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Intelligent Medicine Case for Dosing Monitoring and Support

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Abstract— **In Japan, the number of elderly persons who take medicine regularly has been increasing due to population aging. Since they can have the serious accidents caused by incorrect medication, we propose a medication monitoring system to detect incorrect medication. The system is composed of an intelligent medicine case, house-embedded sensors, and a database server. The case recognizes whether an elderly person has picked up correct medicine from its storage space to confirm the quantity of dosing. The case also estimates the present living condition of him/her to confirm the timing of dosing. By using the results, the case can evaluate the adequacy of medication. The sensors collect the information necessary for living condition estimation. The server accumulates the adequacy into its database. By using the system, caretakers can check the adequacy through a web interface and can receive an emergency e-mail if the adequacy becomes too low. We used background subtraction method for quantity confirmation and fuzzy inference method for timing confirmation. We confirmed that the case was able to detect 4 types of medicines in its storage space with considerable accuracy and the system was able to confirm 11 common timings with satisfactory accuracy by experiments.**

I. Introduction

Recently, the total number of recipients who take medicines regularly has been increasing in aging societies like Japan. They sometimes induce the serious accidents caused by incorrect medication such as overdose because of their cognitive deterioration. To prevent incorrect medication, their caretakers check their conditions about medication by visiting every time they take medicines. However, lack of caretakers is also a social problem in aging societies. Therefore, some medication monitoring systems have been developed for assisting caretakers in monitoring the conditions anytime and anywhere.

For example, Context-Aware Pill Bottle can sense whether a recipient have taken the pill bottle by a set time with IC tag and reader. And, it can transfer the information to caretakers by lighting the LEDs of medication monitor [1]. Although conventional medication monitoring systems can confirm the type of medicine, they cannot confirm the quantity of medicine. Also, they can confirm dosing timing about medicine which should be taken during a set time period (e.g. from 7 a.m. to 8 a.m.), but they cannot confirm dosing timing precisely because many medicines should be taken according to the daily activities of a recipient such as eating and sleeping (see Table I).

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Caretakers should check the quantity and timing of dose every time a recipient takes medicines because mistakes of quantity and timing induce serious accidents. Therefore, medication monitoring system should confirm the quantity and timing of dose, and then it should inform the caretakers of the information. If the system can confirm them precisely, the caretakers can collect enough information necessary for monitoring. Moreover, the system may assist the recipient in taking medicines without any misdirection. In this paper, we propose an intelligent medicine case (iMec) that can confirm the quantity and timing of dose. The case recognizes how medicines are taken by using a couple of sensors embedded in itself. The case also estimates the living condition of a recipient by using a lot of sensors embedded in the recipient's house. The history of medication confirmed by the case is accumulated in a database server so that the caretakers check via the Internet.

This paper is organized as follows. In Section I, we described the background and purpose. Section II provides the design concept of iMec and its system including confirmation algorithm. Section III presents how to implement the system and Section IV shows the experimental results. Finally, our conclusions are summarized in Section V.

TABLE I
COMMON TIMINGS OF DOSE

Timings	Labels	Explanations
After sleeping	AS	30 minutes after sleeping
Before eating breakfast	BE (B)	30 minutes before breakfast
During eating breakfast	DE (B)	During breakfast
After eating breakfast	AE (B)	30 minutes after breakfast
Before eating lunch	BE (L)	30 minutes before lunch
During eating lunch	DE (L)	During lunch
After eating lunch	AE (L)	30 minutes after lunch
Before eating dinner	BE (D)	30 minutes before dinner
During eating dinner	DE (D)	During dinner
After eating dinner	AE (D)	30 minutes after dinner
Before sleeping	BS	30 minutes before sleeping

II. System Design

These days some caretakers use a medicine organizer in order to check whether a recipient has taken medicines when they visit the recipient's house. Most of conventional medicine organizers have 28 divided storage spaces (for 4 times a day and for 7 days a week). Each divided storage space is specified the timings of dose such as before eating breakfast on Monday. The caretakers stock the correct quantities of medicines into each divided storage space periodically at least once a week. If medication monitoring system can detect medicines in each divided storage space, the caretakers can monitor the quantities anytime and anywhere. Also, if the system can estimate the living condition of the recipient in the house, the caretakers can monitor the timings.

We propose an intelligent medicine case (iMec) and its system (iMec System) for realizing above functions. The iMec has a interface for setting the medication schedule of a recipient (i.e. the types, quantities, and timings of medicines on prescription), a couple of sensors for detecting medicines in its storage space, and a computer for estimating the living condition of the recipient. Also, the iMec has a display and a speaker for assisting the recipient. We assume that it is too difficult to estimate the living condition only by using the iMec. Therefore, the iMec use inexpensive wireless sensors (the Ubiquitous Sensors) placed in the recipient's house to collect the information needed for living condition estimation. The iMec is managed by a database server (iMec Server). Since the server accumulates the adequacy of dose as medication history, the caretakers can check the information by accessing the server.

Next, we explain the operational procedure of the system with Fig. 1. First, the caretakers set the correct timings into each divided storage space of the iMec and stock medicines in the corresponding spaces. The Ubiquitous Sensors always senses the living activities of the recipient and sends its sensing data to the iMec. The iMec receives the data and always estimates the living condition of the recipient by inference algorithm. The recipient takes medicines from the iMec regularly (e.g. three times a day). When the recipient picks up medicines, the iMec evaluates the adequacy of type, quantity and timing. If the adequacy is incorrect, the iMec notifies risks of incorrect medication to the caretakers via the iMec Server. The iMec uploads the information onto the iMec Server periodically. The caretakers restock medicines when the storage space of the iMec is empty.

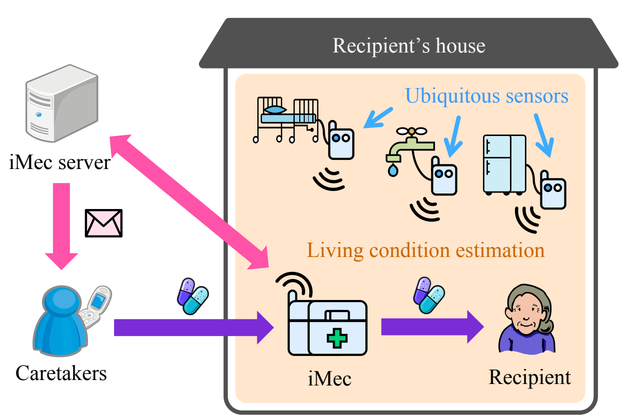


Fig. 1. Configuration of iMec System

A. iMec

Since caretakers restock the correct quantities of medicines into each divided storage space, we conceive that iMec just have to recognize the presence of medicines in each space to confirm the quantities. For example, iMec can judge that the quantity is correct if all medicines in appropriate divided storage space picked up. And, iMec can judge that the quantity is incorrect if some medicines in appropriate divided storage space picked up. Therefore, iMec recognizes partition walls which divide the storage space, and then detects medicines in each space. We assume that camera is the best sensor for recognition and detection because it is inexpensive and manageable. And, it can obtain sufficient information for recognition and detection at once by capturing the bottom side image of the storage space. However, camera is susceptible to ambient light. Accordingly, we fit a opaque black flap over the storage space. We assume that iMec can recognize the partition walls by Hough transform because they are expressed as straight or curve lines in the image. Also, we assume that iMec can detect medicines by background subtraction because the background of the image is almost constant.

iMec can confirm the timings about medicines which should be taken during a specified time period by comparing the set time of dose with the current time of the computer. For example, iMec can judge that the adequacy of timing is correct if medicines which should be taken between 7:00 a.m. and 8:00 a.m. pick up at 7:30 a.m.

B. Ubiquitous Sensors

As explained above, iMec can confirm the timings about medicines which should be taken during a specified time period. However, iMec cannot confirm the timings about medicines which should be taken according to the living condition of the recipient. For confirming precisely, iMec needs to estimate the living condition and compare with the correct timing. For example, iMec can judge that the adequacy of timing is correct if medicines which should be taken during breakfast pick up when the recipient is eating breakfast.

We defined the living condition when the recipient neither eat nor sleep as NT: neutral condition. Since the living activities before eating breakfast is similar to them before eating lunch and before eating dinner, iMec estimates 7 kinds of living condition (i.e. BE, DE, AE, BS, DS: During Sleeping, AS, and NT). And then, iMec make a classification into the category B, L, and D if iMec estimates that the recipient is in BE, DE, or AE condition. By these processes, iMec can confirm the timing automatically.

We assume that humans estimate the living condition based on the habit of the recipient. In the case of the recipient who tend to use a microwave oven in 3 minutes before eating, humans can judge that the recipient may be in before eating condition now after he/she uses the microwave oven 3 minutes ago. It means that iMec can estimate the living condition by inference rules. The inputs of rules are the recipient's position and the usage states of appliances and furniture, and the outputs of rules are the potential possibilities of living conditions. And, we assume that the present living condition is the living condition that the possibility of it is higher than the possibilities of the other living conditions.

The Ubiquitous Sensors means inexpensive ON-OFF state sensors for measuring the recipient's position and the usage states of appliances and furniture. The sensors accumulate ON-state time every constant time interval, and transmits the information (i.e. sensing data) to iMec via radio wave. We can place the sensors on appropriate locations because they have also long-lasting battery. To collect useful information for estimation, we place the sensors in the locations related to eating and sleeping such as the door of refrigerator, the faucet of kitchen unit, the surface of bed, the ceiling of toilet, etc.

Humans change the sensing data to subjective feature quantities and calculate the possibilities of 7 living conditions based on the feature quantities. As the feature quantities, we define degrees of presence and absence for the recipient's position and degrees of use and nonuse for the usage states. We assume that these human senses are expressed as fuzzy sets shown in Fig. 2. Because, the degree of presence when a sensor reacts 50 seconds in 60 seconds is little different from them when the sensor reacts 55 seconds in 60 seconds. iMec can convert the sensing data to the degrees by using the fuzzy sets. For example, the degree of presence or use are 1.0 if the ON-state time is over the upper threshold and are 0.0 if the ON-state time is under the lower threshold.

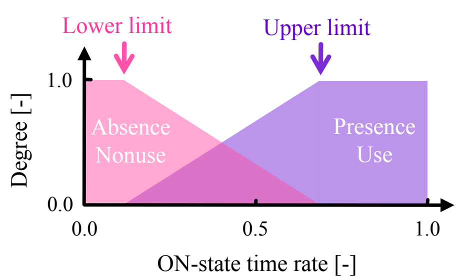


Fig. 2. Fuzzy sets for calculating degrees of feature quantities

The inference rules associate all sensors with 7 living conditions. Since the living activities before and after eating is depend on the person, iMec creates the rules for each recipient by supervised learning. For learning, iMec needs a lot of learning instances that is composed of true (i.e. actual) living condition and the sending data. By using learning instance, iMec calculates the lift values of rules for extracting only effective rules. If the lift value of a rule is 1.0 or less, the sensor of the rule is not relative to the living condition of the rule. The potential probabilities of rules are related to the confidence values of the rules. If the confidence value of a rule is near to 1.0, iMec can judge that the recipient is in the living condition of the rule after the sensor of the rule responds.

We think that iMec can classify into the 3 categories (B, L, and D) based on the current time because each during eating condition seldom occur together. By using learning instance, the occurrence distributions of 3 during eating condition are obtained as shown in Fig. 3. Since there are a significant difference in the dispersion of each occurrence distribution, the dividing time of Mahalanobis generalized distance between 2 categories is calculated as a distinction time. The distinction time between breakfast and lunch (t_{BL}), between lunch and dinner (t_{LD}), and between dinner and breakfast (t_{DB}) are obtained. If iMec estimates that the recipient is in the DE condition between t_{DB} and t_{BL}, it estimates that he/she is during eating breakfast.

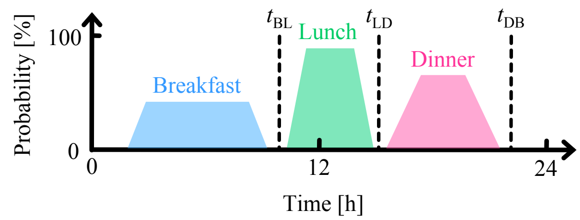


Fig. 3. Meal category distinction

We summarize the procedure of living condition estimation with Fig. 4. First, the Ubiquitous Sensors measures the ON-state time and calculates the ON-state time rates in a predetermined time interval. Second, iMec converts the rates to degrees of presence (or use) and absence (or nonuse) by using fuzzy sets. Third, iMec obtains the possibility of some living condition corresponding to the degrees per rule. Fourth, iMec aggregates all possibilities of the rules per living condition, and calculates the overall possibility of some living state by centroid method. The possibilities of the other living conditions are calculated in the same way. Finally, iMec estimates the living condition which has the maximum possibility among 7 living conditions as the present living condition. If iMec estimates that the recipient is in BE, DE, and AE conditions, it also distinguishes 3 meal categories.

C. *iMec Server*

iMec must transmit the information about the adequacy of type, quantity, and timing to the caretakers, but it has only compact computer. Therefore, we use iMec Server to transmit the information instead of iMec. Since it is important to confirm not only the latest confirmation result but also past confirmation results for medication monitoring, iMec Server receives the adequacy from iMec periodically, and accumulates the information in its database. Also, it receives and accumulates the internal condition of iMec so that the caretakers check if iMec needs to restock medicines. We assume that web interface is useful for monitoring because the caretakers can check the adequacy by using personal computer or cellar phone. When iMec detects signs of incorrect medication, iMec should notify risks of incorrect medication to caretakers automatically and immediately. Since e-mail is easy to receive by using cellar phone, we assume that e-mail is the most appropriate way for realizing

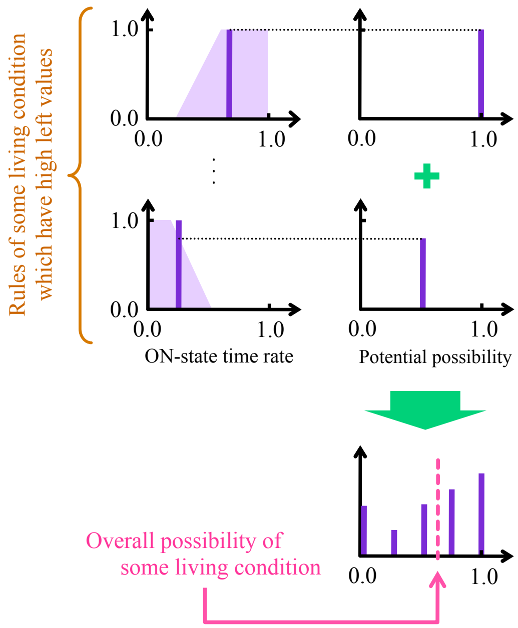


Fig. 4. Illustration of living condition estimation method

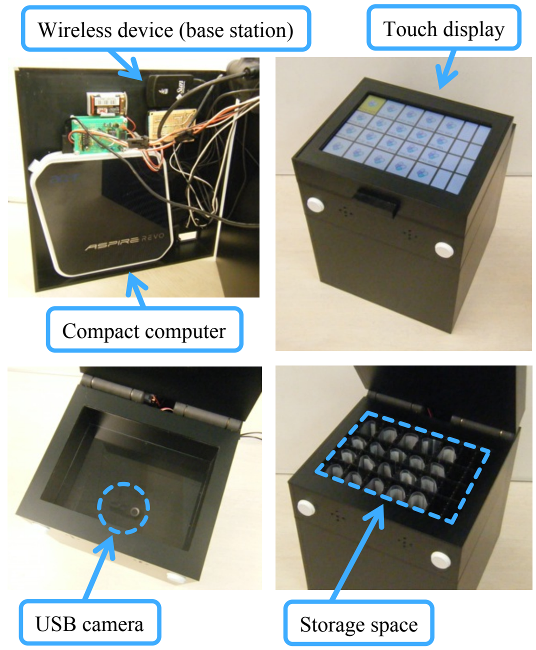


Fig. 5. Appearance of iMec (intelligent medicine case)

this function. The signs are detected by comparing the present living condition and the meal category with the correct dosing timing as shown in Table II. If the adequacy is incorrect, iMec sends e-mail to caretakers via iMec Server.

TABLE II
INCORRECT MEDICATION DETECTION

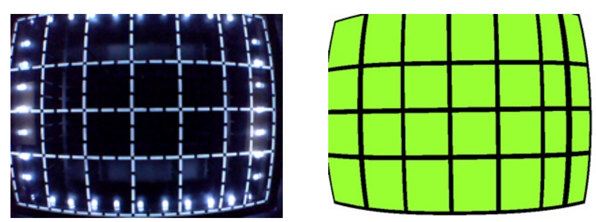
If				Then
Preset timing	Estimated condition	Classified category	Presence of medicine	Adequacy of dose
Before eating breakfast	NT	-	Absence	Incorrect
	BE	(B)	Presence	Correct
	BE	(B)	Absence	Correct
	DE	(B)	Presence	Incorrect

III. IMPLEMENTATION

A. iMec

We developed a iMec as shown in Fig. 5. When its flap is open, the divided storage space will appear. The iMec was made of black acrylic boards except the bottom plate of the storage space. Since a camera (VF0490, Creative) was placed on the bottom plate of the iMec and the bottom plate of the space was made of a transparent acrylic board, the camera can capture the bottom side image of the space. As light sources, white LEDs which are covered with diffusion caps were placed under the space. A touch display is embedded in the flap for setting the schedule into every divided storage space. And a speaker is also embedded in the front side for assisting the recipient in taking medicine. In addition, the iMec has an open-close sensor for measuring the flap condition.

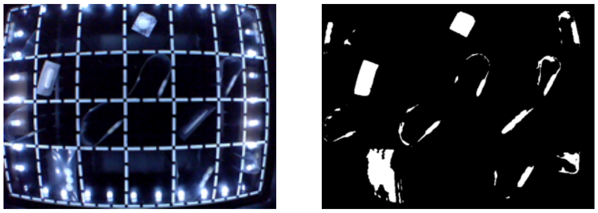
The iMec detects partition walls for recognizing the divided storage spaces. First, the iMec captures a background image as shown in Fig. 6 (a) when there is no medicines in the space, and than removes the lens distortion by approximating the distortion as 7th-degree equation. Second, the iMec calculates the edge strength of the image by using Sobel filter. Third, the straight lines in the image are detected by Hough transform. Finally, iMec returns the distortion into the image. The curve lines on the image show the partition walls (see black lines in Fig. 6 (b)). iMec recognizes the areas which are surrounded by curve lines as the spaces.



(a) Background image (b) Recognized storage spaces

Fig. 6. Result example of storage space recognition

The iMec detects medicine in each storage space as follows. First, the iMec captures a medicine image as shown in Fig. 7 (a) every time the flap is closed, and then converts the image into a grey scale image by simple average method. Second, the iMec subtracts the gray scale values of each pixel in the medicine image from them in the background image. Finally, the iMec converts the image which is composed of subtracted gray scale values to a binary image by a constant threshold. The high values in the image represent the presence of medicine as white pixels in Fig. 7 (b). If there are enough white pixels in the area of a storage space, iMec judges that there is some medicines in the storage space.



(a) Medicine image (b) Detected medicines

Fig. 7. Result example of medicine detection

The caretakers set the schedule by using the setting interface as shown in Fig. 8. The iMec presents the interface on the touch display and shows the divided storage spaces recognized by the above processes at the upper left of the interface. If the caretakers touch a virtual divided storage space that they want to change the schedule, they can select the space intuitively. And, they change the schedule by touching and dragging the text lists displayed at the bottom of the interface. The caretakers can choose 2 kinds of criterion about timing: timing based on living condition and timing based on the clock time.

Fig. 8. Setting Interface on Touch Display

B. Ubiquitous Sensors

As sensors of the Ubiquitous Sensors, we used 6 kinds of sensors: seat, presence, open-close, water flow, push, and light sensors. We make the Ubiquitous Sensors by connecting these sensors to the ports of wireless devices (SunSPOT, Sun Microsystems). The Ubiquitous Sensors calculates the ON-state times of the sensors in past 10 seconds, and then transmits the sensing data to the iMec. We installed the Ubiquitous Sensors in 33 locations related to eating and sleeping as shown in Fig. 9.

We obtained fuzzy sets expressing the human sense about presence and use by questionnaires. For example, we asked 10 subjects "how long ON-state time do you need to feel totally that a recipient was in the place installed a sensor" and "how long ON-state time do you need to feel totally that a recipient was not in the place installed a sensor" to every sensors measuring the recipient's position. As results, the degrees of presence and absent are almost proportionate to the ON-state times. The limits of fuzzy sets about the degrees of use and nonuse are obtained in the same way.

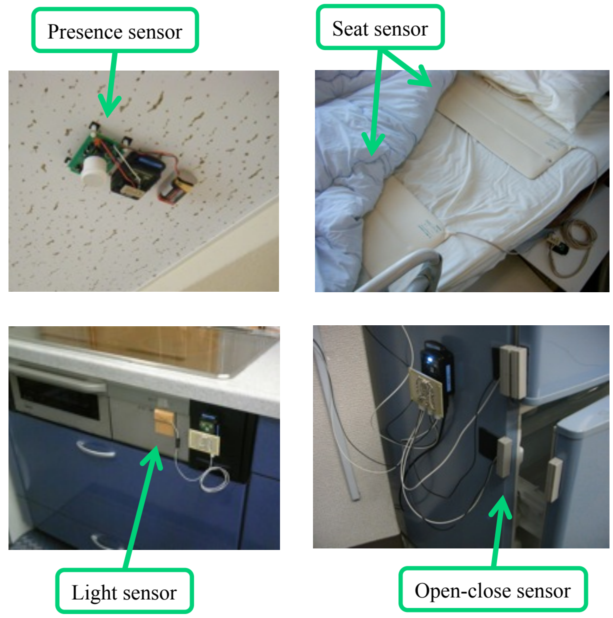
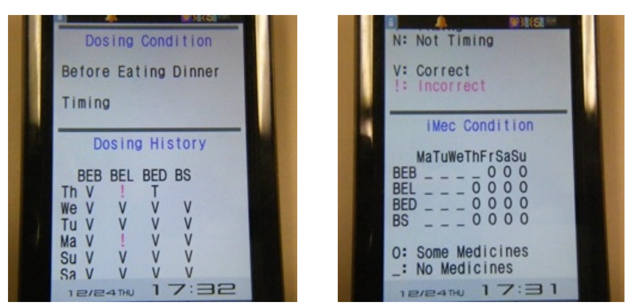


Fig. 9. Ubiquitous Sensors placed in recipient house

The iMec use the sensing data in past 30 minutes for living condition estimation because late sensing data is even more relevant to the present living condition than the previous one. We determined the lower limit of the lift value at 1.0 in order to generate inference rules as many as possible. By trial and error processes, we related the confidence values of the rules to the potential possibilities of the rules as follows. From 0.0 to 0.1, from 0.1 to 0.2, from 0.2 to 0.8, from 0.8 to 0.9, and from 0.9 to 1.0 are 0.00, 0.25, 0.50, 0.75, and 1.00 respectively.

C. iMec Server

The Windows Server 2003 was installed on the iMec Server. The server sends e-mail by using the Internet Information Services of the operating system. We also installed MySQL database for accumulating the adequacy and Apache HTTP Server for managing the web interface. The server provides the monitoring interface as shown in Fig. 10. This interface shows the present condition of medication in the top, the past conditions of medication in the middle, and the storage condition of the iMec in the bottom. If a exclamation mark is selected, the details is displayed. This interface is written in PHP language for connecting to the iMec Server.



(a) Recipient condition (b) iMec condition

Fig. 10. Medication monitoring interface

IV. Experiment

A. Medicine Confirmation

We conducted experiments for evaluating the proposed storage space recognition and medicine detection methods. Experiment procedure is as follows. The 28 divided storage spaces are recognized before experiments. We asked 3 students (24-year-old healthy male) to stock each space with medicine, and then pick up the medicine from each space one by one. We also asked the subjects to use 4 kinds of medicines: powder, tablet, capsule, and ODP (One-Dose Packaging) type.

As results, the powder, tablet, capsule, and ODP type medicines were detected 98, 100, 100, 100 % respectively. This results proved that the iMec can recognize the presence of medicines with absolute accuracy and can evaluate the adequacy of the quantity. But, the iMec failed to detect the powder type medicine when it leaned against the partition walls of the divided storage space.

B. Timing Confirmation

We also conducted experiments for evaluating the proposed living condition estimation and meal category distinction methods. We asked 5 students (healthy male from 22 and 25 years old) to live for 8 days in the virtual house which is installed the Ubiquitous Sensors. We also asked to record the start and end time of eating and them of sleeping for creating learning instances (i.e. the true present living conditions). The distinction times and inference rules are generated by using the instances, and estimation accuracy is calculated by cross-validation method every students.

As results, individualized inference rules are obtained per student. For example, the iMec obtained a following rule: student A could be in the BE condition after he open the door of the microwave oven from 3 minutes ago to 1 minute ago. In the case of student A, the distinction time between dinner and breakfast is calculated at 1:44 and the distinction time between breakfast and lunch is calculated at 10:10. Figure 11 shows a part of the estimation results of student A. He began to make breakfast around 7:00, and then the iMec estimated that he was in the BE condition. The BE condition between 1:44 and 10:10 was recognized as the BE (B) condition.

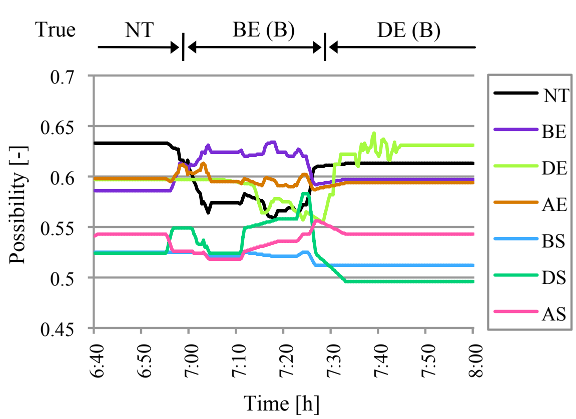


Fig. 11. Result example of living condition estimation

As shown in Fig. 12, the average estimation rates of many common timings are more than 75 % accuracy. These results mean that the iMec can evaluate the timing about medicine which should be taken along with eating and sleeping activities. However, the rates of the AE conditions is too low relatively. Because the activities after eating vary widely from day to day. We were apprehensive that the iMec don't collect sufficient information for estimation.

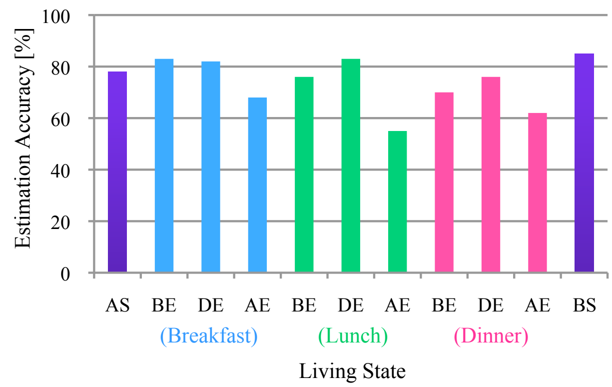


Fig. 12. Results of living condition estimation

V. Conclusion

In this paper, we proposed an iMec (intelligent medicine case) that confirm the quantity of dosing by detecting medicine in its storage space, confirm the timing of dosing by estimating the present living condition of a recipient, and allow caretakers to check the adequacy of medication anywhere. Also, the iMec send e-mail to caretakers if the adequacy becomes too low. For realizing these functions, we placed the Ubiquitous Sensors (house-embedded wireless sensor) to collect the information necessary for living condition estimation, and made an iMec Server (database sever) for providing monitoring interfaces. We confirmed that the iMec was able to detect 4 types of medicines in its storage space by background subtraction method and was able to estimate the living condition by fuzzy inference method.

As future works, we will strengthen the iMec so that it recognizes the type and quantity of dosing precisely. And, we will improve estimation rates by reconsidering the type, number and location of the Ubiquitous Sensors toward practical use.

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