1st International Conference on Sensing Technology
November 21-23, 2005 Palmerston North, New Zealand

Regarding the Accuracy in Horizontal Force Component of Tactile GUI Device

Shigenobu SHIMADA, UEC[1], Tokyo, Japan, shimada@rm.mce.uec.ac.jp
Masami SHINOHARA, AIST[2], Tsukuba, Japan, m-shinohara@aist.go.jp
Yutaka SHIMIZU, UEC[3], Tokyo, Japan, shimizu@se.uec.ac.jp
Makoto SHIMOJO, UEC[1], Tokyo, Japan, shimojo@mce.uec.ac.jp

1. Department of Mechanical Engineering and Intelligent Systems, The University of Electro–Communications
2. Institute for Human Science and Biomedical Engineering,
National Institute of Advanced Industrial Science and Technology
3. Department of Systems Engineering, The University of Electro–Communications

Abstract

A basic device combining a tactile display function and a touch position/force direction sensing function is proposed. The trial device consists of two major components, a tactile graphic display and a 6–axis force/torque sensor. The force sensor measures six dynamic values generated by touch action on the display surface and a PC estimates the touch position based on the data and a simple dynamic principle. The effect of a contact force on the estimated position are examined respectively by a vertical component and a horizontal component. In this paper, we show several problems obtained through the experimental results, and also show the correction methods corresponding to each problems.

Keywords: Tactile Display, Tactile GUI, Blind, Computer Interface, 6–axis Force Sensor

1 Introduction

The spread of graphical user interfaces (GUI) made personal computers easier to use. Users can now directly operate their computer through various visual objects in the so–called "WYSIWYG" style. However, although this style of communicating with a PC is convenient for sighted persons, it is inaccessible for visually impaired persons, and so much effort has been made to overcome the difficulty. For example, several application programs that select visual information which can be converted into text form and convey it as synthesized speech or Braille are already on the market. These programs effectively assist blind PC users, but are still insufficient for conveying nonlinguistic information.

The concept of the tactile graphic display was therefore introduced and several devices are on the market now, but they are still a long way from becoming widely used. This must be primarily due to the lack of mature technologies for providing inexpensive devices with sufficient usability.

Most of the tactile display devices developed in the past were only unidirectional communication tools, that is only display devices [1–3]. If a bidirectional communication function could be provided, graphic information would become more accessible for visually impaired PC users and stimulate their creative activity.

The fundamental function for achieving the bidirectional communication is to detect the location where the user is touching a tangible surface, so we investigated a new method to detect the finger locus [4]. The preliminary investigation was examined by considering the vertical component. Therefore, we now investigate the accuracy of detection when a horizontal force component is placed on our tactile GUI device.

2 Trial Production

Feasible method of constructing such a device can be roughly classified into two types; adding a detection function to each actuator(such as DMD12060 of METEC), and combining, a display component with a detection component independently. The latter can be sub–classified into several methods but most of them involve complicated wiring. Considering higher independence and simpler wiring, we selected a combination of a tactile display and a force/torque sensor.

2.1 Tactile Graphic Display

Four bimorph modules (SC–10, provided by KGS Inc.) were used to assemble the tactile graphic display. Each module has a 32×12 arrangement of pins with 2.4 mm spacing. The pin is 1.3 mm in diameter and must be pushed down with a force of at least 0.098 N in order to touch the surface. The total tactile surface has a 32×48 arrangement activated at a time. The height of the tactor pin when activated by a data signal is 0.7 mm. The refresh time for the entire surface is about 50 ms. The device interfaces with the host PC through a USB port. The left part of **Figure 1** shows the component of the tactile display.

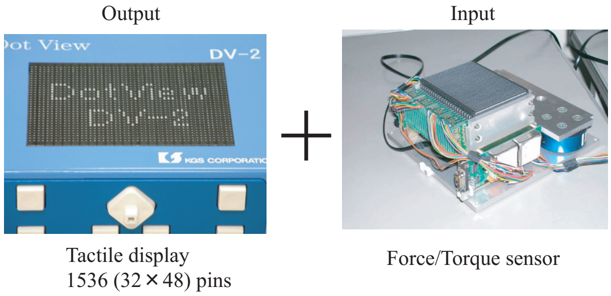

Figure 1: An overview of the trial device consisting of two components. The left part is a tactile display and the right part is a 6–axis force/torque sensor. The tactile display is fixed on a solid plate connected firmly with the force sensor in the load center of the display.

2.2 Force/Torque Sensor

The IFS67M25A 6–axis force/torque sensor and PCI2184S PCI board (NITTA Inc.) were used in the experiments. The sensor measures the force and the torque generated by touch action. The touch action contains important information such as touch position, push direction and push strength. These quantities are estimated based on the measured data and used for discriminating proper touch actions and designing HCI(Human Computer Interaction) functions such as mouse like function, touch scroll function and so on.

The sensing ranges are respectively 60 N (in regard to the x– and y–axis), 120 N (in regard to the z–axis) in force, and 5 Nm (in regard to all axes) in torque. The sensor processes 6–axis data with 8 KHz.

The display is fixed on a solid plate firmly connected to the force/torque sensor as shown in right part of **Figure 1**. The sensor is set roughly below the center of the display component.

2.3 Principle of Estimation

Figure 2 helps to explain the operational principle adopted here. When the user pushes the surface Π with force $\boldsymbol{f}$ at $\boldsymbol{r}$, the following simultaneous equations are formed:

$$\boldsymbol{m} = \boldsymbol{r} \times \boldsymbol{f}, \qquad (1)$$

$$(\boldsymbol{h}, \boldsymbol{r} - \boldsymbol{h}) = 0. \qquad (2)$$

where $\boldsymbol{r}$: touch position vector, $\boldsymbol{f}$: force vector, $\boldsymbol{m}$: force moment vector, $\boldsymbol{h}$: normal vector defining the touch surface, $\times$: vector product, and $(,)$: scalar product.

The touch position is theoretically obtained as the solution of equation (1) and equation (2).

$$\boldsymbol{r} = \frac{\{\boldsymbol{h} \times \boldsymbol{m} + (\boldsymbol{h}, \boldsymbol{h})\boldsymbol{f}\}}{(\boldsymbol{h}, \boldsymbol{f})}. \qquad (3)$$

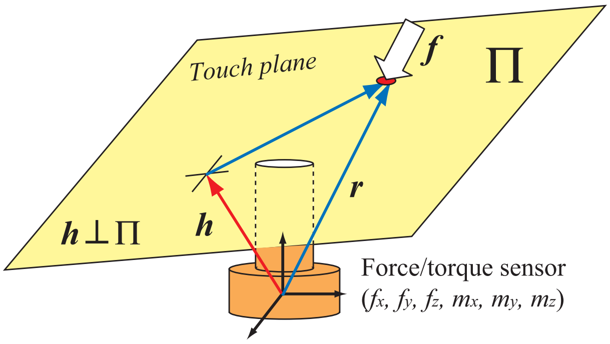

Figure 2: Touch position sensing principle

The data on f and m are measured by the 6–axis force/torque sensor. The sensor coordinate system is three–dimensional, while the touch surface is two–dimensional. Furthermore, the normal vector $\boldsymbol{h}$ may not be parallel with the z–axis of the sensor coordinate system. Thus $\boldsymbol{r}$ requires the application of a coordinates transformation matrix $\boldsymbol{A}$ to obtain the actual touch position coordinates on the touch surface.

3 Estimation Accuracy in Vertical Component

As a basic experiment, the touch surface is weighted in the vertical force component of 500 g, and the detection accuracy of estimated position is evaluated. The evaluation object is a difference between actual touch position and the estimated one. The evaluation criterion is assumed to be 2.4 mm which is the spacing of the pins. In the following, case 1 suppose that no touch action deforms the touch surface and that the coordinate system of the touch surface is formed on the basis of a tactor lattice.

3.1 Case 1: Normal Vector $\boldsymbol{h}$ is Parallel with the z– axis of the Sensor

If normal vector $\boldsymbol{h}$ is expressed in $\boldsymbol{h} = (0, 0, h_z)$, equation (2) is simplified as follows:

$$\boldsymbol{r} = \boldsymbol{A}\tilde{\boldsymbol{r}} = \boldsymbol{A}\frac{\begin{pmatrix} h_z f_x - m_y \\ h_z f_y + m_x \\ h_z f_z \end{pmatrix}}{f_z} = \tilde{\boldsymbol{A}}\frac{\begin{pmatrix} h_z f_x - m_y \\ h_z f_y + m_x \end{pmatrix}}{f_z} \qquad (4)$$

however, $\tilde{\boldsymbol{A}}$ is two dimensional orthogonal matrix. Therefore, $\tilde{\boldsymbol{A}}$ is a rotational transform with a certain shift added.

The results of the estimated position are shown in a **Figure 3**. The maximum difference between the touch position and the estimated one is 3.3 mm, and the average of all measurement points is 1.38 mm. Since the distance between pins of the touch surface is 2.4 mm,

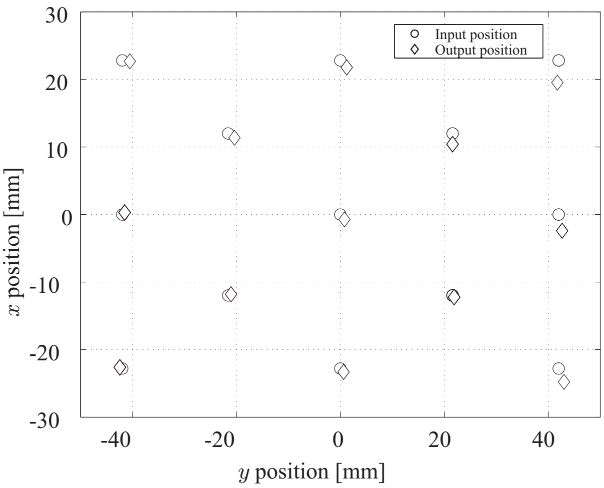

Figure 3: Touch position data

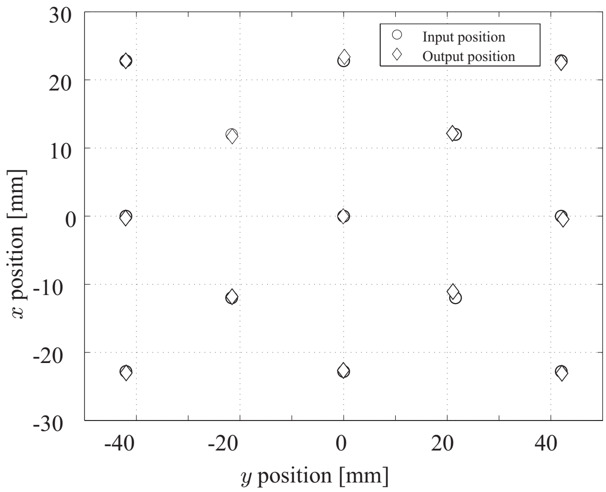

Figure 4: Touch position data after projective transformation

which the range of the one pin is ± 1.2 mm, the difference between the touch position and the estimated position should not exceed 1.2 mm. That is, the estimated position shifts from the touch position based on the experimental result. We can not obtain exact accuracy of the estimated position from equation (3).

3.2 Case 2: Touch Surface is Deformed by Touch Actions

If the display component has insufficient stiffness, the touch surface does not always maintain its shape invariance. The display component consists of four modules not so stiff in themselves and not very firmly connected to each other. Touch pressure might deform each module in resin and the interaction between the modules might make the distortion more complex appropriate. But the touch surface must stretch laterally with a slight vertical displacement since the solid supporting plate restrains the display component upward.

Piecewise approximation is appropriate in such a case, but makes the calibration process troublesome. Thus, in order to simplify the argument, we assume the following:

1. The deformation does not depend on the strength of the push.
2. The vertical displacement is negligible and the horizontal displacement is uniform within the contact surface.
3. The surface forms an irregular quadrilateral outline and all lines are preserved by mapping.

The simplest form satisfying these is the well–known projective transformation.

Projective transformation is expressed in equation form as follows:

$$w\begin{pmatrix}x'\\y'\\1\end{pmatrix}=\begin{pmatrix}p_{11}&p_{12}&p_{13}\\p_{21}&p_{22}&p_{23}\\p_{31}&p_{32}&p_{33}\end{pmatrix}\begin{pmatrix}x\\y\\1\end{pmatrix}=\boldsymbol{P}\begin{pmatrix}x\\y\\1\end{pmatrix} \qquad (5)$$

where w : indeterminate coefficient, x', y' : estimated touch position, x, y : actual touch position, $\boldsymbol{p}_{ij}$: member of projective transformation. A member of the projection matrix is obtained by least squares estimation of the experimental data. Then, touch position may be calculated from the inverse matrix of $\boldsymbol{P}$.

The estimated touch position after the projective transformation is shown in **Figure 4**. The maximum difference between the actual touch position and the estimated one is 1.0 mm. The average of the difference between the actual touch position and the estimated one is 0.36 mm. Since it is within pin spacing, the touch position and the estimated position correspond to single position.

4 Estimation Accuracy in Horizontal Component

Our device is not easy to manipulate using only the vertical component. Therefore, we carried out the experiment which considers a horizontal force component, and evaluated the performance of the device.

4.1 Experimental Condition

Figure 5 shows the experimental apparatus. The horizontal force component is applied by a tilted weight. The experimental condition is follows:

1. Weight is 500 g, and its shape is a column of 82 mm and a cone of 29 mm.

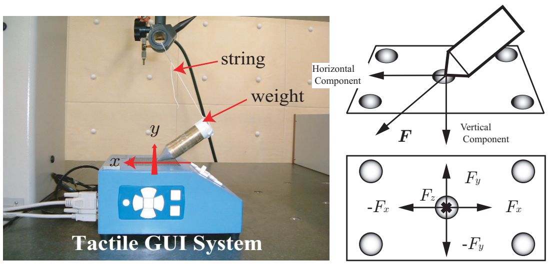

Figure 5: Experimental apparatus using horizontal component

2. Transformation matrix is projective transformation.
3. Forces are measured by a 6–axis force/torque sensor.
4. Measurement carried out at five points, i.e. top left (Point 1), top right (Point 2), center (Point 3), bottom left (Point 4), bottom right (Point 5).
5. Each measurement point is measured in four horizontal directions and one vertical direction.

The experimented procedure is as follows:

1. The weight is suspended with a thread to contact with Point1.
2. Point 1 is loaded in vertical direction (f_z) with 4.9 N by adjusting the string.
3. Next, Point 1 is loaded in the horizontal direction (f_x+) to 1.0 N by adjusting the string.
4. In a like manner, Point 1 is loaded f_x-, f_y+, and f_y- direction with 1.0 N.
5. The above-mentioned procedure is carried out for Point 2 ∼Point 5.

4.2 Experimental Result

The experimental results are shown in **Figure 6** Non correction. It turns out that the estimated positions are highly precise near the center of the contact surface(Point 3), and are inaccurate in the edge of the touch surface. Especially, the measurement points of Point 1 and Point 2 are not estimated within the range of ± 1.2 mm from the touch position.

The maximum difference between the touch position and estimated one in all the measurement point is 7.3 mm. That difference means three pins shift from the touch position. Therefore, it was found that projective transformation is not sufficient for use when the horizontal component is added.

The shifting cause of the estimated position can consider displacements in the positions between the touch surface and the 6 axis–force sensor that occur during assembling, and a measurement error of the 6 axis–force sensor. It is known that if multi axes of the 6 axis–force sensor are loaded simultaneously, the force between the axes interfere with each other, so that the error of loading multiple axes is larger than a single axis loading. However, the correction method for the measurement error of the 6–axis force sensor is not proposed. Therefore, we consider improving the accuracy of the estimated position when the fitting error corrects. Below, the correction method is proposed and the results are shown.

4.3 Estimation Accuracy with Correcting Normal Vector $\boldsymbol{h}$

Here, the normal vector $\boldsymbol{h}$ has been assumed to be $\boldsymbol{h} = (h_x, h_y, h_z) = (0, 0, 74.4)$ mm. Since the touch surface and the 6–axis force/torque sensor are connected by bolts, there is a fitting error between them. Therefore, the normal vector $\boldsymbol{h}$ is corrected to near a true value and we investigate the estimated touch position using $\boldsymbol{h}$.

First, we choose a search range of $\boldsymbol{h}$. That is, h_x and h_y range from −2 mm to 2 mm at 0.1 mm intervals. Furthermore, h_z ranges from 70.4 mm to 74.4 mm at 0.1 mm intervals.

In this experiment, since five directions are measured per the measuring point, $\boldsymbol{f}$, $\boldsymbol{m}$ and the group of $\{h_x, h_y, h_z\}$ are rewritten with $\boldsymbol{f}_j$, $\boldsymbol{m}_j$ and $\boldsymbol{h}_{ij}$, respectively. As mentioned above, the touch position $\boldsymbol{r}_{ij}$ by $\boldsymbol{h}_{ij}$ is calculated as follows:

$$\boldsymbol{r}_{ij} = \frac{\{\boldsymbol{h}_{ij} \times \boldsymbol{m}_j + (\boldsymbol{h}_{ij}, \boldsymbol{h}_{ij})\boldsymbol{f}_j\}}{(\boldsymbol{h}_{ij}, \boldsymbol{f}_j)}. \tag{6}$$

Let the projective transformation of $[r_{xij}\ y_{yij}]'$ is written with $\tilde{\boldsymbol{r}}_{ij}$ as follows:

$$\begin{pmatrix} \tilde{\boldsymbol{r}}_{ij} \\ 1 \end{pmatrix} = \boldsymbol{P} \begin{pmatrix} r_{xij} \\ r_{yij} \\ 1 \end{pmatrix}. \tag{7}$$

Since r_{zij} is h_{zij} from the equation (5), rearrange equation (7) as follows:

$$\hat{\boldsymbol{r}}_{ij} = \begin{pmatrix} \tilde{\boldsymbol{r}}_{ij} \\ r_{zij} \end{pmatrix}. \tag{8}$$

where $\hat{\boldsymbol{r}}_{ij}$ is a estimated value of $\boldsymbol{r}_{ij}$. The $\hat{\boldsymbol{r}}_{ij}$ is chosen from $\hat{\boldsymbol{h}}$ which minimizes the following evaluation functions using $\hat{\boldsymbol{r}}_{ij}$.

$$\boldsymbol{J}_i = \sum_{j=1}^{5} (\hat{\boldsymbol{r}}_{ij} - \overline{\boldsymbol{r}_i})^2, \tag{9}$$

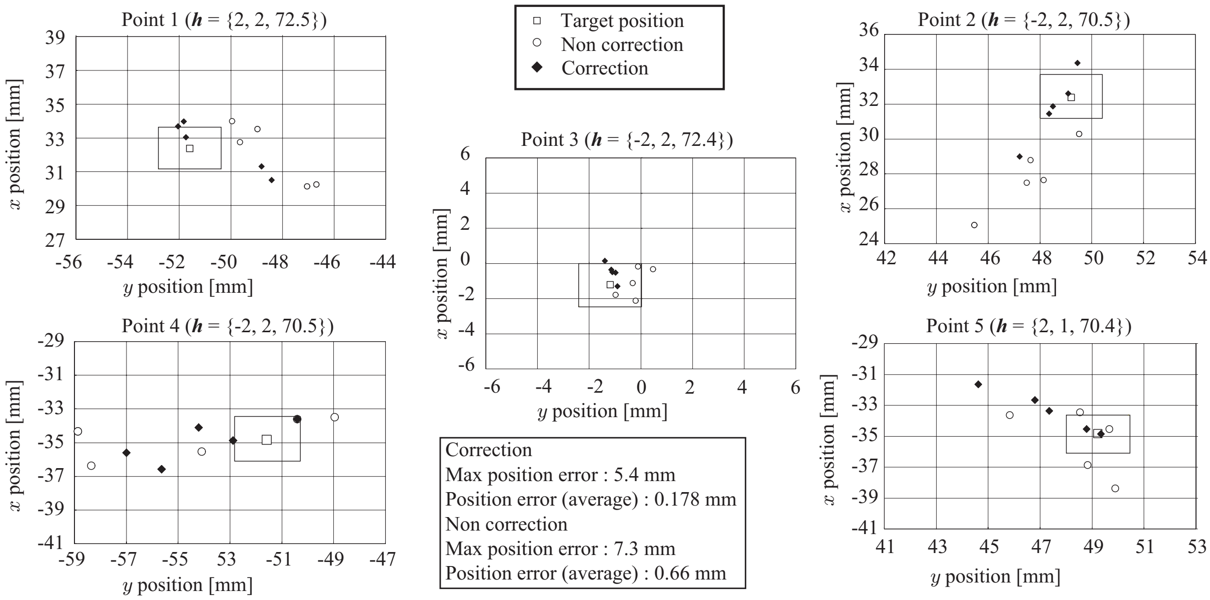

Figure 6: Touch position data using correction method of normal vector ***h***

$$min(\boldsymbol{J}_i) \rightarrow \hat{\boldsymbol{h}}. \quad (10)$$

The experimental result is shown in **Figure 6** Correction. Accuracy has improved 26% in comparison with Non correction. The maximum difference between the touch position and the estimated one is 5.4 mm.

5 Conclusion

A tactile display is one means transmission of information for visually impaired persons. However, the function of display is limited to one–direction. In this study, a basic device combining a tactile display and a force sensing function was proposed. The principle equation (3) of this study assumed a solid body model, and the touch surface is assumed to be orthogonal to the sensor coordinate system. These assumptions is changed whenever the touch surface was weighted by the following three causes:

1. Distortion of the display module.
2. Measurements error in the 6–axis force sensor.
3. The fitting error.

We focused on item 3. and carried out the experiment of considering the horizontal force component using the proposed correction method. Although 26 % of improvement in accuracy is found by the experimental result which corrected the fitting error as compared with the experimental result of No correction, it was not able to estimate to the distance between pins of the tactile display i.e., less than ± 1.2 mm. However, the area of contact of the finger is about 10×10 mm^2, and the object on the tactile display is shown by set of two or more pins. Therefore, the estimated error of two to three pins is a permissible range, and our device can use enough for practical use.

A future schedule is the following:

I. The mechanism of the measurements error of 6 axis–force sensor is clarified from the investigation of an estimated position which is not settled in the distance between pins.
II. The proposal of a concrete application of this device.
III. Development of the new device in consideration of the problem which became clear from these experiments.

References

[1] P. S. Wellman, W. J. Peine, G. Favalora, and R. D. Howe, "Mechanical design and control of a high–bandwidth shape memory alloy tactile display," in Lecture Notes in Control and Information Sciences vol. 232, Springer–Verlag, 1997, 56–66.

[2] M. Shinohara, Y. Shimizu and A. Mochizuki, "Three-dimensional tactile display for the blind," IEEE Trans. On Rehabilitation Engineering, 6, 3, 1998, 249–256.

[3] C. R. Wagner, S. J. Leederman and R. D. Howe, "A tactile shape display using RC servomotors," in Proc. of Satellite Meeting of the Annual IEEE VR'02, 2002, 354–356.

[4] M. Shimojo, M. Shinohara, M. Tanii, Y. Shimizu: "An approach for direct manipulation by tactile modality for blind computer users: Principle and practice of detecting information generated by touch action, " Computers Helping People with Special Needs (ICCHP2004), Springer, pp. 753–760, 2004.