A Smartphone Mediated Portable Intelligent Medicine Case for Medication Management Support

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Abstract— **We developed an epoch-making portable intelligent medicine case for recipients who take medicine every day. The medicine case consists of a recipient's smartphone and a mirror-embedded pill organizer. The smartphone captures medicines in the storage compartments of the organizer by using its built-in camera. The positions and shapes of mirrors were optimized in order that the smartphone can confirm the whole spaces. The medicine case calculates changes caused by medications and approximates them by quadratic curves. If a fitted curve in a space was convex downward, the medicine case judged that there are medicines in the space.**

I. INTRODUCTION

In aged societies like Japan, there are a lot of elderly recipients who take medicine every day. Elderly recipients frequently forget to take medicine due to their cognitive deterioration. This kind of mistake decreases beneficial effects of medicine and may produce serious side effects; therefore, some medication reminders were developed to prevent inappropriate medications.

In many surveys, it is pointed out that recipients are apt to forget their medication while they are away from home. Accordingly, some portable reminders were developed. For example, MedSignals warns a user of inappropriate medications at preset times by using a speaker, a display, and LEDs [1]. This reminder recognizes the states of cover flaps of storage spaces by using open–close sensors; therefore it can judge whether a user has opened a particular flap at an appropriate time. It has also a SIM card slot in order to communicate with a database server to make user medication records.

However, conventional portable reminders are unable to recognize the presence of medicines in the storage spaces. We developed a stationary intelligent medicine case with a camera for homecare support [2]. By using a camera, the medicine case was able to detect medicines in each storage compartment. We note that the shooting function of a smartphone can be expanded by using a smartphone cover. For example, a cover with a red lens enables a smartphone to shoot red-tinged images. Hence, we attempt to develop a portable intelligent medicine case by attaching a pill organizer to a camera-embedded smartphone.

According to reports of the Japan Pharmaceutical Association, recipients occasionally forget to take medicine by forgetting to bring their pill organizer when going out. We regard a smartphone as one of the most important personal items along with a wallet, a house key, and so on. Therefore, the portable intelligent medicine case will reduce a risk of leaving it. The initial cost of the proposed medicine case will be less than that of the conventional portable reminder because a user just has to buy a sensorless pill organizer. Moreover, the monthly communication charge will also be less because a user does not need to sign a special telecommunication line in addition to a smartphone line.

In this study, we propose a novel medication reminder using a recipient's smartphone. First, we design a pill organizer with mirrors and optimize the positions and shapes of the mirrors in order that the smartphone can monitor the internal states of storage spaces of the organizer. Second, we develop an image processing method to recognize the spaces and detect medicines in them.

II. SYSTEM DESIGN

The stationary intelligent medicine case has a touch display to set medication intake times for storage compartments, a camera to monitor medicines in each compartment, and a processor to manipulate images for medicine detection. A smartphone has a touch display, a camera, and a processor, so the portable intelligent medicine case can realize the same functions for users.

The stationary intelligent medicine case sends results of image processing to a database server. The server accumulates the results and provides a website for remote medication monitoring. Additionally, it sends emergency e-mails when the medicine case detects a sign of an inappropriate medication. The above functions are also useful for the portable intelligent medicine case.

The portable intelligent medicine case checks medication on the basis of the clock time and the user's present location. When a user goes out or a preset time for restock comes, the medicine case prevents the user from forgetting to stock medicines. When a user goes into a restaurant or a preset time for food-related medication comes, it prevents the user from forgetting to take medicine before eating a meal. When a user goes into a hotel or a present time for sleep-related medication comes, it prevents the user from forgetting to take medicine before sleeping.

III. ORGANIZER DESIGN

A. Detection Sensor

A common smartphone has a power button, a touch panel, a back-facing camera, an acceleration sensor, and

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*This work was supported by JSPS KAKENHI Grant Number 25880010.

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a proximity sensor. We selected the camera for medicine detection because there are a lot of object detection systems using cameras [3]–[5]. Furthermore, the camera has a great potential to recognize the types and quantities of medicines.

Generally, a pill organizer has three or four storage spaces for breakfast, lunch, dinner, and bedtime. Accordingly, we considered the use of mirrors in order that the medicine case may monitor the entire spaces by only using one camera. Mirrors can change the range that a camera records by specular reflection.

We designed a pill organizer with one plane mirror and three cylindrical mirrors. The plane mirror was fixed at 45 degrees to a camera; therefore, it reflects the detectable range of the camera at a 90-degree angle, i.e., to the direction of the cylindrical mirrors. Each cylindrical mirror distributes the range to three opaque walls of an assigned storage space. The shape of each cylindrical mirror was represented with a Bezier curve. This curve is a popular parametric curve and is used for path design of machine tools. The shape of the curve is specified by start, control, and end points. Hence, we determined the start and end points of each cylindrical mirror to correspond with two ends of each assigned space, and then we optimized the uniformity of resolution in the detectable range by adjusting the control point for every space.

B. Optical Simulation

We used an iPhone 4S manufactured by Apple as a general smartphone and made a 3D object model of the mirror-embedded pill organizer as shown in Fig. 1. The pill organizer has three spaces for medicines and a hole for the built-in camera. We call the three spaces A, B, and C in order from the camera side. The cylindrical mirror side of the spaces was formed of a transparent acrylic board; therefore, the camera can monitor the internal states of the spaces.

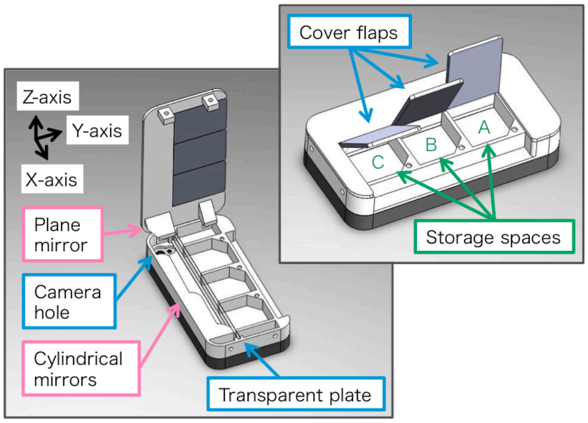


Fig. 1. The 3D object model of the mirror-embedded pill organizer

Before making a prototype of the mirror-embedded pill organizer, we confirmed whether the camera could capture the entire storage spaces. We used MATLAB developed by MathWorks for numerical simulation. As shown in Fig. 2, all of the storage spaces were filled with the detectable range of the camera by optimizing the coordinate values of the start, control, and end points. The three red curve lines mean the shapes of the cylindrical mirrors, the green straight lines mean the opaque back walls of the storage spaces, and the blue straight lines at 0.5-degree intervals mean the range that the camera can monitor. Table I shows the optimized coordinate values of each cylindrical mirror.

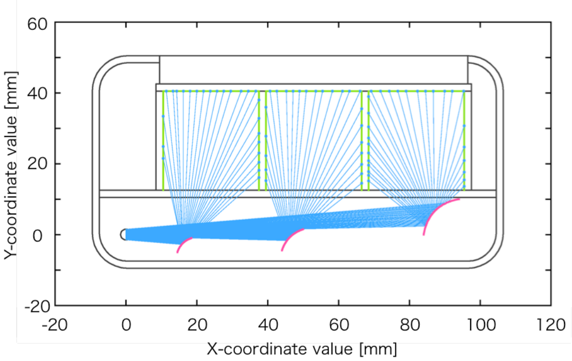


Fig. 2. The simulation result of mirror shape optimization

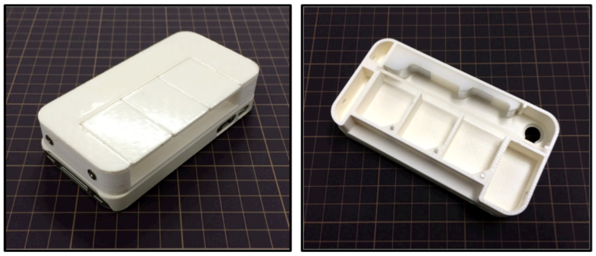
TABLE I
The Optimized Coordinate Values of Cylindrical Mirrors

Mirror	Start point	Control point	End point
A	(14.8, -4.8)	(15.7, -1.7)	(18.8, -0.8)
B	(42.6, -4.6)	(44.0, 0.0)	(48.6, 1.4)
C	(81.0, -1.8)	(81.0, 7.2)	(90.0, 7.2)

C. Implementation

A common pill organizer has a transparent cover flap to each storage space, for medicines in the organizer are visible from outside. In this study, the smartphone can prompt a user to take correct medicines by using a display, a speaker, and a vibrator. Since change in ambient light reduces the accuracy of image processing, we employed opaque flaps.

We made a prototype of the pill organizer by using a 3D printer (uPrint SE Plus, Stratasys). Fig. 3 shows the prototype. The cylindrical mirrors need smooth surfaces; therefore, we made a cylindrical mirror part by using a CNC machine tool. The cylindrical mirror part was made of POM resin and the rest was made of ABS resin. Specular surfaces of the cylindrical mirror part were made by pasting aluminum sheets. The thickness of the portable intelligent medicine case was 26 mm and the weight was 209 g.



(a) appearance (b) inside

Fig. 3. The prototype of the portable intelligent medicine case

IV. IMAGE PROCESSING

A. *Image Acquisition*

We created an original smartphone application with Apple's frameworks to take adjusted images. Fig. 4 shows two examples: the left image was captured when there are no medicines in the spaces and the right image was captured when there are four medicines in the space B. Some smartphones have a closeup mode, but most smartphones do not have the mode. Therefore, we attempted to detect medicines on the basis of unfocused vague images. The width and height of each image are 2448 and 3264 pixels, which are the maximum values of the iPhone 4S. We set the left lower pixel of images as the origin.

(a) no medicines (b) four medicines

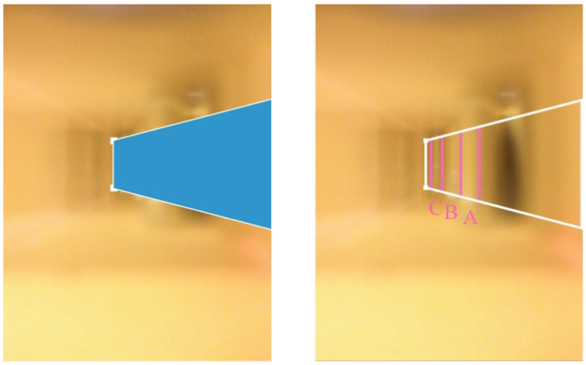
Fig. 4. Images obtained by an experimental smartphone application

B. *Space Recognition*

Medicines for breakfast, lunch, and dinner are stocked into the storage spaces separately; therefore, the portable intelligent medicine case needs to recognize the spaces before detecting medicines. We clipped the region of the cylindrical mirror part from each image because changes associated with medications occurred mainly in the region. By removing the lens distortion, the left and right edges of the target region were expressed as two vertical lines. The left edge was set at an appropriate value between the storage spaces and the cylindrical mirror part, i.e., on the farthest sidewall. The right edge was simply set at the right edge of each image. The upper and lower edges were expressed by two tilted lines because the target region became narrow with depth. The slope of the upper edge through the point (1010 pixels, 2010 pixels) was set at 0.26 and the slope of the lower edge through the point (1010 pixels, 1580 pixels) was set at -0.26. As a result, the target region was presented by a trapezoid as shown in Fig. 5 (a).

The target region was divided into three by four vertical lines. Because the cylindrical mirrors do not have barrel or spool shapes, similar changes due to the presence of medicine occurred in the vertical direction. Hence, we calculated vertically-averaged changes in the region and determined four separating lines on the basis of inflection points of the change curve.

The portable intelligent medicine case was a cuboid, so we considered six patterns of lighting environment. For this reason, we obtained six images in circumstances where we placed the cuboid each face up. The arithmetic average curve was calculated on the basis of the six images. To reduce the effect of lighting changes, the color space of the images was converted from RGB to HSL. The change curve relative to the lateral coordinate value was calculated by the average of H and S values. Fig. 6 shows the change curve of the HS features. A trough of the curve means a boundary between cylindrical mirrors or one edge of a cylindrical mirror. As shown in Fig. 5 (b), four inflection points corresponded to four separating lines. As a result, the lateral coordinate values of the four lines were calculated to be 1060, 1160, 1330, and 1500 pixels.



(a) the target region (b) the separating lines

Fig. 5. The result of storage space recognition

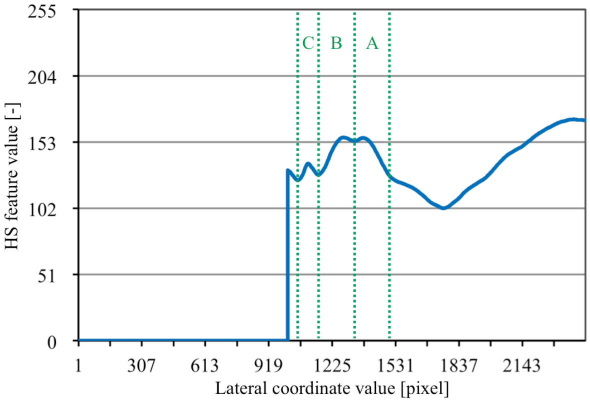


Fig. 6. The four inflection points on the averaged change curve

C. *Medicine Detection*

It is difficult to detect medicine by a simple background subtraction method because lighting environment around the medicine case will change. In related works, object detection methods based on background models were proposed [2]–[5]. However, these methods need to use previous knowledge about target objects or take huge quantities of images to create statistical models. Expressing common knowledge on a wide variety of medicines can be difficult and the processing power of the medicine case is limited, so we should propose a new method.

We attempted qualitatively to judge the presence of medicines instead of calculating the difference of gray-scale values. If so, an image processing method for medicine detection will be tolerant of lighting changes. We did not create medicine models, but we made the most of the shapes of the cylindrical mirrors. Concretely, we noticed the characteristic that a peak existed between adjacent troughs in the process of storage space recognition. In consequence, we conceived a new method to approximate peaks by quadratic curves. If there are no medicines in a storage space, the coefficient of the squared term in the space will be negative. Conversely, if there are medicines in a storage space, the coefficient in the space will be positive because a change due to the presence of medicines will not occur in the both sides of the cylindrical mirror corresponding to the space.

We approximated a peak in each space by the standard form of a quadratic equation as shown in Eq. 1. The medicine case judged the presence of medicines by confirming the sign of the coefficient a. The shape of each cylindrical mirror will be adjusted for smartphone size, but the coefficient b expresses the change. The coefficient c expresses the average of gray-scale values in each cylindrical mirror. Thus, we might say that the proposed method has high adaptability to environmental change.

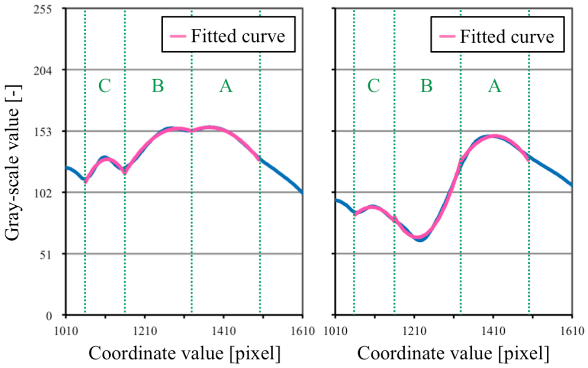
$$y = ax^2 + bx + c \tag{1}$$

We used the method of least squares to calculate the coefficient a. As shown in Eq. 2, it was estimated by eight different types of summations. Here, the symbol N means the number of data points in each space. The coefficient a was calculated by the simple gray-scale transformation in the RGB color space, not in the HSL color space, in order to provide medication support services in real time.

$$a = \frac{N_0X_2Y_2 - X_1X_1Y_2 + X_1X_2Y_1 - N_0X_3Y_1 + X_1X_3Y_0 - X_2X_2Y_0}{2X_1X_2X_3 + N_0X_2X_4 - X_1X_1X_4 - N_0X_3X_3 - X_2X_2X_2} \tag{2}$$

$$\begin{aligned}
X_1 &= \textstyle\sum_{n=1}^{N} x_n & Y_0 &= \textstyle\sum_{n=1}^{N} y_n \\
X_2 &= \textstyle\sum_{n=1}^{N} x_n^2 & Y_1 &= \textstyle\sum_{n=1}^{N} y_n x_n \\
X_3 &= \textstyle\sum_{n=1}^{N} x_n^3 & Y_2 &= \textstyle\sum_{n=1}^{N} y_n x_n^2 \\
X_4 &= \textstyle\sum_{n=1}^{N} x_n^4 & N_0 &= \textstyle\sum_{n=1}^{N} 1
\end{aligned}$$

In Fig. 7, the left graph shows an example of three approximated curves in the situation that there are no medicines in all the spaces and the right graph shows another example of the curves in the situation that there are four medicines in the middle space B. We stored an opaque white tablet, an opaque yellow tablet, a translucent black capsule, and a translucent yellow capsule. The calculated coefficients a of the storage spaces A, B, and C were -0.0035, -0.0009, and -0.0021 in the former situation. Those were -0.0032, +0.0093, and -0.0039 in the latter situation. By storing the above medicines into the space B, the gray-scale values in the space C clearly diminished. However, the value of the coefficient a in the space C did not largely change and the sign of the coefficient a did not invert.



(a) no medicines (b) four medicines

Fig. 7. Three fitted curves in three storage compartments

D. Pilot Experiments

We conducted pilot experiments in our laboratory to verify the nature of the approximated curves. The experimental environment was a bright room with fluorescent lights on the ceiling and a window in one sidewall. Since the medicine case confirms the presence or absence of medicines, we set eight stored situations (two patterns × three spaces). We captured 48 images while the direction of the medicine case was changing (eight times × six directions) and 16 images under the condition that the medicine case was held in hand (eight times × two hands). The medicine case was exposed to approximately-constant ambient lighting, the coefficient a of each fitted curve changed as we expected. Thus, the success rate of medicine detection reached 100%.

V. CONCLUSIONS

In this study, we proposed a portable intelligent medicine case using a smartphone and developed a prototype of it by using a 3D printer. We confirmed that the medicine case could monitor all its storage spaces by optical simulation and was able to detect medicines in the spaces by calculating the coefficients of fitted curves. This image processing method does not need any background models, so it is feasible for mobile devices like smartphones.

We conducted indoor experiments in a bright environment. Then, we will verify the performance of the medicine case in a dark environment (i.e., in a bag) and in an extremely bright environment (i.e., in direct sunlight). Accordingly, we are going to improve the proposed method and are considering the use of a flashlight on a smartphone.

REFERENCES

[1] Medsignals Corp.: Medsignals, http://www.medsignals.com/.

[2] T. Suzuki and Y. Nakauchi: Intelligent Medicine Case for Dosing Monitoring: Design and Implementation, SICE Journal of Control, Measurement, and System Integration, Vol.4, No.2, pp.163–171, 2011.

[3] S. Kaneko, I. Murase, and S. Igarashi: Robust Image Registration by Increment Sign Correlation, Elsevier Transactions on Pattern Recognition, Vol.35, No.10, pp.2223–2234, 2002.

[4] D.M. Tsai and S.C. Lai: Independent Component Analysis-Based Background Subtraction for Indoor Surveillance, IEEE Transactions on Image Processing, Vol.18, Issue1, pp.158–167, 2009.

[5] J.Y. Hao, C. Li, Z. Kim, and Z. Xiong: Spatio-Temporal Traffic Scene Modeling for Object Motion Detection, IEEE Transactions on Intelligent Transportation Systems, Vol.14, Issue1, pp.295–302, 2013.