Pattern Adaptive and Finger Image-guided Keypad Interface for In-vehicle Information Systems

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Abstract- In this paper we propose a pattern adaptive keypad interface for in-vehicle information system. The keypad interface recommends the estimated input sequence to fit the user's preference based on individual model of operation pattern. Pattern (shape) of button switches corresponding to the estimated input sequence is actively reformed. Button switches are displayed tactilely and visually. Finger image is shown on the monitor in real-time in order to guide input operation on the tactile input device. To confirm the effect of the keypad interface, experiments are performed comparing with a touch screen on which pattern (shape) of buttons switch is unchanged.

Index terms: Pattern adaptive, re-formable keypad, vehicle user-interface design, tactile input device.

I. INTRODUCTION

A driver's lack of attention to the task of driving caused about 41 percent of the traffic accidents of Japan in 2007 [1]. This includes the driver not monitoring the current road conditions and not monitoring other vehicles on the roadway proximate the driver's car. Drivers typically encounter many distractions while driving. Examples of distractions encountered by drivers include viewing in-vehicle information systems such as car navigation, utilizing a cellular phone [2]. As in-vehicle information systems become diverse, the needs of an interface to operate it become complicated. A new device to meet the needs has been studied in hardware or software design [3] [4] [5] [6]. In the experiment of the method of presenting information by using vibrotactile display set up in the driver's seat, the result demonstrated that the fastest reaction time to navigation messages was found with the multi-modal display among visual, tactile and multi-modal navigation displays [3]. A remote, multi-modal device placed on the driver's seat arm rest is proposed to eliminate the highly distracting task of looking at the own finger to touch the right control on touch-screens and peripheral buttons [4]. A GUI has been designed for telematics systems limiting the amount of displayed information like a number of choices [4]. The system to recommend content adapted to a user's preferences and situations automatically is proposed, which helps drivers retrieve and select content [5]. In recent years the human factor issues such as avoiding cognitive and sensory overload, using physical controls appropriately are emphasized for vehicle user interface and information visualization design [6].

A tactile display for the multi-modal display has also been studied vigorously. Several advanced tactile display units have been developed using such as shape memory alloys (SMA), solenoids, pneumatic actuators, piezoelectric actuators, electrostatic actuators. Among them, piezoelectric actuators whose element is small have fast response time and a simple structure and have the advantage of cheapness than other actuators [7], so that products such as braille cells, tactile graphic display, braille display activated by piezoelectric actuators have been manufactured. In the meantime, tactile display units have been used to help the blind in computer or communication media use [8]. And it has also been developed for the blind to recognize the 3D shapes [9]. In addition it has been used as a haptic feedback device in virtual environment [10].

In this paper we propose a pattern adaptive keypad interface to reduce interaction time by updating hardware and software design for in-vehicle information systems. Input sequences are modeled by forward-backward algorithm of hidden Markov models and the estimated input sequence in the special situation by using the model is proposed to the user. In addition pattern (shape) of button switches corresponding to it is reformed to be recognized quickly and to be operated easily.

Section II describes user interface design and characteristics of pattern adaptive keypad interface. In section III, the mechanism generating pattern of input sequence has been discussed. The keypad interface whose button shapes are reconfigured has been discussed in section IV. Section V describes the formation mechanism of finger image and experimental results to confirmed the effect of the proposed keypad interface have been reported in section VI. This paper has been concluded in section VII.

II. IN-VEHICLE USER INTERFACE DESIGN

A remote controller, a touch screen and a knob array are HMI (Human Machine Interface) for in-vehicle systems in order to support simple and rapid operation of input. Many of HMI for in-vehicle systems are a touch screen, which is usually installed in the near the windshield and is distant from users for the visual information of a monitor to be recognized. However, a user needs to stretch his arm repeatedly in order to touch the input unit united with display unit which is distant form him and to confirm the following and the area covered by hand or fingers. To reduce the moving of hand, methods to set up a mouse type controller or a knob (e.g. BMW *iDrive*) near the driver are proposed. But it has another problem. The interface to move a cursor makes the driver's feeling of operating menu decreased and makes the operation time prolonged by the method to move a cursor to the desired icon using successive approximation. In addition it has too many options or actions to select and to watch [4].

In this paper two important guidelines for the design of interface which is recognized and is operated easily and quickly are cited as follows: The first guideline for the system is to improve the design of the hardware division. The shape and size of a button which is the base of interface can be changed to help the user's visibility and operations. The second guideline is the design of software that personal information to manipulate the information system is accumulated and modeled. The purpose of this study is to develop a whole new interaction interface by (i) integration between visual and tactile information, (ii) improvement of visibility and operation ability of vehicle information system, (iii) adaptive system based on modeling of the user's personal characteristics of the operation. In this paper the prototype development and evaluation of keypad interface has been reported in the point of (i) and (ii) and the concept has been proposed in the point (iii).

a. Button's pattern adaptive interface

The control panel of our proposed interaction device is separated from monitor and can be installed near the driver's seat. The remote device enables the user to do input operations intuitively and rapidly because it is unnecessary to move driver's gaze and arm position simultaneously [11] [12]. In addition, it is unnecessary to move a pointer like a knob because the input control panel uses pin matrix to display tactile information and is operated in conjunction with the monitor to display visual information. In addition, it makes shape, size and position of button changed to reflect the estimated result of user's intent. Pattern (shape) of button switch of the current conventional system is unchanged and there is no example to build adaptive GUI interface whose button shapes are changed so far. The system consists of input unit, display unit and adaptive information system as shown in figure 1.

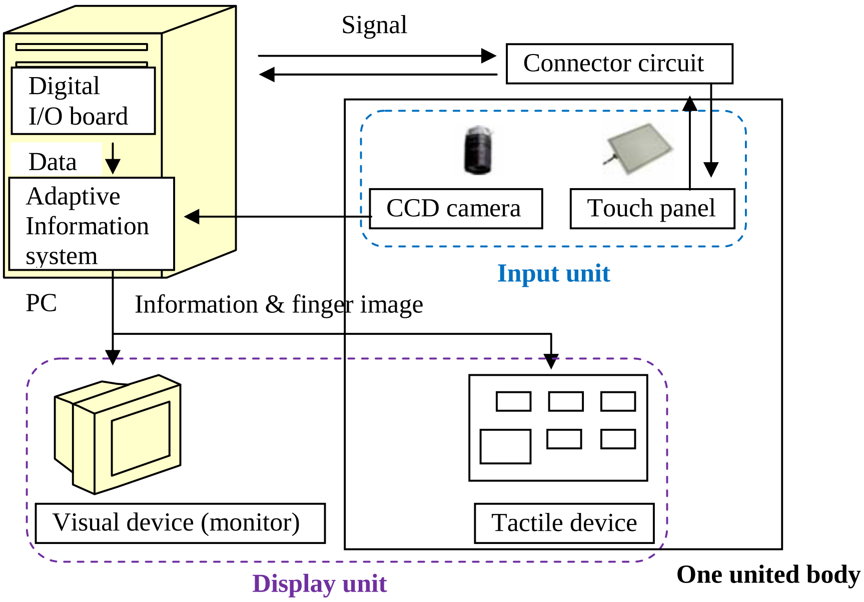


Figure 1. System architecture

The proposed keypad interface is composed of a tactile graphic display, a resistive touch panel for the operation of tactile display, a digital I/O board, a connector circuit, a PC to control the system and a monitor (visual display). The combination of visual and tactile display do not require to move a cursor like a knob and offers benefit not relying on only the visual information like a touch screen, which enables a user to achieve rapid recognition and intuitive operation. There are three important points to consider the intuitive operation of the developed device: First, it offers the adaptive change of the button shape. Second, it offers information confirmation through visual and tactile mode. Third, it offers remote control. A vehicle information system with touch screen needs alternating operation between a monitor and a handle of a car. The developed device unlike a visual display has the tactile display united with a touch panel to achieve input operation and realizes the remote control to be arranged close to the user. Remote control enables a driver to permit not only continuous input by putting hand on the touch panel but also conversion between input operation and driving operation while maintaining body's posture of the driver.

b. Input sequence adaptive interface

In this study, we propose input sequence adaptive interface not to present information in a given order like many conventional information systems. It proposes navigation order based on user modeling of input pattern to the user. Figure 2 shows the block diagram of input sequence adaptive interface.

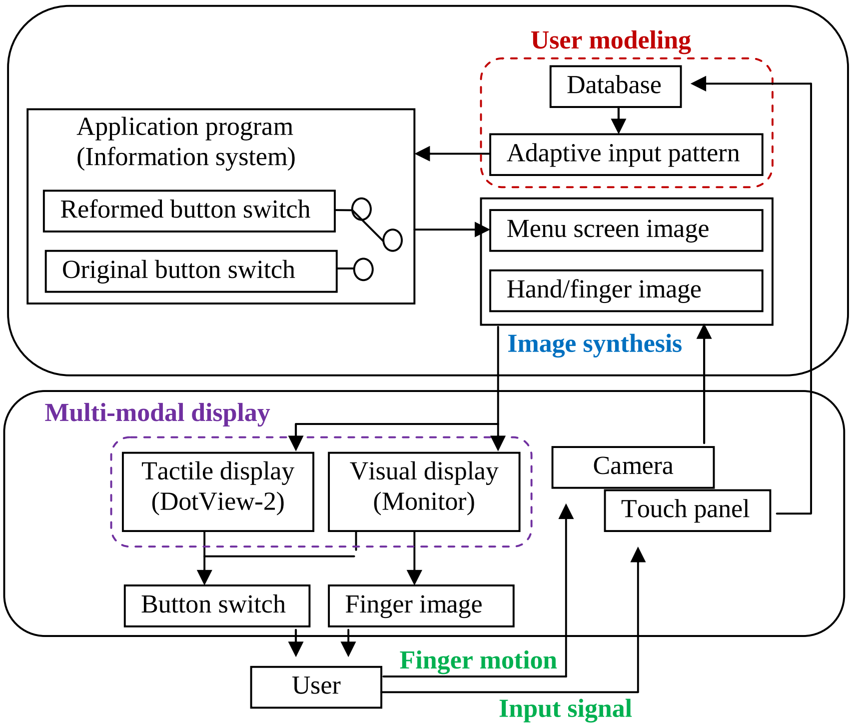


Figure 2. Block diagram

The retrieved data of input operation are used to model user's pattern model by forward-forward (Baum-Welch) algorithm of HMMs (hidden Markov models). HMMs are built according to various situations such as individuals, physical condition and tastes of each individual. HMM is probability model and is defined by two processes. Unknown parameters are under the Makov chain process. Parameters of the model can be estimated from observation information and the probability distribution to follow a stochastic process [13]. Figure 3 shows the example of hidden Markov model of user's input sequence on an operation of car navigation. In figure 3, the user's intent transitions are unobservable process and input sequences of chosen menu are observable information. Left-to-right model is used because we assume that the user's intent becomes crystallized according to time increase. It is possible to make the model of user's input pattern by training data of the user's input sequences.

As shown in figure 4, the user's input sequences can be sorted by the user's situation and the input sequences which responds to each situation can be trained by Baum-Welch (forward-backward) algorithm. Another important element is to change the shape of a button switch. Button switch of input sequence which is estimated as the closest to the user's intent using the user's pattern model and the current input data becomes large than the other button switches on the same screen and is offered on the tactile display and visual display.

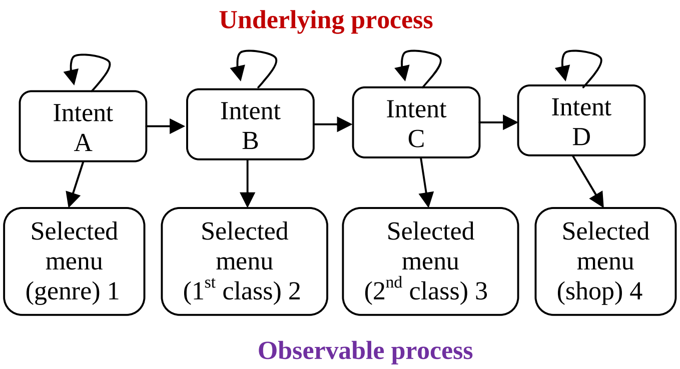


Figure 3. Hidden Markov model: left-to-right model

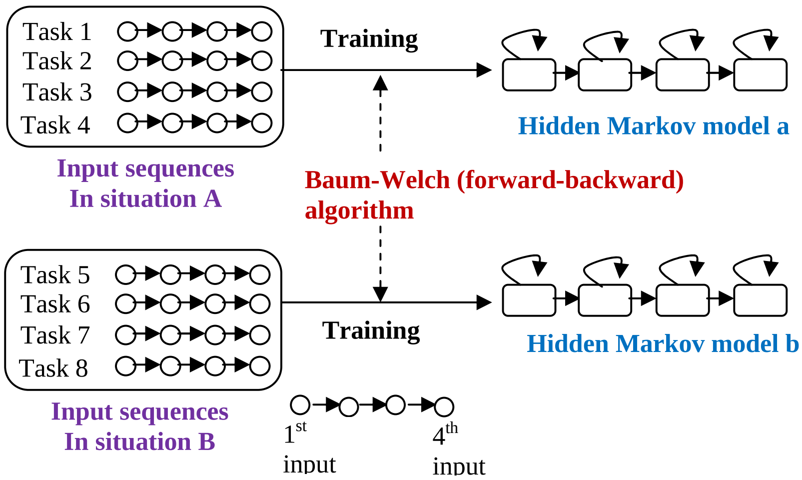


Figure 4. User modeling (training) by Baum-Welch algorithm

c. Tactile display guided by finger image

We take advantage of the benefit of shortening the length of time to recognize and to operate information from multi-modal display and propose dynamically shape-reconfigurable keypad interface which enables a user to operate intuitively and to present visual and tactile information at the same time. Figure 5 shows multi-modal device. Tactile graphics cell (DotView-2) of KGS Corporation as tactile display is pin matrix to present figure or letter. Each pin is controlled by the piezoelectric actuator and its diameter is 1.3mm, dot pitch is 2.4mm and it rises 0.7mm in height. DotView-2, the display matrix with 1,536 dots (48 x 32) converts two-dimensional information such as letters and images into two values and presents stereoscopic images as two states of pins up and down.

The blind who master a braille can recognize the tactile information, the uneven surface shape by using fingertip touch, but it is difficult for a user who has not experienced a braille to understand the button shape and position accurately and quickly. So a guide on the visual display (monitor) to recognize the finger position itself put on the tactile display is designed. The user's finger image on the tactile display observed by the camera is extracted and is overlapped on the monitor in real-time. As shown in figure 5, the camera is set up at the top of the tactile display to extract the user's hand and finger movements.

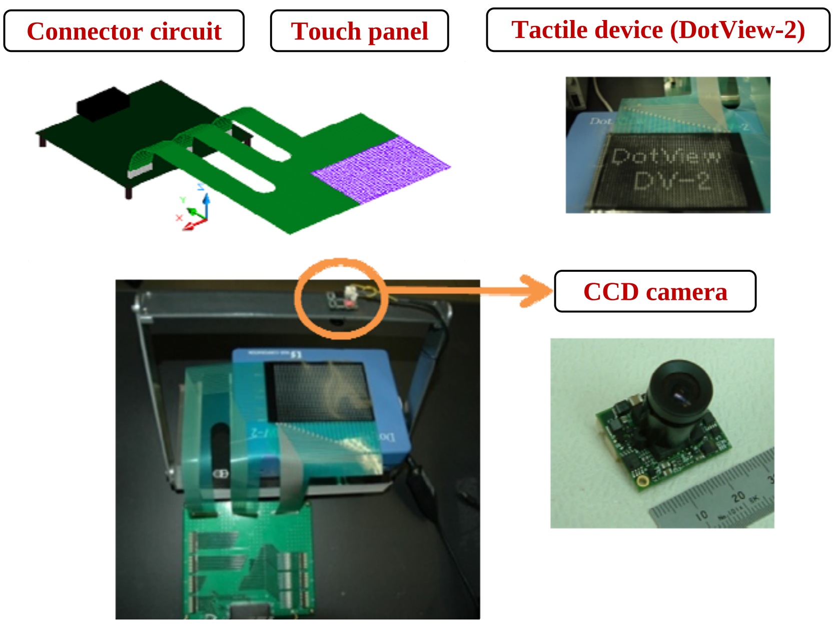
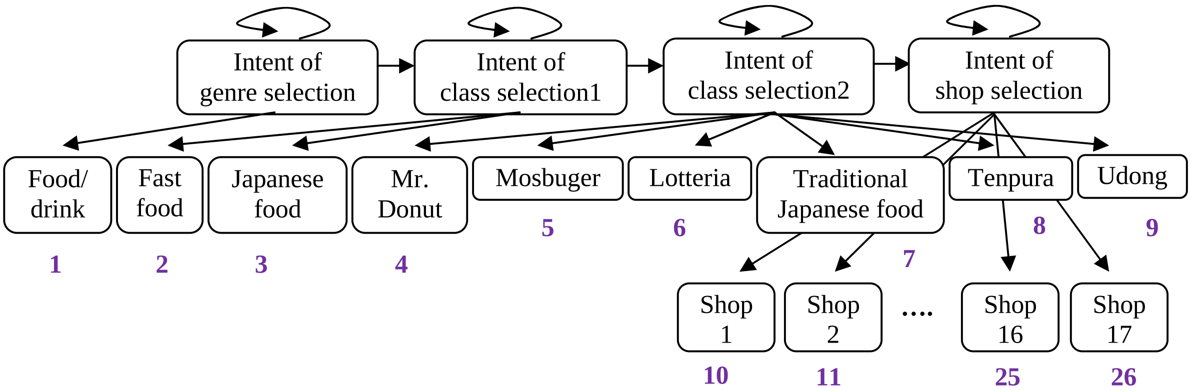


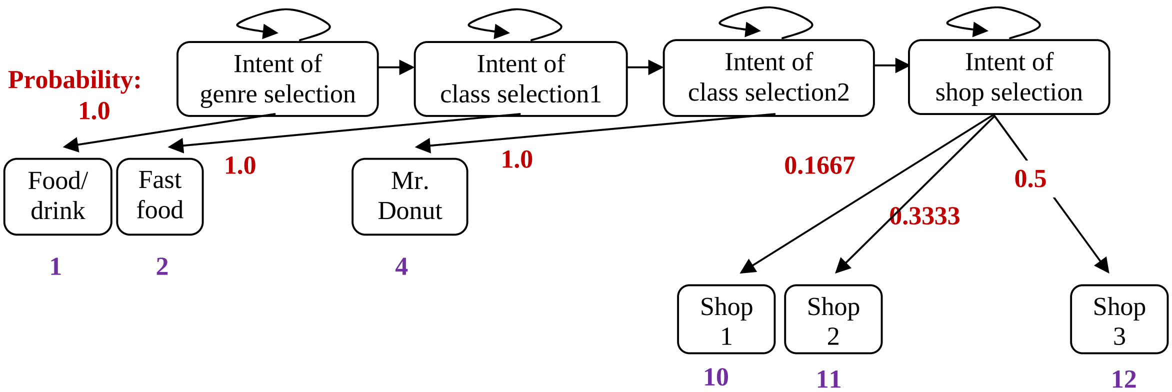
Figure 5. Multi-modal device: tactile display guided by finger image

III. ADAPTATION MECHANISM OF INPUT SEQUENCE

Figure 6(a) shows an example of hidden Markov model of input operation on the car navigation of the target of this study. The number of Markov states (q_i) is 4, the number of observation symbols (o_i) is 26. In general, hidden Markov model is defined as three parameters $\lambda = (A, B, \pi)$. Here A is a transition matrix composed of transition probability $a_{ij} = \Pr(q_{t+1} = s_j \mid q_t = s_i)$, B is a observation probability $b_{ij} = \Pr(o_t = v_k \mid q_t = s_i)$, π is a initial transition probability and s_i is a state of model [13]. The number of training data for the model is 6. 3 kinds of sequence are used such as 1(Food/drink)-2(Fast food)-4(Mr.Donut)-10(Shop1), 1(Food/drink)-2(Fast food)-4(Mr.Donut)-10(Shop2), 1(Food/drink)-2(Fast food)-4(Mr.Donut)-10(Shop3). Figure 6 (b) shows the hidden Markov model acquired by training. Input sequence, 1(Food/drink)-2(Fast food)-4(Mr.Donut)-10(Shop3) which is close to the user's intent is estimated from the trained model.



(a) Initial HMM



(b) Trained HMM

Figure 6. User modeling using training data

Figure 7 shows various genres and the following sequence on the car navigation system. The best input sequence inferred by the trained model is reflected to the car navigation as shown in figure 8 (a). However, the inference process or the method to reflect the inferred input sequence to car navigation is not implemented in this paper and it remains future works. As shown figure 8 (b), the pattern of estimated button switches are changed and proposed to the user automatically.

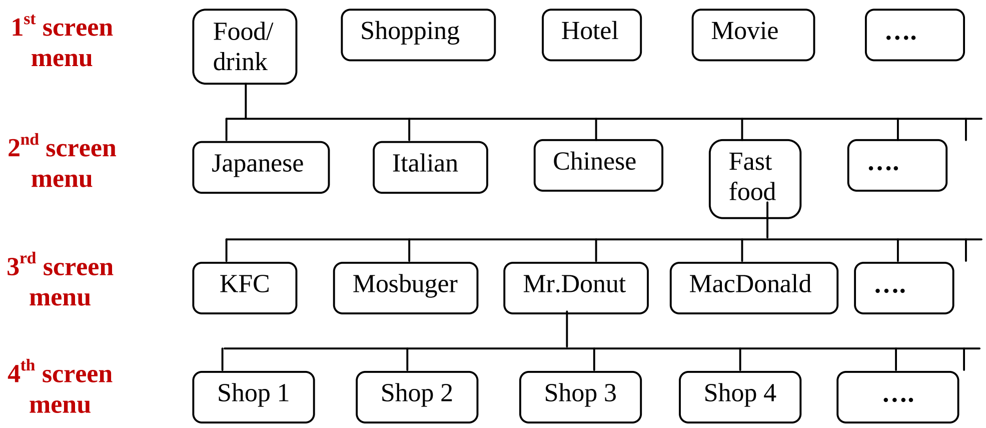
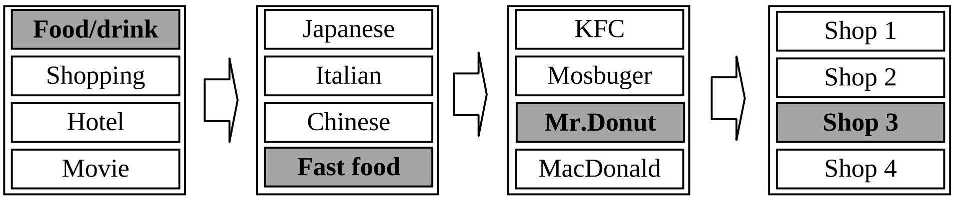
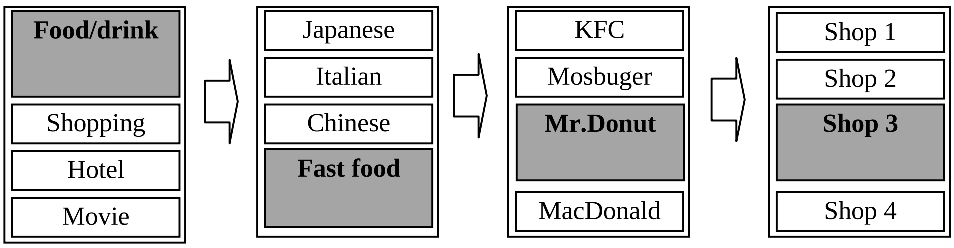


Figure 7. Structure of input sequence



(a) Button switches corresponding to the estimated input sequence



(b) Reformed button switches

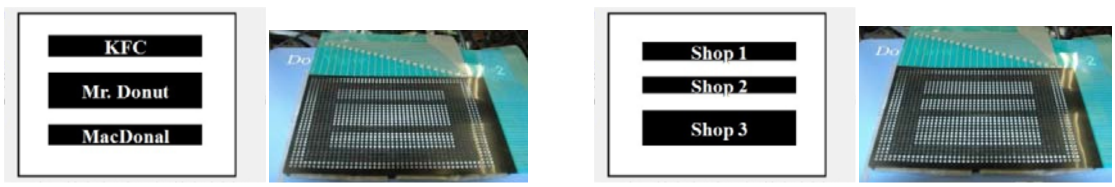
Figure 8. Process of pattern adaption

IV. BUTTON'S PATTEN REFORMABLE KEYPAD

a. Intuitive keypad and button's pattern reflecting user's characteristics

Figure 9 shows the reconfiguration of the button switch on the keypad by the adaptive mechanism in section III, which is presented to a user via successive input operation. In the car navigation as application some menu icons are displayed on the touch panel and the input operation of menu icons on the tactile display is carried out in accord with the input coordinate by the touch panel. The maximum characteristic of the developed reformable keypad is to change the size or pattern of the button switch with a high frequency of usage, which helps the user to recognize and operate (push) it. The operation executed by the tactile display supports visual attention and it is suitable for the intuitive usage. Reformable keypad which can offer tactile display achieves the tactile input at the same time owing to the touch panel of 33 x 24 lines placed on the tactile display. It shortens the interaction time of the loop from the recognition by touch to the input operation between a user and information system.

(a) First menu screen (b) Second menu screen



(c) Third menu screen (d) Fourth menu screen

Figure 9. Multi-modal display of adapted button switches

b. Scan mechanism

The touch panel, which detects user's input, is developed as resistant type with a matrix of holes in order to feel pin stroke of the tactile display with 0.7 mm while the tactile display does not has the driving force to life the film of the touch panel. Figure 10 shows the structure of a resistant type touch panel. When there is an input by pushing the touch panel, vertical line contacts with horizontal line and the input is detected by the signal level (High/Low) each vertical line. The digital I/O board connected to the touch panel uses 64-channel input-out board (Contec Corp: DIO-6464T-PE). The connector circuit receives 33 data and transfers it to the touch panel. 24 input signals of touch panel are transferred to the I/O board.

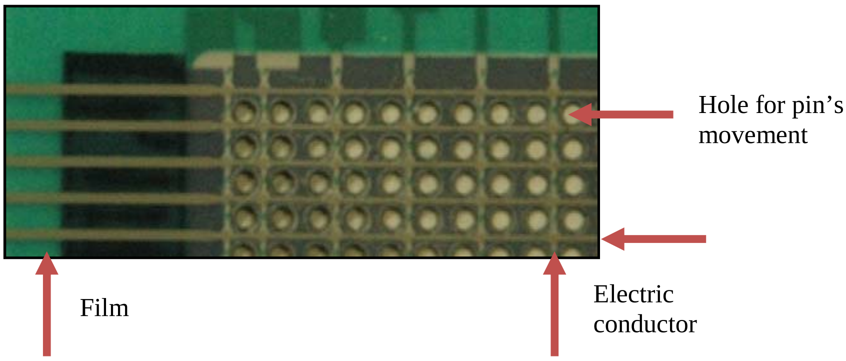


Figure 10. Structure of resistive touch panel

Figure 11 shows scan process. A vertical line is defined as y coordinate and a horizontal line as x coordinate. The number of x coordinate as output channel is 24 and the number of y coordinate as input channel is 33. 'on' signal is sent to a line of a single channel to detect and 'off' signals are sent to the other 32 channels at the same time. On the other hand, 'on' signal by the logical calculation of x and y coordinates is sent to each channel in y coordinate line to detect the touched point. About 10 ms are necessary to scan whole area of the touch panel. The mouse cursor on the screen is moved the estimated coordinate pushed on the touch panel or the center coordinate of multiple touched points obtained.

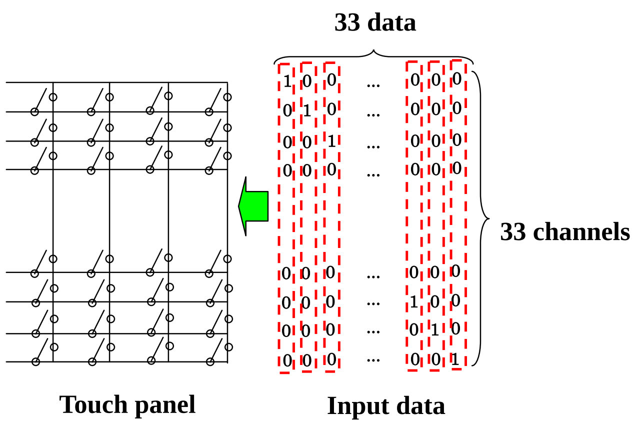


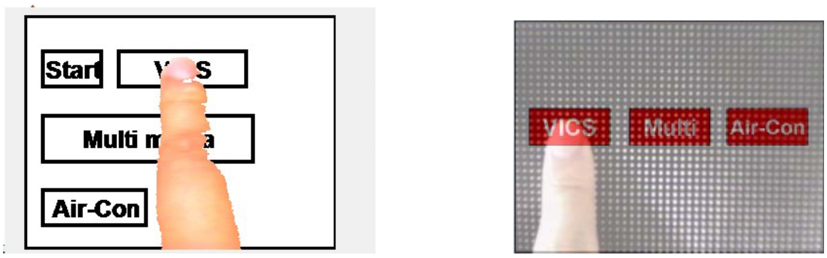
Figure 11. Scan principle of clicked points

V. GENERATION MECHANISM OF FINGER IMAGE

The user's finger image above the tactile display is extracted and is displayed on the monitor in real-time in order to quickly distinguish the uneven shape and form of button switch on the tactile display. Extracted finger image by camera is displayed in conjunction with the menu screen on the monitor. There are two options in synthesizing the two images. One is image synthesis by treating the hand image as the fore-ground and the menu image as the back-ground as shown figure 12 (a). The hand portion of the hand image is determined by thresholding the R values of the image such as

$$I_{monitor}(i,j) = \begin{cases} I_{hand}(i,j) & if \quad R_{hand}(i,j) > T \\ I_{menu}(i,j) & o.w. \end{cases} \tag{1}$$

where I_{hand} is the hand image captured by the camera, I_{menu} is the menu image and $I_{monitor}$ is the image to be displayed on the monitor. Arguments i, j are the indices of image columns and rows. R_{hand} is the red component of I_{hand} and T is a threshold value. Images from this method provides the fore and back ground relationship between the two images, hence make it easy to understand the spatial conditions of the hand motion relative to the touch screen. However the performance is prone to degrade depending on T.



(a) Synthesis (b) Merge

Figure 12. Image superposition

Second method is image superposition or merge, averaging RGB values of the two images pixel by pixel such as

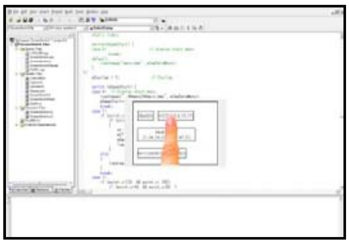
$$I_{monitor}(i,j) = \frac{1}{2}[I_{hand}(i,j) + I_{menu}(i,j)] \quad (2)$$

This method does not provide the spatial relationship between the two images as shown in figure 12 (b). However, since there is no threshold, its performance is robust to ambient light conditions. Actually we examined the operation of the system using two methods and the method in figure 12 (b) has the problem that the screen information is not accurately reflected to the tactile display. Thus in this study the method in figure 12 (a) is adopted.

VI. EXPERIMENS

In this section experiments were performed to examine the effect of the keypad interface when button switches corresponding to the estimated input sequence are enlarged and the impact of movement like shaking hand to affect the accuracy of input operation. The object to evaluate and compare is the touch screen which is now widely used as user interface for in-vehicle information systems. The standard to evaluate the proposed keypad interface is to shorten the time of input operation (reaction time). Size of touch screen (resolution 1280 x 1024, Orient Corp.) is 17 inch and size of application program is 4.7 inch and fixed to consider software design of the device as shown in figure 13.

(a)



(b)

Figure 13. Touch screen and screen menu

The vision system to guide visually the user consists of a USB capture cable (USB-CAP, I/O DATA Corp.) and a USB camera (54C0N) with resolution 320 x 240 pixels. We calibrated between the camera image frame and the monitor frame using calibration software. The number of menu screen (number of input) used to compare the speed of input operation is a total of 39 frames. In other words, 39 clicks of input operation continuously were given to subjects. Furthermore, virtual input sequence (scenario) different with the example in section III were made and 39 kinds of menu screen were changed continuously by pressing a button switch each menu screen. 10 subjects at ages between 23 and 32 were asked to press a button. The order of input sequence was predetermined and everyone pushed 39 button switches according to the same sequence. Experiments were carried out three times each four conditions.

a. Effect of button's pattern adaptation

In the experiment of changing the shape of button switches to meet the estimated sequence by the user model are enlarged 100%, 200% and 250% and tested. Figure 14 shows button layout used in experiments. In experiment using a touch screen two cases, 'direct touch' and 'remote touch' were conducted. 'direct touch' case is that a subject continues input operation above the touch screen without moving hand. However, 'remote touch' case is that a subject stretches hand to the touch screen and draws hand back again repeatedly every input operation (click). These two input method is the same circumstance set such as operation in stop and in driving. In the experiment of 'remote touch' case the travel distance of hand is 27cm but in experiments by using the keypad interface a subject always puts hand on the keypad during the operation.

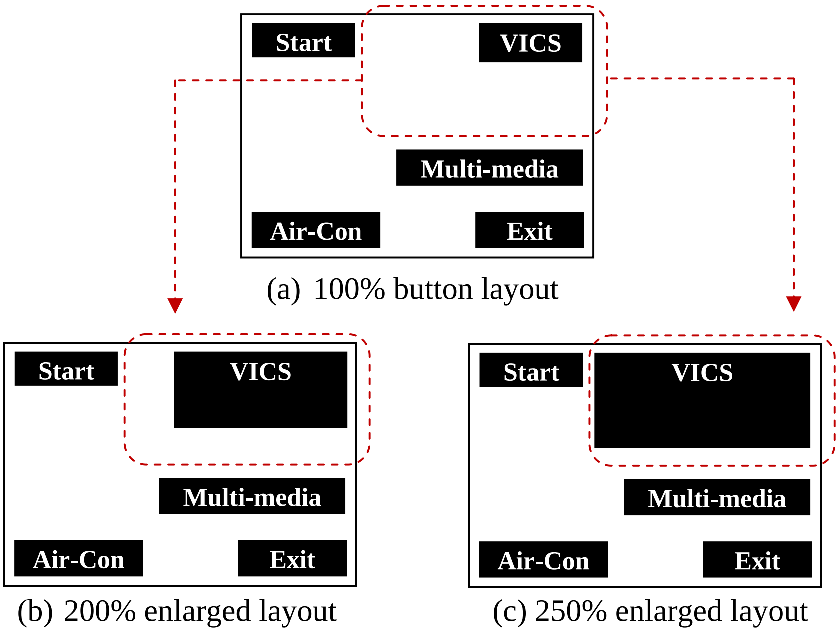


Figure 14. Layout of button switch

In general, many of experiment in human shape recognition use the time of shape recognition and the error rate in the two as performance indicator [15]. We define the reaction time from information display to input operation as the time of shape recognition and measured the time to enter the next menu screen after input operation by touch. According to this, the reaction time contains movements such as shape perception, judgment and operation. Figure 15 and 16 show only 13 data among 39 experimental data. Figure 15 shows the average response time each button switch all the trial of 10 subjects. The average reaction time of three cases: (a) ‘direct touch’ and a fixed pattern of button switch, (b) ‘remote touch’ and a fixed pattern of button switch, (d) keypad and 250% enlarged button switch is 1,143 ms, 1,969 ms and 1,053 ms each button switch of all subjects. Input operation on keypad is from 90 ms (about 8%) to 916 ms (about 47%) earlier than (a) and (b) on the touch screen.

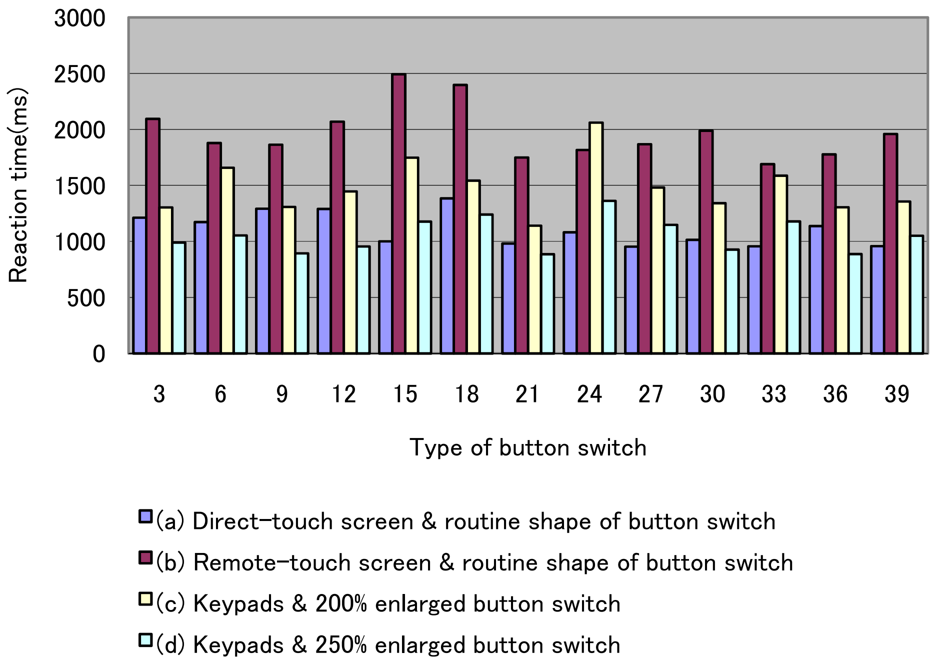


Figure 15. The comparison of response time

Figure 16 shows the average response time each button at the third trial of 10 subjects. In other words, figure 16 shows data when subjects are familiar to operate the keypad interface. Drawing comparison between figure 15 and 16 and paying attention to (d), we see that as the number of attempts grows, subjects adapted themselves to tactile information. In fact, in figure 16 (d) of the third attempt of all subjects the average response time is 1,000ms and this is 143ms(about 13%), 969ms(about 49) earlier than (a) 'direct touch' and a fixed pattern button switch, which clearly demonstrates effect of the keypad.

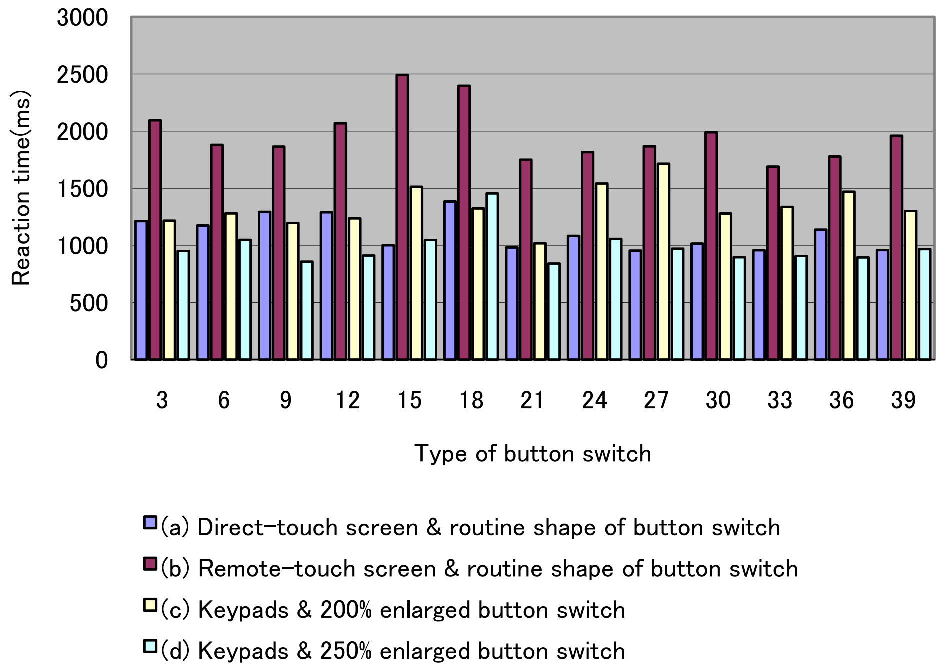


Figure 16. The comparison of response time at third trial

The interesting characteristic that the subject to do input operation using the keypad needs intuitive adaptation to tactile information was also found from the experimental results as shown in figure 17. The reaction time of (a) first trial, (b) second trial and (c) third trial is 1,754 ms, 1,409 ms and 1,320 ms. Thus, as the subject repeats input operation without the advice of actions, the reaction time become shorter so we become to know that the subject adapts himself to input operation by intuitive discretion. But the different characteristics are shown about the tactile sensation adaptation in figure 18. Comparing 100% and 200% enlarged button switch, the reaction time of 100% and 250% enlarge button switch was changed little regardless of trials. As a result, the button size with which it does not the tactile sensation adaptation exists so it is better to refer the result of this to design of button layout.

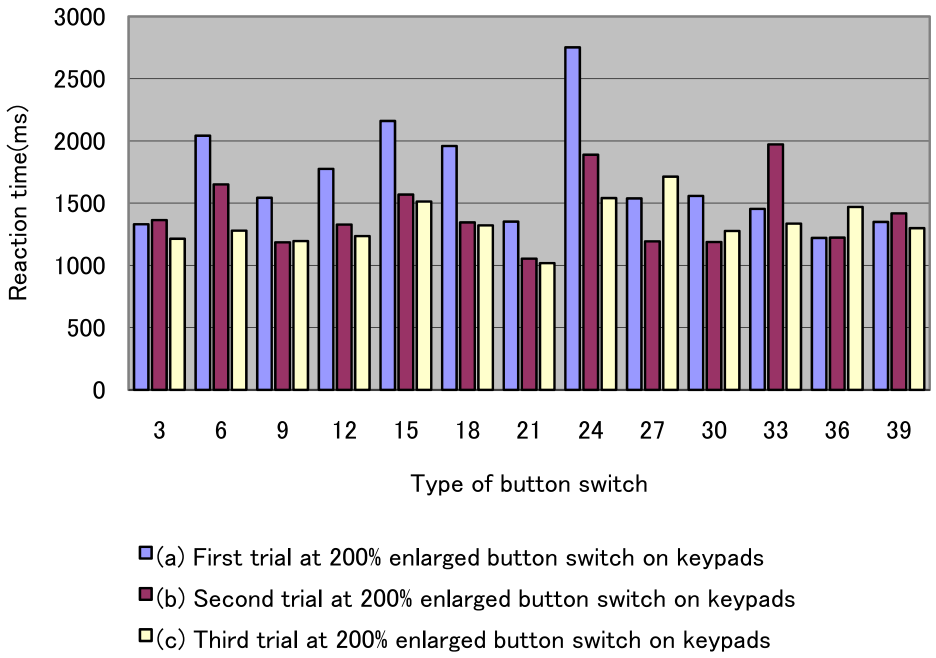


Figure 17. Response time each button switch which is enlarged 200%

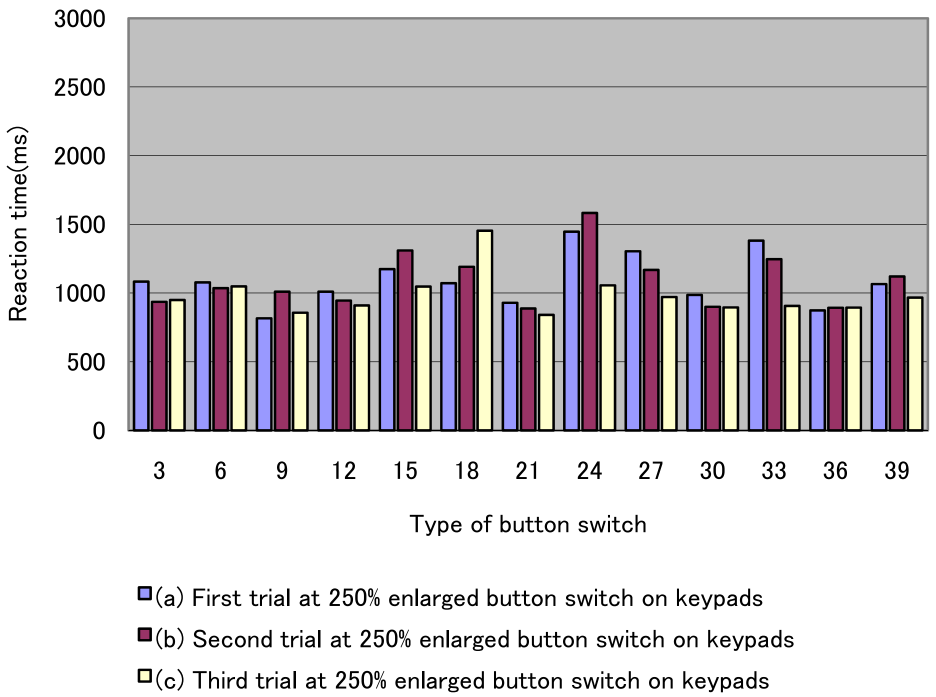


Figure 18. Response time each button switch which is enlarged 250%

b. Effect of input unit's location

In the experiment using touch screen with two cases, 'direct touch' and 'remote touch', the effect of input unit's location was examined. We measured number of trial times to go to the next stage (menu screen) as shown in figure 19 and the distance between touched point of finger and the center of button switch pushed as shown in figure 20.

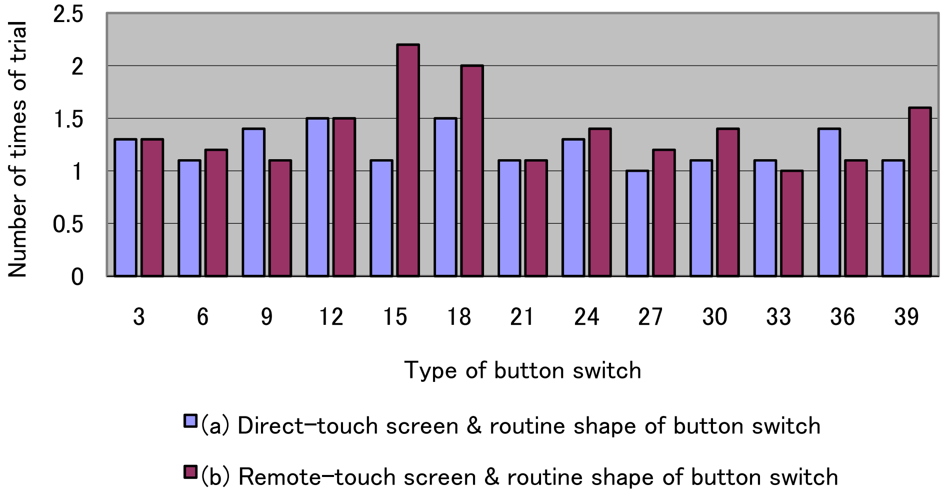


Figure 19. Number of times of trial to go to the next step

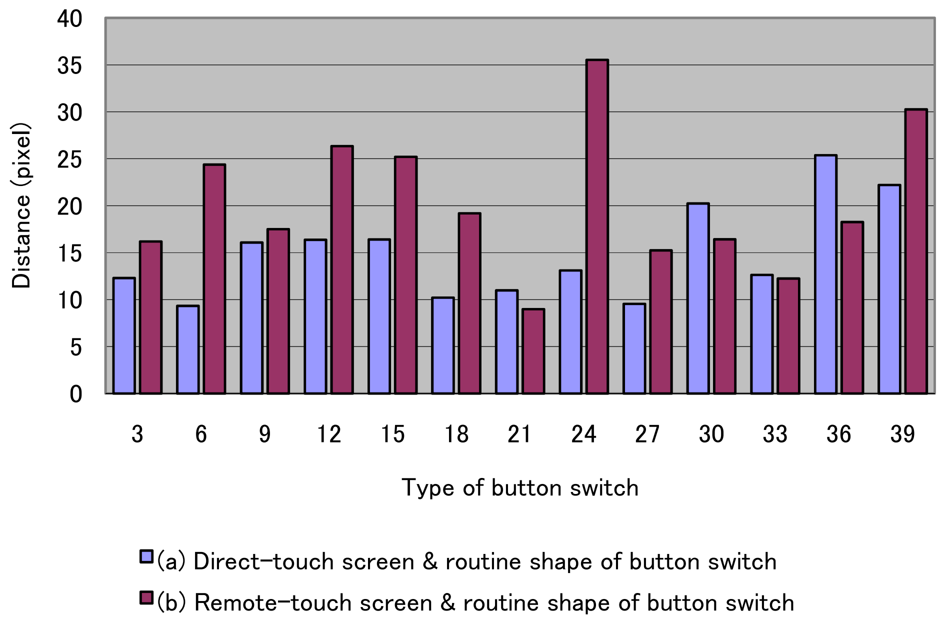


Figure 20. Distance between touched point and center of button switch

The number of trial times of ‘direct touch’ and ‘remote touch’ is 1.2 times and 1.36 times and the distance of two cases is 14.3 pixels and 19.6 pixels so shaking or moving hands affects the accuracy of input operation as we guessed.

VII. CONCLUSION

In this study a pattern adaptive keypad interface for in-vehicle information systems is proposed and the development and experimental results to evaluate the use of the prototype were reported. The system is design to suggest the estimated pattern of input sequence to fit the user’s preference based on individual model of operation pattern as the design of software part. The keypad interface allows the shape of button switch to actively be reconfigured to express the user’s preference and presents it as tactile and visual information. It is possible to grasp the finger position on the keypad easily by capturing finger image and displaying the synthesized image on a monitor. As the tactile display offers a various forms of button switch and input operation in conjunction with information awareness, the intuitive operation has been achieved. The experimental results assess the effectiveness of the proposed keypad interface to shorten the time of the user’s input action by reconfiguring the shape of the button switch actively. Thus the proposed keypad interface is considered to allow users to operate the desired button switch in faster, simple and easy manner.

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