31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Dosing Monitoring System Using iMec and Ubiquitous Sensors

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***Abstract*—Recently, the number of senior citizens who are living alone and taking medicine is increasing due to population aging. Since these people have many risks of incorrect dosing, their caretakers living at a distance are concerned about their health. Therefore, we developed iMec (intelligent medicine case) and propose iMec system that is composed of iMec and ubiquitous sensors. The system can support correct dosing of recipient and dosing monitoring of their caretakers. The iMec is a medicine case that not only detects medicine in the medicine case by image processing but also notifies about dosing timing and dosage by touch display and speaker. The ubiquitous sensors assist the iMec to decide dosing timing. We have confirmed the validity of the image processing methods by experiments.**

I. Introduction

RECENTLY, as a social problem, declining birthrate and population aging make the number of senior citizens who are living alone increase. In general, since these people have many risks for solitary death, their families living at a distance are concerned about their health.

Usually, the number of senior citizens who are taking medicine regularly is large. They sometimes induce incorrect dosing such as “forget to dose” and “overdose” as shown in Fig. 1, because of cognitive deterioration. Since incorrect dosing decreases the efficiency of the medicine and may lead to serious accident, some dosing monitoring systems have been developed [1]-[3]. For example, “MedSignals” notifies predetermined dosing timing by speaker, confirms whether the flap of the medicine case has opened, and provides that information to caretakers at a distance [1].

Since the medicines are taken periodically (e.g. after every meal, before going to bed), we could suppose if the person is alive by using the dosing condition. Some systems that watch daily life of senior citizen by using sensors are being developed. For example, “i-Pot” monitors the usage of electric pot and notifies them to his/her caretakers living at a distance [4]. But there are no systems that monitor dosing condition and use that information for life monitoring.

In this paper, we propose a dosing monitoring system named “iMec system”. iMec is a medicine case that can sense whether the medicine was picked up correctly by using camera. The iMec system is a system that is composed of iMec and ubiquitous sensors embedded in senior citizen’s house. With these sensor data, the system can notify a senior citizen about the correct dosing timing for not forgetting, can monitor if a senior citizen is likely to overdose, and can notify if a senior citizen is alive to his/her caretakers at a distance.

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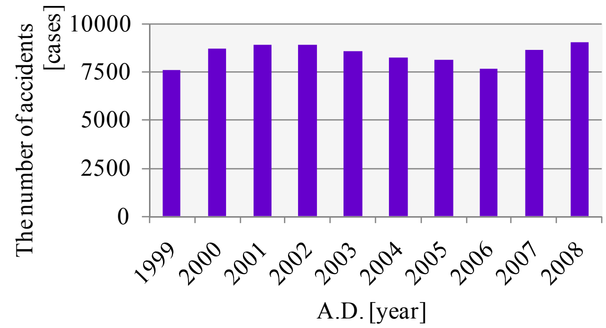


Fig. 1. Domestic accidents related to incorrect dosing in Japan.

II. Configuration

The configuration of iMec system is shown in Fig. 2. The iMec system is composed of iMec (intelligent medicine case) and ubiquitous sensors. As shown in the Fig. 1, the recipient is the person who takes medicines from the iMec regularly. The caretakers are the persons who monitor the recipient health regularly and restock medicines into iMec periodically.

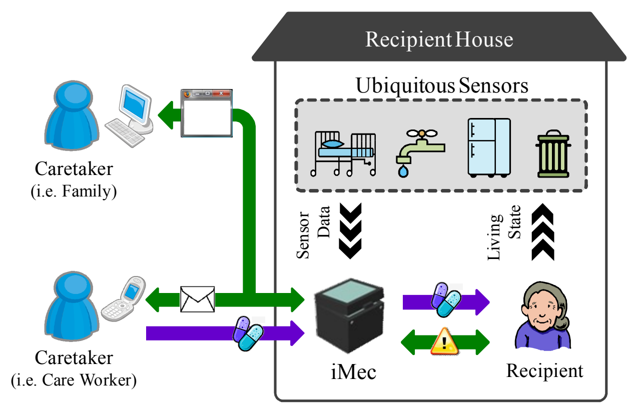


Fig. 2. Configuration of iMec System.

A. Ubiquitous Sensor

Some medicines should be taken every several hours. Also, most of medicines should be taken according to living states of the recipient (see right column of Table I). In order to notify dosing timing correctly, the iMec system should estimate recipient states related to dosing timings (see left column of Table I). The states include “eating” and “sleeping”. The relationship between recipient states and dosing timings is shown in Table I.

In order to estimate the recipient states, the iMec system measures recipient behaviors by using the ubiquitous sensor. The ubiquitous sensors are various sensors which are embedded in the recipient house invisibly in order not to bother the recipient and invade the recipient privacy.

TABLE I
RELATIONSHIP BETWEEN RECIPIENT STATES AND DOSING TIMINGS

Recipient State	Dosing Timing
Eating State	Before Eating
	During Eating
	After Eating
	Between Eating
Sleeping State	Before Sleeping
	After Sleeping

B. *iMec*

Since it is very important to take medicines correctly according to prescription, the caretakers should confirm if the recipient take the correct amount of medicine. Therefore, iMec should be able to confirm if the recipient picks medicines up correctly and notify about the correct dosing timing and correct dosage instead of the caretakers to reduce their burden. We are assuming that iMec is restocked by caretakers since it is difficult for recipient to restock medicines correctly.

Notification of dosing timing and dosage should be displayed simply and retrieved easily because the system is used by elderly recipient. And, in order to maintain cognitive ability of elderly recipient, the system offers minimum supports. Also, the size of iMec should be large enough to make recipient aware of the dosing. As a medicine case, the number and the size of storage spaces should be customizable since dosing schedule may vary (e.g. three times a day, four times a day).

C. *iMec System*

As we mentioned in section I, "forget to dose" and "overdose" cause perilous situations to the recipient. In this paper, we define "forget to dose" as the dosing condition where the recipient forgot to take the medicines at correct timing and "overdose" as the dosing condition where a recipient took an excess amount of the medicines instructed in prescription.

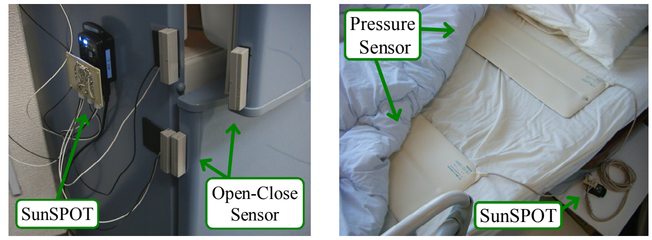
The iMec system should recognize both of "forget to dose" and "overdose" conditions by using iMec and ubiquitous sensors. When the system detects that the above mentioned incorrect dosing is about to occur, it should notify the recipient and the caretakers to prevent it. The system should also accumulate the dosing condition as the dosing history, which will be used for dosing monitoring.

III. IMPLEMENTATION

A. *Ubiquitous Sensor*

1) *Installation*

As ubiquitous sensor, we use seat type pressure sensors and magnet type open-close sensors. To transfer sensor data of the ubiquitous sensors to the iMec by wireless, we use SunSPOT that has wireless communication module and 4-channel A/D converter. Ubiquitous sensors are connected to the A/D converter port of SunSPOT. We have installed ubiquitous sensors in the recipient house as shown in Fig. 3.



(a) Sensors in Kitchen (b) Sensors in Bed

Fig. 3. Ubiquitous sensor.

2) *Eating State Estimation*

In order to estimate the eating state, the iMec system uses pressure sensors and open-close sensors as ubiquitous sensor. The pressure sensors are laid on a chair seat for eating and on the floor in front of a kitchen unit. The open-close sensors are used to sense the usage of appliances by attaching them to the door of the microwave oven, on the door of the refrigerator, on the operational panel of the IH cooking heater, on the flap of garbage box, and etc.

Fig. 4 shows the procedure of eating state estimation using behavioral flags. At first, the system is at "Normal State". If "Before Eating Behavior" is turned on, the state will transfer to "Before Eating State". If "During Eating Behavior" is turned on, the state will transfer to "During Eating State". If "After Eating Behavior" is turned on, the state will transfer to "After Eating State". And then, "Two Hours Later" (two hours have passed), the state transfers to "Between Eating State". When another two hours have passed, the state returns to "Normal State". The Table II shows the correspondence between the behavioral flags used in the flow chart and the sensor responses.

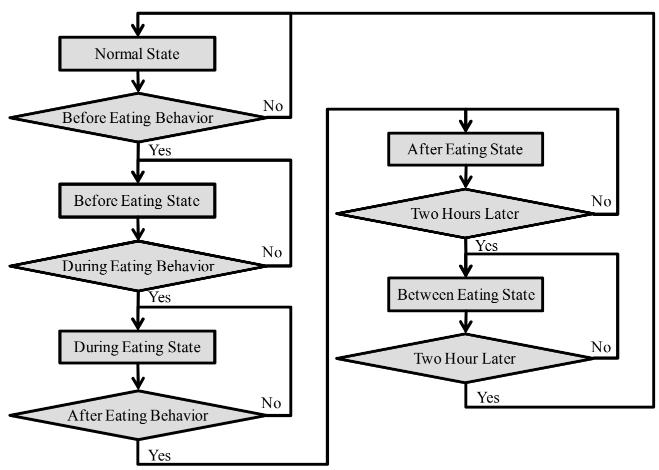


Fig. 4. Flow chart of eating state estimation.

TABLE II
CORRESPONDENCE BETWEEN FLAGS AND RESPONSES

Behavioral Flag	Response of Ubiquitous Sensor
Before Eating	Microwave Oven(On), Refrigerator(On), Freezer(On), IH Cooking Heater(On), Pantry(On), Cupboard(On)
During Eating	Chair(On), Floor(Off)
After Eating	Faucet(On), Trash Box(On)

3) Sleeping State Estimation

For the estimation of sleeping state, the pressure sensors are used as ubiquitous sensor. Two pressure sensors are laid on the bed (beneath the bed sheet at the shoulder and buttock parts) as shown in Fig.3 (b) in order to estimate if the recipient lies on the bed. The procedure for sleeping state estimation using behavioral flags is simple as shown in Fig. 5.

If both of the pressure sensors turned on for ten seconds ("Going to Bed Behavior"), the state transfers from "Normal State" to "Sleeping State". If both of the pressure sensors turned off for ten seconds ("Uprising from Bed Behavior"), the state returns to "Normal State".

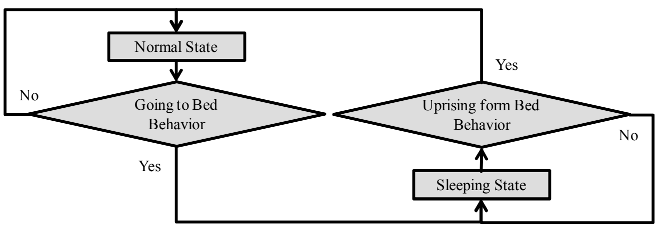


Fig. 5. Flow chart of sleeping state estimation.

B. iMec

1) Hardware

We have developed iMec as shown in Fig. 6. When the flap of iMec is open, the medicine case part will appear. The medicine case part is made of transparent acrylic. A camera is placed at the bottom of iMec for capturing the medicine case part from the bottom. White LEDs are also attached under the medicine case part as a light source of the camera. The white LEDs are arranged at shallow angles towards the bottom of the medicine case part so that neither the specular reflections nor the direct lights are captured by the camera. We used diffusion caps for white LEDs to obtain uniform image.

In addition, a touch display is placed in the flap of iMec. With the touch display, a recipient can check the dosing information simply and can operate the iMec system intuitively. The flap of iMec has an effect to intercept ambient light so that the camera won't be affected. The deterioration of medicine is also prevented. iMec is equipped with a speaker so that it can notify the recipient by sound. The medicine case part of iMec can be divided into storage spaces by partition. This allows recipient to customize the medicine case according to the dosing schedule and the size of the medicine.

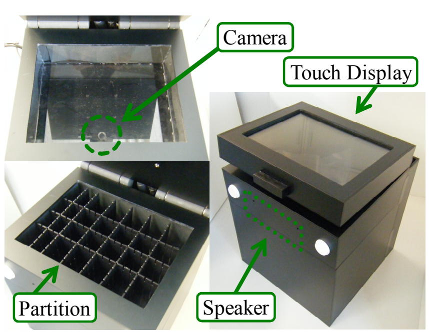


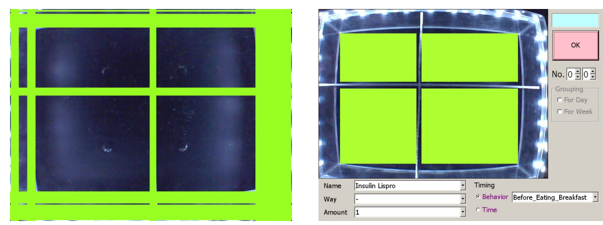
Fig. 6. iMec.

2) Setting

Since the size and the number of storage spaces change, iMec must recognize the storage spaces every time the partition arrangement has changed. The recognition procedure of the storage spaces is as follows.

First of all, the edge strength of the background image is calculated by using Sobel filter, and then it is converted to a binary image by a threshold. Secondly, the straight lines of the binary image are detected by Hough transform. An image that consists of the straight lines is created, and then a dilatation operation is applied to the image as shown in Fig. 7 (a). Finally, the areas which are large enough to accommodate medicine are detected as regions for storage spaces.

Caretakers set the dosing schedule of the storage spaces by using the setting interface as shown in Fig. 7 (b). The storage spaces detected by the above method are displayed on touch display. If caretakers touch a storage space on display, they can change the dosing schedule of that storage space.



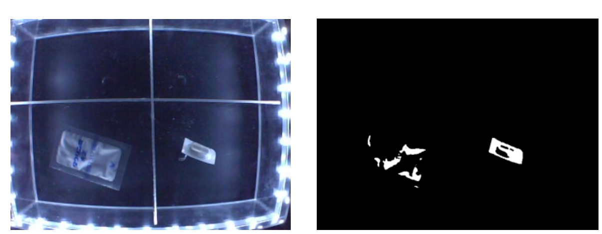
(a) Straight Line Detection (b) Setting Interface

Fig. 7. Setting of iMec.

3) Medicine Detection

Medicines in the medicine case part are detected by the background subtraction method using a medicine image and a background image. The medicine image is captured every time the flap of iMec is closed. Since the partition of the medicine case part is flexible, the background image is captured every time the partition arrangement has changed. The medicine detection procedure is as follows.

At first, both of the captured the medicine image (see Fig. 8 (a)) and the background image are converted into grey scale images, and then the gray-scale values of each pixel in the medicine image are subtracted from that of the background image. Next, the image that is composed of subtracted gray-scale value is converted to binary image by a threshold. Finally, dilatation and contraction operation is applied to the binary image for denoising. In this way, the high values of the binary image prove the presence of medicines (see white pixel on Fig. 8 (b)). Since caretakers restock the medicines correctly, iMec can confirm that the recipient picks the correct amount of medicine form that information.



(a) Original Medicine Image (b) Obtained binary image

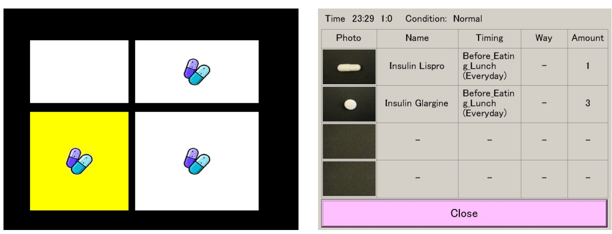
Fig. 8. Process of medicine detection.

C. iMec System

1) Support for the Recipient

Since the iMec system can confirm dosing timing and dosage, it can support correct dosing by using touch display and speaker of iMec. When dosing timing has come, the touch display blinks in yellow or red several times and the speaker plays synthetic male voice such as “Take medicine before eating lunch”. By above way, the system can prevent “forgetting to dose”. Also, when a recipient picks incorrect medicine, the system can prevent “overdose” by similar way. The system can counsel the dosing of medicine which should be taken at a certain time, when the pre1determined time has come. It can also counsel the dosing of medicine which should be taken according to living states (e.g. after every meal), when the corresponding living behavior is recognized by the ubiquitous sensors.

The touch display of iMec shows condition in the medicine case part of iMec as shown in Fig. 9 (a). If the recipient touches the virtual medicine on display, he/she can confirm dosing schedule easily as shown in Fig. 9 (b). And also, the system notifies the dosing information to the recipient by speaker when the medicine is picked up from iMec.



(a) Virtual Medicine (b) Dosing Information Screen

Fig. 9. Interface for the recipient via touch display of iMec.

2) Support for Caretaker

The iMec system provides caretakers with a dosing monitoring interface via browser as shown in Fig. 10. With this interface, caretakers can confirm the current dosing condition and the dosing history. They can confirm if the recipient is alive from this information. Also, caretakers can confirm the condition in the medicine case part of iMec. They can also check if iMec needs to restock medicine. Moreover, the system can send email to caretakers for immediate attention when it detects incorrect dosing and changes the dosing schedule of storage spaces.

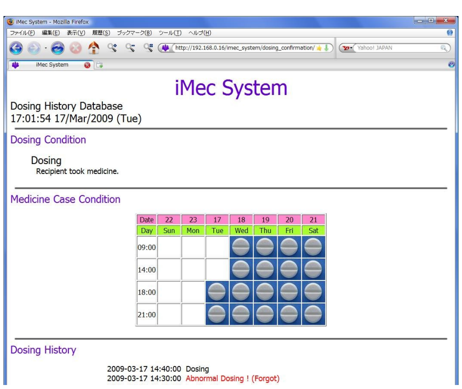


Fig. 10. Dosing monitoring interface for caretaker via browser.

IV. Experiments

In order to evaluate the medicine detection process, we have conducted experiments as follows. We asked three subjects (23-year-old healthy male) to restock and pick up a medicine one by one for every partitioned storage space of iMec. The storage space of iMec used for the experiments is divided into 28 places for seven days and for four times a day. We asked the subjects to use three kinds of medicines: powder, tablet, and capsule as shown in Fig. 11.

(a) Powder (b) Tablet (c) Capsule

Fig. 11. Types of medicine are used for the experiments.

The experimental results were as shown in Fig. 12. We have confirmed that the proposed processing could detect the medicines with high accuracy for all kinds. The system failed to detect powder type medicine when it closely leans against the partition walls.

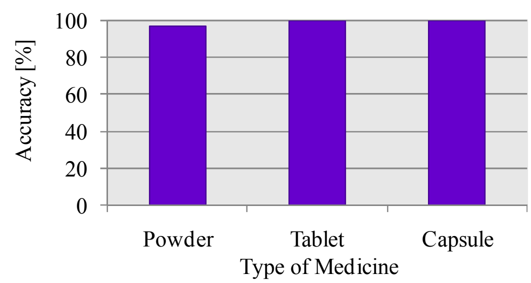


Fig. 12. Experimental results.

V. Conclusion

In this paper, we proposed iMec system that monitors and supports recipient dosing by using iMec and ubiquitous sensors. The method for the recipient state estimation and the medicine detection were explained. We also conducted experiments with subjects and confirmed the proposed system was able to detect any type of medicine with high accuracy.

As future work, we are planning to extend the system so that it can identify the kind of medicine by its shape and color. With this function, the system can detect if the correct medicine is restocked at the correct storage space. Also, we are planning to improve the state estimation system so that it can detect the recipient behavior even if he/she is not living alone. Eventually, we will conduct substantiative experiment.

References

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