. *Outgoing* is a state that discharging is done for outgoing and the time is not on yet. *On_Time_Outgoing* occurs when the schedule of outgoing medicine is time to take. *Fail_Discharge* is a state that the pillbox failed to discharge the medicine for some reasons. *Button_Incorrect* means that user presses the wrong button to discharge medicine. *Button_Pushed* is a state that user presses the button despite not the time to take medicine. In such situation, if the user pushes the button again, then the system regards user as taking out the medicine for outgoing purpose, and discharges the medicine. *Empty* is a state that there are no medicine bags in the pillbox.

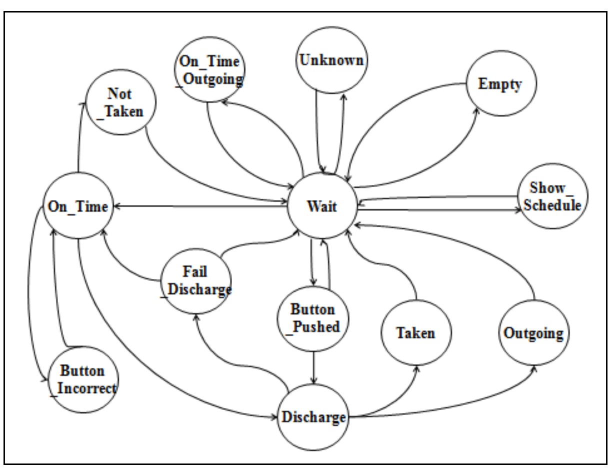

Fig. 3. State Transition Model.
Starting from the *Wait*(default) state, the application transits the state based on environment data. If the state reaches to one of final states – *Taken*, *Not_Taken, Outgoing_Done, or Unknown*, the schedule is changed to next and the state is initialized to *Wait* state.

The state *On_Time*, *Outgoing*, *On_Time_Outgoing*, and *Show_Schedule*, belong to categories of *Notifying*. *Not_Taken*, and *Button_Incorrect* states belong to *Warning* category and, *Fail_Discharge* and *Empty* can be contained in *Error Reporting* category. All final states belong to *Recording* category. Some state can under more than 2 categories, for example, *Not_Taken* belongs to both *Warning* and *Recording*.

Table 1 shows conditions of the state to be satisfied. Based on the previous state, if all conditions are met, then the state translation is occurred to other state. The criteria of changing the state are time, types of button pushed, fact that discharging is detected, types of touch pressed, and types of schedule state.

Table. 1. State transition condition
Based on the previous state and condition values, current state is decided. For example, in *On_Time* state, if the button is pressed then the state is changed to *Discharge*. Similarly, if the sensor detects discharging of medicine bags in the *Discharge*, then the state is changed to *Taken,* and so on.

State	*Condition*				
	Time	Button	Discharge Sensor	Touch	Schedule State
On_Time	on	off	-	-	undone
Button_Illegal	on	on_diff	-	-	-
On_Time_Outgoing	on	-	-	-	out
Button_Pushed	off	on	-	-	undone
Discharge	on	on	-	-	-
	on	-	-	schedule	-
	off	on_same	-	-	-
Fail_Discharge	-	-	off	-	-
Show_Schedule	off	-	-	user	-
Taken	on	-	on	-	undone
Not_Taken	over	-	-	-	undone
Outgoing_Done	on	-	-	-	on_out
Unknown	over	-	-	-	Initial
Outgoing	off	-	on	-	undone

III. RESULTS

Depending on the service model, we implemented a medication assistance system. Figure 4 shows an implemented system and the status of monitoring the medication.

A. System Implementation

As described in chapter 3, the system is composed of pillbox, application, and display. To control the sensor and several HW units in the pillbox, we implemented an embedded application, which is operated in AVR processor. It mainly controls the pillbox itself and translates data to PC through USB connection. The application which infers the status and actuates the service is in PC. We utilized the APIs of legacy vendors to send a short message.

(a) (b)

Fig. 4. PROMES system implementation
(a) shows an arrangement of system components. An alarm contents are transferred to user through images of display, messages of pillbox, and voice over speaker. (b) show the medication monitoring status of the system. For each user, daily taken status is indicated.

B. Evaluation

To evaluate the system, we applied it to elderly patients with chronic disease - hypertension or heart disease - and monitored the medication activity about a month. The experimental group is organized in 10 elderly who take medicine at least one time every day. Most of them live with their family and we got a feedback not only from the participants but also from their families. We measured the adherence as the ratio of medicines actually be taken over total medicines have to be taken.

In the results, most of the participants used the system and the average adherence ratio is over than 65%. Table 2.(a) shows that the adherence ratio of male is higher than that of female and (b) shows that adherences of age 40s and 60s is higher than that of age 70s. Actually, one female participant of age 70 repeated entering and leaving the hospital during the experiment, so we had a difficulty in measuring the adherence of her.

Table. 2. Adherence measured
(a) shows the adherence ratio by gender, and (b) show the adherence by age

(a)

Gender	*Number of participants*	*Adherence ratio(%)*
Male	3	77
Female	7	66

(b)

Age	*Number of participants*	*Adherence ratio(%)*
40s	1	75
60s	4	78
70s	5	61

One month later, we interviewed participants and their families. They were affirmative to the system and commented that the system is useful and it is worth buying to care their health.

IV. Discussion and Conclusion

We designed and implemented a medication assistance system to enhance the medication compliance of the elderly with chronic disease. We applied our system to the elderly in real life and measured the medication adherence. We got adherence ratio over than 65, which is higher than average adherence ratio, 50%.

The system seems to be useful, but there exist some problems to solve. All computational processing is executed in the PC, but it is a burden to use a PC to only to offer medication service. So, we are porting our application into the pillbox to provide a service only using it. And we are also developing server based prescription managing method to handle and synchronize schedules with a pillbox.

In the future, we expect to be evaluated the effectiveness of the system is estimated as an aspect of the healthcare's view, for example, how much the medication adherence is enhanced and how much the condition of a disease improves.

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