Multi-Push Display: Functional Extension to Three-point Push

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Abstract: In our previous study, we have proposed a multi-push display. The multi-push display provides a multi-push sensation by using a 6-axis motion platform. The display mechanically controls the position and orientation of a surface panel. A user touching an on-screen button with one finger can push the button vertically. When the user subsequently touches the display with a second finger, the surface panel declines and the position of the first finger remains unchanged. The user can push at two positions on the surface panel.

In this paper, we have proposed the extended function that achieves the third push by using the same hardware as the previous study. This function can be achieved by rotating the surface panel along the line connecting the touch points by first and second fingers.

Keyword: Touch panel; tactile feedback; 6-axis motion platform

1 Introduction

Touch panel technology is widely used in applications such as mobile phones, ATMs, ticket-vending machines, and car navigation systems. Conventional touch panels provide audio and visual feedback to the user in order to clarify the system’s status and responses. Although some forms of tactile feedback, such as vibration, are used in certain touch panels, the sensation of operation of such touch panels is different from that when depressing conventional push buttons. Previous studies incorporated the push-button sensation into touch panels [1, 2]. However, these touch panels do not offer multi-position push sensation.

Nagamatsu et al. developed a novel tactile display that provides a two-point push sensation by using a 6-axis motion platform[3]. The tactile display mechanically controls the position and orientation of the surface panel. A user touching an on-screen button with one finger can push the button vertically. When the user subsequently touches the other on-screen button with a second finger, the surface panel declines and the position of the first finger remains unchanged. Thus, the user can push at two positions on the surface panel.

In this paper, we propose an extended function of Nagamatsu's system, which realizes the three-point push. After the second finger pushes the panel, the system allows the third finger to push the surface panel keeping the positions of first and second fingers by rotating the surface panel about the line that connects the touch points with the first and second fingers.

2 Related works

Several techniques were developed that provide tactile feedback on a touch panel. For example, Active Click [4] provides tactile feedback in the form of vibration; this technique is currently used extensively in applications such as mobile phones and car navigation systems. However, vibration is different from natural tactile feedback. TeslaTouch [5] is based on electrovibration, which does not make use of any moving parts. It provides a wide range of tactile feedback sensations to fingers moving across a touch surface but does not provide a push sensation.

Some previous studies constructed a moveable display panel. For example, TouchMover [6] is a visual+haptic device that combines 3D stereo visualizations, multi-touchscreen interactions, force sensing, and 1D haptic actuation perpendicular to the
Further, Gesture output \cite{7} is a technique that actuates the user’s finger in two dimensions by using a transparent foil overlaid on the touchscreen. Finally, WobblySurface \cite{2} controls the rigidity of a surface panel such that when a user touches an on-screen button, the normally rigid surface becomes wobbly and is able to be pushed mechanically like a button; it uses three degrees of freedom. Thus, the maximum number of degree of freedom achieved was three.

Other studies developed systems for realizing localized tactile sensation. For example, MudPad \cite{8} realizes multi-position tactile feedback; however, it has a soft contact surface. Harrison et al. \cite{9} and Tactus \cite{10} developed techniques that provide dynamically changeable physical buttons on a visual display; however, the tactile features in these displays are statically arranged. inFORM \cite{11} provides localized tactile sensation by using numerous pins. Thus, we developed a technique that provides a multi-push sensation through a flat hard contact surface\cite{3}. However, the system achieves only two-point push. This paper describes how to realize the third-point push.

3 Two-point-push display

In this section, we describe the previous system that realizes two-point-push sensation.

3.1 Principle for realization of two-point-push sensation

In the previous study \cite{3}, we developed a technique that allows users to push at two positions on a surface panel. This technique is based on the principle of declining the surface panel, as shown in Fig. 1. When the user touches the surface panel with Finger 1 (Fig. 1 a), the panel moves along the normal vector of the plane formed by the surface panel and comes to rest at the position shown in Fig. 1 b. Next, when the user pushes the surface panel with Finger 2, the panel rotates around the point of contact of Finger 1 (Fig. 1 c).

We define the positions of the surface panel shown in Figs. 1 a–c as Positions A, B, and C, respectively.

3.2 Hardware design

To realize the concept of a multi-push display, we designed the system as shown in Fig. 2. The surface panel is supported by six rods connected to six servomotors. One end of each rod connects to the surface panel and the other end connects to the arm of a servomotor via ball joints. This mechanism is the so-called Stewart platform.

In our system, a finger touch is detected by the frustrated total internal reflection (FTIR) technique \cite{12}. Infrared light-emitting diode (IR LED) arrays are installed on two opposite sides of the surface panel, and the positions of the fingers are detected by an IR camera.

An image is back-projected by a projector onto the screen located under the surface panel. A notable characteristic of our system is that the screen and touch panel are isolated from each other. Since the surface panel is transparent, the image on the screen is
static. The image of only the button area can be changed when the on-screen button is pushed.

In the figure, \( X_0, X_1, X_2, X_3, X_4, \) and \( X_5 \) correspond to the position vectors of the surface panel of the connection points of the rods from servomotors 0–5, respectively.

### 3.3 Estimation of finger position in the world coordinate system

We estimate the position of finger touch in three dimensions by means of the IR camera. We detect the corresponding 2D position on the surface panel by using three fiducial markers attached to the panel. The position vectors of the fiducial markers in three dimensions are denoted as \( \mathbf{A}, \mathbf{B}, \) and \( \mathbf{O} \) as shown in Fig. 2. In our system, \( \mathbf{A}, \mathbf{B}, \) and \( \mathbf{O} \) change in response to the movement of the surface panel; nevertheless, the system is constantly aware of them.

In the camera coordinate system, let \( \mathbf{c}_A=(x_A, y_A), \mathbf{c}_B=(x_B, y_B), \) and \( \mathbf{c}_O=(x_O, y_O) \) denote the position vectors of the fiducial markers on the surface panel, and let \( \mathbf{c}_F=(x_F, y_F) \) denote the finger position vector, as shown in Fig. 3. Then, these positions are related as follows:

\[
(\mathbf{c}_F - \mathbf{c}_O) = a(\mathbf{c}_A - \mathbf{c}_O) + b(\mathbf{c}_B - \mathbf{c}_O)
\]

Here, \( a \) and \( b \) are coefficients that can be calculated as,

\[
a = \frac{(x_F - x_O)(y_B - y_O) - (x_B - x_O)(y_F - y_O)}{(x_A - x_O)(y_B - y_O) - (x_B - x_O)(y_A - y_O)},
\]

\[
b = \frac{(x_A - x_O)(y_F - y_O) - (x_F - x_O)(y_A - y_O)}{(x_A - x_O)(y_B - y_O) - (x_B - x_O)(y_A - y_O)}.
\]

Thus, the position \( \mathbf{F} \) is expressed in the 3D world coordinate system as follows:

\[
\mathbf{F} = a(\mathbf{A} - \mathbf{O}) + b(\mathbf{B} - \mathbf{O}) + \mathbf{O}
\]

### 3.4 Calculation of the position of surface panel after first finger touch

When the first finger touches the surface panel, the position of the surface panel, i.e., \( X_0, X_1, X_2, X_3, X_4, \) and \( X_5 \), is easily determined by moving the surface panel vertically by \( \text{depth}_1 \) mm. In our study, \( \text{depth}_1 \) is set to 2 mm.

### 3.5 Calculation of the position of surface panel after second finger touch

When the second finger touches the surface panel, the system causes the surface panel to decline. The vector of the rotation axis, \( \mathbf{l}_2 \), shown in Fig. 4, is defined as

\[
\mathbf{l}_2 = (\mathbf{F}_2 - \mathbf{F}_1) \times \mathbf{n}_B
\]

where \( \mathbf{F}_1 \) and \( \mathbf{F}_2 \) are the touch positions of the first and second fingers, respectively, and \( \mathbf{n}_B \) is the normal vector of the surface panel at position \( \mathbf{B} \).

The rotation angle \( \alpha_2 \) is calculated from the push depth as follows:

\[
\alpha_2 = \arcsin \left( \frac{\text{depth}_2}{d_2} \right)
\]

\[
d_2 = \| \mathbf{F}_2 - \mathbf{F} \|
\]
where $d_2$ is the depth pushed by the user and $d_2$ is the distance between the touch positions of the two fingers on the surface panel. Thus, the angle $\alpha_2$ through which the system rotates the surface panel is determined. The new positions of $X_0$, $X_1$, $X_2$, $X_3$, $X_4$, and $X_5$ are determined by rotating the surface panel by angle $\alpha_2$ along the axis $l_2$.

### 3.6 Determination of Rotation Angle of Servomotors

In order to move the surface panel, we must determine the rotation angle of each servomotor. The position $X$ in the world coordinate system is transformed to the position $X'$ in the coordinate system of the servomotor $i$ as follows:

$$X' = ^iR_w(X - ^iT_w)$$

where $^iR_w$ and $^iT_w$ are, respectively, the rotation matrix and the translation vector from the world coordinate system to the coordinate system of servomotor $i$. These are determined by measuring the direction and position of the servomotors.

Figure 5 shows a servomotor, an arm, and a rod in the coordinate system of servomotor $i$; here, $l$ is the length of the rod connecting the panel to the servo arm, $r$ is the arm length, and $\theta$ is the angle of rotation of the servomotor.

$\theta$ must be determined such that the end of the rod passes through the position $X' = (x, y, z)$. Therefore, the relation satisfies the following equation:

$$l^2 = (rcos \theta - x)^2 + (rsin \theta - y)^2 + (0 - z)^2$$

Then, we have

$$\sin(\theta + \beta) = \frac{x^2 + y^2 + z^2 + r^2 - l^2}{2r\sqrt{x^2 + y^2}}$$

where $\beta$ satisfies $\sin \beta = \sqrt{\frac{x}{x^2 + y^2}}$ and

$$\cos \beta = \sqrt{\frac{y}{x^2 + y^2}}$$

Therefore,

$$\theta = \arcsin \left( \frac{x^2 + y^2 + z^2 + r^2 - l^2}{2r\sqrt{x^2 + y^2}} \right) - \beta$$

or

$$\theta = \pi - \arcsin \left( \frac{x^2 + y^2 + z^2 + r^2 - l^2}{2r\sqrt{x^2 + y^2}} \right) - \beta$$

We select an appropriate $\theta$ value according to the direction of the servomotor.

### 4 Extension to three point push

#### 4.1 Principle for realization of three point-push sensation

In this paper, we propose an extended function to three point push. In order to realize the third push, after pushing at two points (Position C), the system declines the surface panel along the line connecting the touch points of Finger 1 and 2 on the surface panel as shown in Fig. 6. Then, the Finger 1 and 2 remain at the same positions while the Finger 3 pushes the surface panel.

![Fig.6 Principle for realizing third-point-push sensation.](image)

#### 4.2 Calculation of the position of surface panel after third finger touch

When the third finger touches the surface panel, the system causes the surface panel to decline. The
vector of the rotation axis $l_3$, shown in Fig. 7, is defined as

$$l_3 = F_2 - F_1$$

The rotation angle $\alpha_3$ is calculated from the push depth as follows:

$$\alpha_3 = \arcsin \left( \frac{\text{depth}_3}{d_3} \right)$$

$$d_3 = \frac{\| (F_2 - F_1) \times (F_3 - F_1) \|}{\| F_2 - F_1 \|}$$

where $F_3$ is the touch position of the third finger and $\text{depth}_3$ is the depth pushed by the user and $d_3$ is the distance between the touch position of the third finger and the rotation axis $l_3$. Thus, the angle $\alpha_3$ through which the system rotates the surface panel is determined. The new positions of $X_0, X_1, X_2, X_3, X_4, X_5$ are determined by rotating the surface panel by angle $\alpha_3$ along the axis $l_3$.

The previous implementation of two point push system ignored the error due to the thickness of the surface panel. In the real situation, the surface panel has the thickness and the ball joints causes offsets as shown in Fig. 8.

Therefore, the calculation of angle of the servomotors should be done by using the position of connecting point of ball joint $X'_i$ instead of $X_i$. $X'_i$ can be calculated by using the normal vector of the surface panel as,

$$X'_i = X_i - n$$

where $n$ is the unit normal vector of the surface panel and $t$ is the distance between the center of the ball joint and the upper surface of the panel.

6 Implementation

A prototype system was implemented, as shown in Fig. 9. The system consists mainly of a surface panel, six servomotors (Kondo Kagaku Co., Ltd., KRS 4033HV), a screen, an IR camera, IR LEDs (Vishay Intertechnology, Inc., VSMG2700), a PC, and a projector. Before operation of the system, the focus of the projector was adjusted on the screen and projection area was adjusted at the time when the surface panel took the Position A.
Figure 10 shows the system in operation. Figure 10 a shows a display movement when two fingers touch the panel. Figure 10 b shows a movement when the third finger touches the panel. In this stage of implementation, the surface panel immediately moves downward when a touch is detected.

![Two-point push](image)

![Three-point push](image)

Fig.10 System in operation.

**7 Conclusion**

This paper proposed the functional extension of the multi-push display. The multi-push display has become to achieve three-point push. The system is based on the principle of declining the surface panel. A user touching an on-screen button with one finger can push the button vertically. When the user subsequently touches the display with a second finger, the surface panel declines and the position of the first finger remains unchanged. After that, when the third finger touches the surface panel, the surface panel declines along the line connecting the touch position of the first and second fingers.

**References**


