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Eye-controlled virtual keyboard using a new coordinate transformation of long and narrow region

CHERN-SHENG LIN[1*], CHIA-HAU LIN[1], YUN-LONG LAY[2], MAU-SHIUN YEH[3], HSING-CHENG CHANG[1]

[1]Institute of Automatic Control Engineering, Feng Chia University, Taichung, Taiwan

[2]Department of Electronic Engineering, National Chinyi Institute of Technology, Taiping City, Taichung Hsien, Taiwan

[3]Chung-Shan Institute of Science and Technology, Materials and Electro-Optics Research Division, Taoyuan County, Taiwan

[*]Corresponding author: lincs@ fcu.edu.tw

In this paper, we present the development of an eye-tracking and virtual keyboard control system using a PC camera.The image inputs at the channel of the PC camera directly and we can control the cursor of the screen through the sequential image processing. Three-section-correction method is used to correct the eye controlled system. The pupil center position corresponding to the gaze spot on the screen is used to calculate the mouse's motion coordinate on the screen with new coordinate transform equations for the long and narrow region. With the combination of the new eye-tracking and control algorithms, the sensitivities and operations of these systems would be improved greatly.

Keywords: eye-tracking, virtue keyboard, three-section-correction method.

1. Introduction

The virtual keyboard can be projected and touched on the desktop and enables the user to tap the images of the keys to operate the compatible personal digital assistant (PDA) or personal computer (PC). The optical infrared technology is used to detect the users hand movements over the keyboard. Here we develop an eye-tracking and virtual keyboard control system which detects not only the users fingers but also his eye movement to translate that action into keystrokes (Fig. 1).

When using infrared LED to project light on faces, a glint will be reflected on the cornea. In this paper, the infrared CCD camera was employed to capture images of eye movement, and to record the change of relative position of a glint and the center of the cornea with dynamic tracking techniques. The keyboard's size is usually

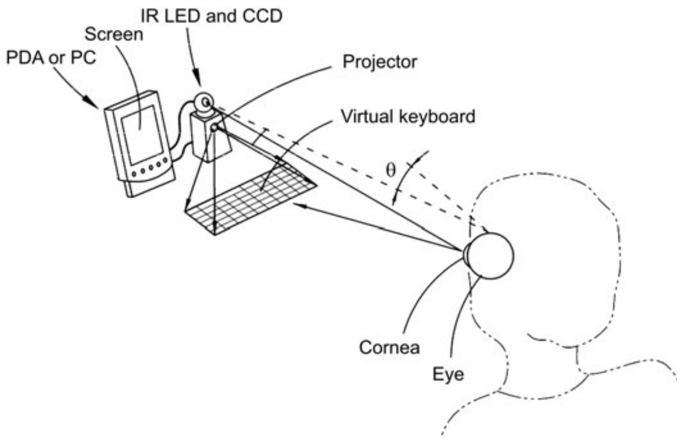

Fig. 1. The structure of an eye-tracking and virtual keyboard control system.

configured as a long and narrow region. The target of vision or the viewing angle θ ($\approx 40-45°$) is transformed to the position of the cursor [1–3] by the directly corresponding coordinate in order to control the virtual keyboard.

Head and body tracking techniques have been well developed in this field while visual tracking is still in the early stage of development [4–7]. However, the application of visual tracking has always drawn attention for its straightforwardness, naturalness and bidirectionalness. Obviously all visible forms of target and command and other input methods (ex. hand or head) are under the guidance of visual input, *i.e.*, users position the target and other input methods or commands are then introduced.

2. A structure of system

The CCD camera was placed with the virtual keyboard near to a 45 degree angle to capture the eye movement. Since the eyes are spherical, so when moving the sight from the left to the right along three horizontal lines passing above, through and below

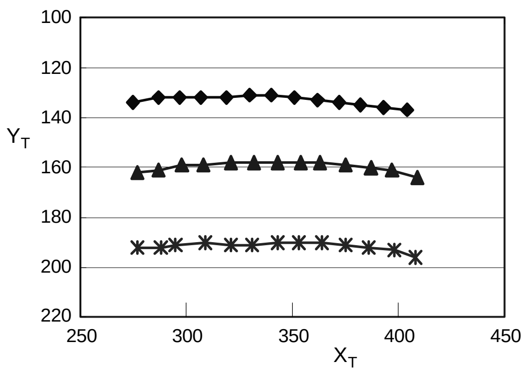

Fig. 2. Paths of the cornea center coordinates (in pixels).

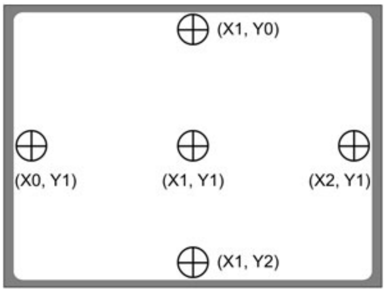

Fig. 3. Coordinates of initial five points.

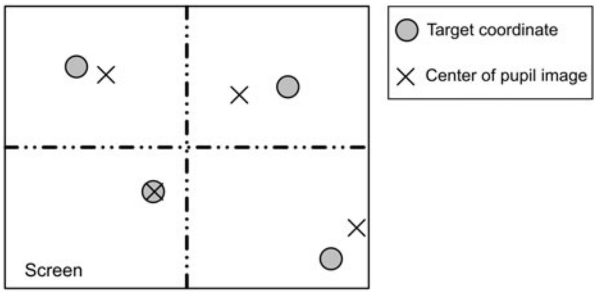

Fig. 4. Deviation of cursor tracks.

the virtual keyboard, the paths of the coordinates of the cornea center were calculated as shown in Fig. 2 [8–12]. The paths were an arc rather than straight lines, which easily deviated during the coordinate transformation. Users needed to look at 9 preset points on the virtual keyboard and press ‘enter’ for each point to correct the error. The process was tedious, therefore we employed another correction and coordinate transformation method as follows. Two cameras were used to accomplish this: one camera at a preset angle captured the eye movement, and the other one caught the finger movement at the preset angle as well. Users can control the virtual keyboard with sight and finger simultaneously.

Although the five point correction method (Fig. 3) was generally used in coordinate transformation, the actual deviation in every quadrant was neither equal nor linear, and therefore it cannot be corrected by adding a fixed deviant. The deviation of every quadrant was shown in Fig. 4.

In this study we try to improve the above method to generate more precise coordinate transformation.

3. Method for new coordinate transformation of long and narrow region

When an angle exists between the CCD camera and eye sight, the path of eye movement is a curve in the horizontal direction and a straight line in the vertical direction since eyes are spherical. Coordinates of every point along a horizontal line, when looking at the virtual keyboard, form a curvature. Figure 5**a** showed the eye movement path when the CCD camera was positioned below the eyes, while Fig. 5**b** was the path when CCD was above the eyes.

The vertical movement of eyes being linear is therefore not discussed in this study. The curve of horizontal movement is segmented into 3 parts for analysis; Figure 6**a** showed the three segments of the eye movement path when CCD camera was

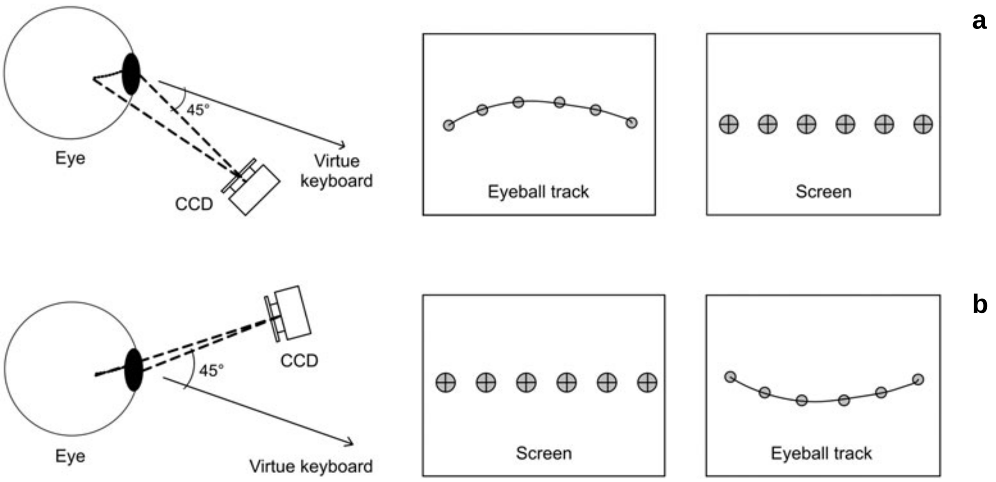

Fig. 5. Eye movement path with CCD positioned below the eyes (**a**). Eye movement path with CCD positioned above the eyes (**b**).

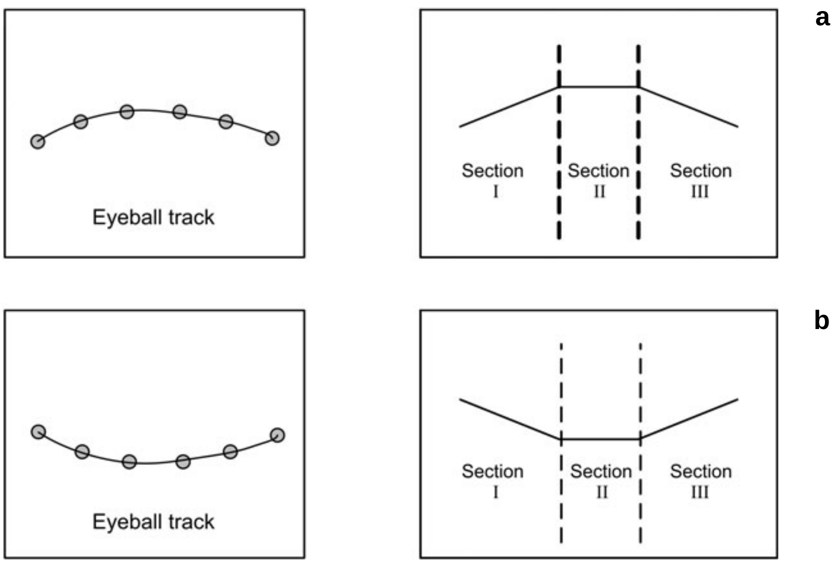

Fig. 6. Segments of eye movement path with CCD positioned below the eyes (**a**). Segments of eye movement path with CCD positioned above the eyes (**b**).

positioned below the eyes, while Fig. 6**b** shows the segments when CCD was above the eyes. All the analysis below was performed with the CCD camera positioned above the eyes.

Three-section-correction method was used in this study. The distribution of the five correction points on the virtual keyboard were shown in Fig. 7, and the distance between points were Ly_s, Lx_1, Lx_2, Lx_3. The coordinates of the eye looking at these points were (x_2, y_2), (x_0, y_0), (x_a, y_a), (x_b, y_b), (x_1, y_1) as the segment of the eye movement path in Fig. 8.

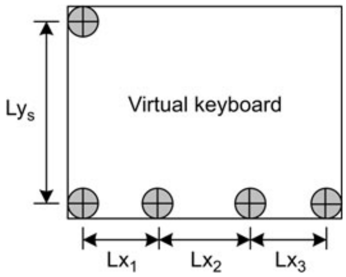

Fig. 7. Distribution of correction points.

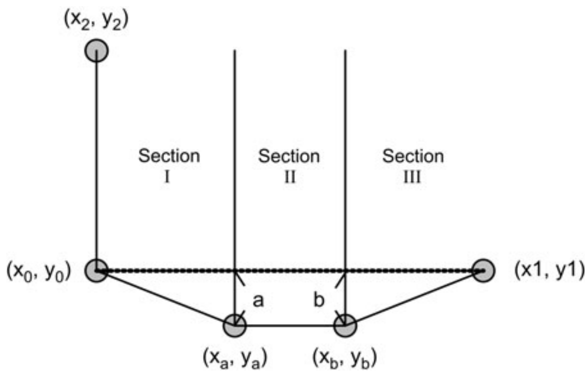

Fig. 8. Segment of eye movement path of three-section-correction method.

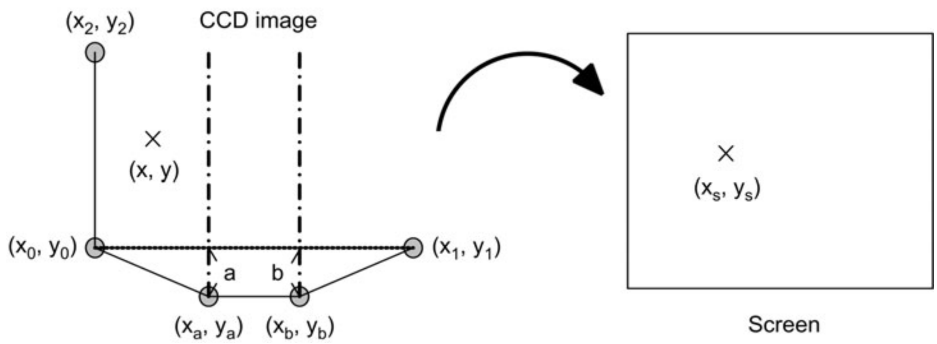

Fig. 9. Coordinate transformation of three-section-correction method.

Figure 9 shows the transformation of coordinates. The coordinates of a point of the eye center (x, y) from camera image can be associated with corresponding coordinates (x_s, y_s) on a screen:

– when $x_0 \le x < x_a$ and within segment I:

$$y_s = \frac{Ly_s}{y_2 - y_0}(y - y_0) + a\frac{x - x_0}{Lx_1}$$

$$x_s = \frac{Lx_1}{x_a - x_0}(x - x_0)$$

– when $x_a \le x \le x_b$ and within segment II:

$$y_s = \frac{Ly_s}{y_2 - y_0}\left(y - \frac{y_0 + y_1}{2}\right) - a + (b - a)\frac{x - x_a}{Lx_2}$$

$$x_s = \frac{Lx_2}{x_b - x_a}(x - x_a) + Lx_1$$

– when $x_b < x \le x_1$ and within segment III:

$$y_s = \frac{Ly_s}{y_2 - y_0}(y - y_1) + b\frac{x_1 - x}{Lx_3}$$

$$x_s = \frac{Lx_3}{x_1 - x_b}(x - x_b) + Lx_1 + Lx_2$$

Where a and b are the decline distances (Fig. 8). This correction method can precisely transform the coordinates to the screen in a long and narrow region, and the calculation and degree of complication were both greatly decreased.

4. Experimental results and discussions

The coordinates of the glint of the eye-controlled virtual keyboard were (X_P, Y_P), while the coordinates of the cornea center were (X_T, Y_T). When the position of a head was fixed, X_P and Y_P were constants, and X_T and Y_T were variants. Rapid calculations in all directions were as follows:

– center: $|X_T - X_P| < c$ and $|Y_T - Y_P| < d$,
– up: $|X_T - X_P| < c$ and $|Y_T - Y_P| > d$,

– down: $|X_T - X_P| < c$ and $|Y_T - Y_P| < -d$,
– left: $|X_T - X_P| < -c$ and $|Y_T - Y_P| < d$,
– right: $|X_T - X_P| > c$ and $|Y_T - Y_P| < d$,
– upper left: $|X_T - X_P| < -c$ and $|Y_T - Y_P| > d$,
– upper right: $|X_T - X_P| > c$ and $|Y_T - Y_P| > d$,
– lower left: $|X_T - X_P| < -c$ and $|Y_T - Y_P| < -d$,
– lower right: $|X_T - X_P| > c$ and $|Y_T - Y_P| < -d$.

In the above equations c and d were constants defined by the system, and they were were related to the distance between the user and computer, the size of a screen, resolution and coordinates of the glint and cornea in the center position. In this study the path of horizontal eye movement was segmented in three, and less calculation was performed in each segment, therefore the process was greatly simplified. First, all kinds of deviation were defined: X-axial error was the horizontal difference between the cursor and target, and Y-axial error was the vertical difference. The distance between the cursor and target was defined as a radial error. Users looked at sixteen points for 3 seconds in different areas on the screen, and every corresponding cursor coordinate was calculated. We found that the conventional coordinate transformation of the cursor was distorted seriously, and the new method has largely improved it.

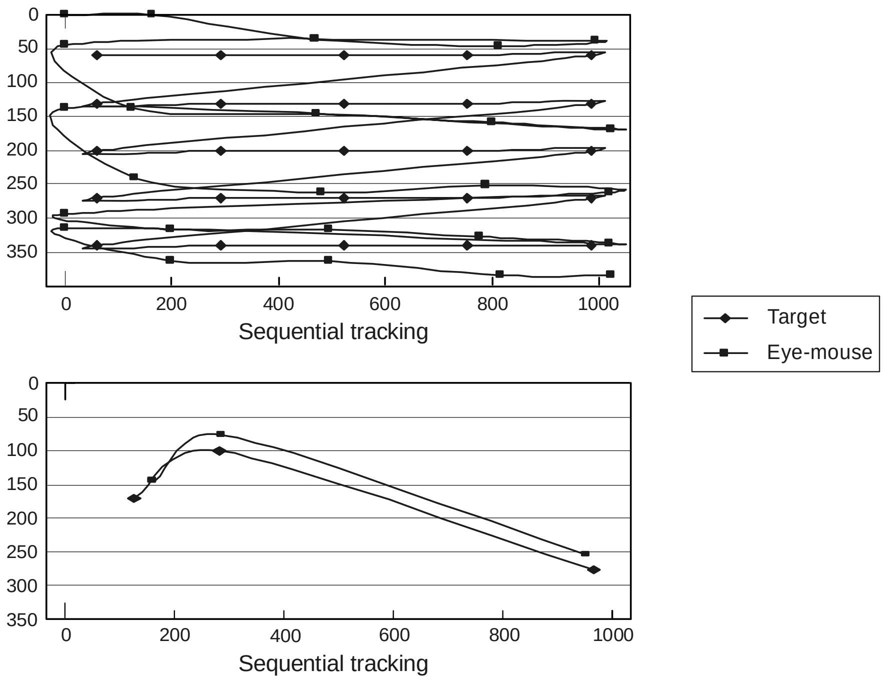

Fig. 10. Results of eye-controlled virtual keyboard experiment of three-section-correction method in a long and narrow region.

T a b l e. The comparisons of two methods in a long and narrow region.

	Conventional five-point- -correction method	Three-section- -correction method
The percentage of errors	2.35%	1.3%
Response	0.1 s	0.1 s
Resolution	±6 pixels	±3 pixels

Screen resolution for this experiment was set at 1024×374 pixels. We move the target dot both in order and randomly with duration of 0.1 second between positions; after 25 seconds the results of Fig. 10 were obtained.

The new coordinate transformation has significantly improved the *X*-axial, *Y*-axial and radial errors and precision of the system has been elevated in a long and narrow region and the testing results of 20-users experiment are shown in the Table. We have concluded that the operational limits of the system were within 10 pixels; on a 1024×374 screen there can be up to 11×7 icons, which allows users to easily select the desired ones.

5. Conclusions

The eye-tracking and virtual keyboard control system can be used in communications and entertainment environments through innovative virtual interface technology. In this study the results can be concluded as follows:

1. More precise coordinate transformation: the five correction points were positioned along two adjacent sides of the virtual keyboard, and divided the virtual keyboard into three sections horizontally. Not matter what area was visually clicked, calculation was performed for this particular area only and the visually clicked key was precisely calculated. It was a very simple linear calculation.

2. Easy correction: five correction points were positioned along two adjacent sides of the virtual keyboard to form three arc-shaped areas which were very close to the actual layout of the virtual keyboard, therefore minimal five points can precisely be corrected with very little error.

3. Establishing 77-key eye-controlled virtual keyboard with 1024×374 resolution: the result of this study can be used for a rectangular virtual keyboard with slight curvature. Five correction points were positioned along two adjacent sides of the keyboard where 4 of the points were evenly distributed on the longer side. It was quite precise when transforming the coordinates for a rectangular virtual keyboard with slight curvature.

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References

[1] CHERN-SHENG LIN, CHIH-CHUNG CHIEN, NANJOU LIN, CHIAO-HSIANG CHEN, *The method of diagonal--box checker search for measuring one's blink in eyeball tracking device*, Optics and Lasers Technology **30**(5), 1998, pp. 295–301.

[2] CHERN-SHENG LIN, CHIEN-WA HO, CHAO-NING CHAN, CHI-RE CHAU, YIENG-CHIANG WU, MAU-SHIUN YEH, *An eye-tracking and head-control system using movement increment-coordinate method*, Optics and Laser Technology **39**(6), 2007, pp. 1218–25.

[3] CHERN SHENG LIN, KAI-CHIEH CHANG, YOUNG-JOU JAIN, *A new data processing and calibration method for an eye-tracking device pronunciation system*, Optics and Lasers Technology **34**(5), 2002, pp. 405–13.

[4] WHITE K.P., HUTCHINSON T.E., CARLEY J.M., *Spatially dynamic calibration of an eye-tracking system*, IEEE Transactions on System, Man and Cybernetics **23**(4), 1993, pp. 1162–8.

[5] ALLISON R.S., EIZENMAN M., CHEUNG B.S.K., *Combined head and eye tracking system for dynamic testing of the vestibular system*, IEEE Transactions on Biomedical Engineering **43**(11), 1996, pp. 1073–82.

[6] GOLDSTEIN S.R., DAUBE-WITHERSPOON M.E., GREEN M.V., EIDSATH A., *A head motion measurement system suitable for emission computed tomography*, IEEE Transactions on Medical Imaging **16**(1), 1997, pp. 17–27.

[7] PASTOOR S., JIN LIU, RENAULT S., *An experimental multimedia system allowing 3-D visualization and eye-controlled interaction without user-worn devices*, IEEE Transactions On Multimedia **1**(1), 1999, pp. 41–52.

[8] CHERN-SHENG LIN, CHIA-CHIN HUAN, CHAO-NING CHAN, MAU-SHIUN YEH, CHUANG-CHIEN CHIU, *The design of a computer game using an eye tracking device for eye's activity rehabilitation*, Optics and Lasers in Engineering **42**(1), 2004, pp. 91–108.

[9] CHERN SHENG LIN, *An eye behavior measuring device for V.R. system*, Optics and Lasers in Engineering **38**(6), 2002, pp. 333–59.

[10] CHERN-SHENG LIN, TAI-HEN SHI, CHIA-HAU LIN, MAU-SHIUN YEH, HUNG-JUNG SHEI, *The measurement of the angle of a user's head in a novel head-tracker device*, Measurement **39**(8), 2006, pp. 750–7.

[11] CHERN-SHENG LIN, CHIEN-WA HO, KAI-CHIEH CHANG, SAN-SHAN HUNG, HUNG-JUNG SHEI, MAU-SHIUN YEH, *A novel device for head gesture measurement system in combination with eye-controlled human-machine interface*, Optics and Lasers in Engineering **44**(6), 2006, pp. 597–614.

[12] CHERN-SHENG LIN, CHIEN-WA HO, WEN-CHEN CHEN, CHUANG-CHIEN CHIU, MAU-SHIUN YEH, *Powered wheelchair controlled by eye-tracking system*, Optica Applicata **36**(2–3), 2006, pp. 401–12.

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