The measurement of the angle of a user’s head in a novel head-tracker device

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Abstract

The measurement of the angle of a user’s head in a novel head tracker is presented. From the image of multi-light-sources the computer transforms the total positions into polar coordinates and determines the angle of the swinging head to improve the performance of mouse operation. Once the user has finished system adjustment and remained at the same distance, the user can precisely control the mouse to any position for any distance. This system can create the head’s dynamic motional space using the relative positions of multi-light-sources. If the user is closer to the monitor, the user will achieve better system performance. This is great improvement on the inaccuracy of previous head-control systems and the angles of user’s head swimming can control the speed of the cursor. This head tracker is more precise and has superior performance, especially for the icon clicking of a computer operation.

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1. Introduction

Most of the operations in GUI operation systems can be simply completed using a mouse. The variable, the distance between computer screen and user, is the most difficult problem involved in controlling the mouse [1]. In this research we neglect the distance variable by measuring the angle of the user’s head in a novel head tracker, because the measurement of the angle is more feasible at different distances. With multi-light-sources this system could transform total positions into polar coordinates and determine the angle of the swinging head to improve the performance of mouse operation. This will be a great convenience for the operators in the present controlling field. This improvement not only provides flexibility in controlling the mouse but also increases the efficiency of operation, especially in clicking on icons. In addition to controlling the mouse, we could take advantage of the angle to apply to science and technology, such as rehabilitation of a patient and working in a 3D virtual environment [2].
Owing to the development of information technology, the convenience of the internet, and the popularity of computers, there is a new trend for all kinds of powerful software being applied to training, teaching, learning and aided design for all groups in our society. However, the general mouse is usually designed for normal users. For the disabled (such as with ineffective or uncontrollable fingers) who want to use computers, it is very difficult to move a general mouse in front of a computer desk. Therefore, various kinds of traditional human–machine interface have been designed for people to control and use computers more flexibly and easily [3–5]. The worldwide internet also shortens the distance between people, because they can apply and easily obtain resources from it.

The new head-tracking system in this paper is a head-ware light source placed on the user’s head. A CCD camera captures the picture of the movement of user’s head. An algorithm was employed to process the captured pictures and show the shifting angles for user’s head on the monitor. This procedure controls the movement of the mouse [6,7]. When the image-capturing card inside the computer drives the CCD camera to capture the images of the head’s movement, the image data will be transmitted to the computer and saved in fixed addresses. The light-source image is a 8-bit color image, so each pixel is made by three sets of color (red, green, and blue) with a brightness range between 0 and 255.

The analysis of red, green, and blue light in the system is discussed as follows:

1. Blue light: First, we search the coordinate of the light-source containing the most blue ingredient \( \text{MAX}(V_B) \), which is greater than the threshold. We decrease the searching area around \( \text{MAX}(V_B) \) and then calculate the geometric center \( (X_{B0}, Y_{B0}) \)

\[
X_{B0} = \frac{\sum X_{BP}}{N_{BP}}, \quad Y_{B0} = \frac{\sum Y_{BP}}{N_{BP}},
\]

\( X_{BP}, Y_{BP} \): coordinate values of the blue pixel in the captured image; \( N_{BP} \): accumulating every number of the blue pixels.

Since the search algorithm originates from the red–green multi-light-sources head-tracking system, the geometric center of the blue light is in the direction of the user’s gaze.

2. Red light and green light: There are four green light-sources and two red light-sources in this system. We only judge the ingredient which is greater or less than the threshold for red or green light-sources. All red or green light-sources will tally with our conditions. We might obtain a light-source with a greater ingredient, but we cannot be sure that this light-source is the one right in front of the screen. Therefore, we need to consider another element-brightness.

### 2. Design of head-control light-source transmitter

We use many LED as our light-sources, allowing us to achieve good directional function. This means if one LED is right in front of the CCD camera, then this light source will be the brightest. So that, we can verify the brightest light from five LED (one blue light, two green lights and two red lights), and obtain the angle adjustment.

The definition of one pixel’s brightness is \( (\text{Red} + \text{Green} + \text{Blue})/3 \), and the value will be in the range of 0–255. If the value is greater, the brightness will be more. Thus, we define the greatest brightness of the red light as satisfying this system.

1. The red ingredients are greater than the “Threshold of color”.
2. The brightness is greater than the “Threshold of brightness”.

Also, the green light is the brightest that can be defined by this method.

Placing the blue light in the center of the transmitter indicates the central position of the head.
otherwise, an individual puts four green lights at 15° of separation up, down, left, and right of the blue light. Two red lights will be beside the blue light at 30° of separation horizontally. These are shown in Fig. 1.

We fixed the angle for each light-source on the hardware. No matter what the distance is between the user to monitor, the green light would face toward the monitor if the transmitter shifted 15° up, down, left, or right and the red light source would also face toward the monitor if the transmitter shifted 30° left or right as shown in Fig. 2. When the computer program finished the regulation, the angle accuracy would not be affected by any distance between the user and monitor.

3. Detection of the angle

(1) When the user’s head faces toward the monitor and he/she presses the button “Correct center”, the system would set a reference center point \((m_0, n_0)\). The blue light’s geometrical center point \((X_{B0}, Y_{B0})\) is the direction of the user’s head facing towards the monitor.

(2) This system is similar with a spherical coordinates system \((R, \theta, \phi)\), where \(R\) is the distance between the user’s head and monitor, \(\theta\) is the angle formed as a result of a vertical shift in the user’s head and \(\phi\) is the angle formed as result of a horizontal shift in the user’s head (Fig. 3).

(3) When the system corrects the red light, \(\phi\) would be 30° (Fig. 4). Fig. 5 indicates the profile of the half-power envelope of an LED beam pattern. Since the irradiance of the beam decreases gradually at the edges, the definition of the beam width to the point of zero irradiance is impractical. From the half-power...
envelope we can obtain the emitting angle of an LED. The beam width is defined as the distance across the center of the beam for which the irradiance equals 1/2 of the maximum irradiance. Also, the useful measurement used to characterize the diameter of the laser diode module is known as the full width at half maximum (FWHM). We could obtain the distance of movement in the image when the user’s head shifts by 30°.

\[
R_{\text{RED}} = \frac{S}{\tan(\phi)}, \quad S = (X_{B0} - m_0)
\]

(4) In the same way, we could obtain the distance \(R_{\text{GREEN}}\) to the monitor when the user’s head shift by 15° (up, down, left, and right) while the system was correcting for green light sources.

For example, in the case of 15° up/down

\[
R_{\text{GREEN}} = \frac{S}{\tan(\theta)}, \quad S = (Y_{B0} - n_0).
\]

(5) After finishing the regulation of all light sources (Fig. 6(A)), the system could immediately calculate the (left/right) degrees for the user’s head.

\[
\phi = \tan^{-1}\left(\frac{X_{B0} - m_0}{R_{\text{RED}}}ight) \quad \text{or} \quad \phi = \tan^{-1}\left(\frac{X_{B0} - m_0}{R_{\text{GREEN}}}ight)
\]

(up/down) degrees

\[
\theta = \frac{Y_{B0} - n_0}{R_{\text{GREEN}}}
\]

The detected head’s rotating degrees will be displayed under the monitor where the dpi could reach the second number of the decimal point.

4. Experimental method

The systems structure is shown in Fig. 6(B). We placed the CCD camera on the computer monitor to capture the images forming the head-control light-sources. The image capture card will transfer the images into the computer. The user wore a seven color light-source transmitter on his head, and the CCD camera chased the seven color light points on the user’s head.

4.1. System operation procedures

The user comfortably sat on the chair and put on the head-control light-source operating this system. Fig. 7 is the initial window while starting this program. The white frame of seven spots is the margin for image searching.

The procedures for operation are given in the following:

1. Adjust the diaphragm to becloud the background with the clear light-sources [8, 9].
2. Adjust the CCD camera to set the blue light source close to the central monitor; meanwhile, direct the other six light-sources to the monitor.
3. Adjust the “threshold value of color” to ensure that system captures the light point near the ground without diffusion.

![Fig. 6. (A) Executing window after regulating. (B) The systems structure of a novel head-tracker device.](image-url)
4. Adjust the “threshold value of brightness” to ensure that the correct light-source is being thought of as the brightest.

It has to do some adjustment in the beginning before using this system, because this program would not make any adjustment automatically. The adjustment procedure can be described as follows:

1. Face the monitor and press the “Adjust center” button. There will be two white cross lines in the monitor and the intersection is the center point when the user faces the monitor.
2. Make a left turn to place the red light at the center. Then the system will adjust the head direction to the left by 30°.
3. Make a right turn to place the green light at the center. Then the system will adjust the head direction to turn right by 15°.
4. Make another right turn. Set the blue light opposite to the center point. Prepare to adjust the right light.
5. Make a right turn to set the green light opposite to the center point. The system will adjust the head direction to turn 15° to the right.
6. Make a right turn to set the red light opposite to the center point. The system will adjust the head direction to turn 30° to the right.
7. Make a left turn to set the blue light opposite to the center point. Prepare to adjust the upper light.
8. Make an up turn to set the green light opposite to the center point. The system will adjust the head direction to turn by up 15°.
9. Make a down turn to set the blue light opposite to the center point. Prepare to adjust the underneath light.
10. Make the next down turn to set the green light opposite to the center point. The system would adjust the head direction to turn down by 15°.

When the system has completed the adjustment, it displays the head movement of the head in degrees detected by the CCD camera. The dpi can calculate to an accuracy of one hundredth. If the red or green light opposite to the center was not the brightest, we can tune the “Adjusting brightness threshold value” in the left-down monitor as shown in Fig. 7. When the adjustment work is finished, pressing the “Start button” will activate the head-control system. This enables us to control the functions of the mouse with the user’s head.

4.2. The conversation of coordinates

Pressing the START button will activate the head-control system. This will convert the movement of light source spots into the coordinates in the monitor as shown in Fig. 8. We preset a small cross reference coordinates like \((P_0, Q_0), (P_1, Q_1), (P_2, Q_2), (P_3, Q_3), \) and \((P_4, Q_4)\) in the program. The coordinates on the screen are \((X_1, Y_0), (X_0, Y_1), (X_1, Y_1), (X_2, Y_1), \) and \((X_1, Y_2)\). Both \((P_2, Q_2)\) and \((X_1, Y_1)\) will coincide with each other. \(\overline{I_m}\) and \(\overline{I_n}\) are the difference in the \(x\)-axis and \(y\)-axis for the blue light source. Since the projection magnification will convert coordinates into new coordinates, we must first calculate the “Virtual Distance” \(R_1\)
between the user and monitor as shown in Fig. 9.

Then, we will obtain the correct coordinates of the mouse \((D_m, D_n)\) by calculating the relation between \(R_I\) and the switching angles of the user’s head. The relationships are given as follows:

\[
R_I = \frac{X_0 - X_1}{\tan(30^\circ)}
\]

If \(T_m \geq 0\) and \(T_n \geq 0\):

\[
D_m = X_1 - R_l \times \tan(\phi)
\]
\[
D_n = Y_1 + R_l \times \tan(\theta)
\]

If \(T_m \geq 0\) and \(T_n < 0\):

\[
D_m = X_1 - R_l \times \tan(\phi)
\]
\[
D_n = Y_1 - R_l \times \tan(\theta)
\]

If \(T_m < 0\) and \(T_n \geq 0\):

\[
D_m = X_1 + R_l \times \tan(\phi)
\]
\[
D_n = Y_1 + R_l \times \tan(\theta)
\]

If \(T_m < 0\) and \(T_n < 0\):

\[
D_m = X_1 + R_l \times \tan(\phi)
\]
\[
D_n = Y_1 - R_l \times \tan(\theta)
\]

4.3. Lingering clicking

We have termed this innovation “Head-Control Mouse”, because we could use the movement of the user’s head to control the mouse location. The mouse will be automatically clicked when the cursor stays at a point for long enough. We will set a reference range \(R\) near to our reference point \((D_m, D_n)\) for the coordinates of the mouse between the two different times. If the user’s sight lingers in this reference range for \(T\) time, the system will make the mouse left click.

Initial values

\[
Sm = 0, \quad Sn = 0, \quad z = 0
\]

If \(|D_m - Sm| < R\) and \(|D_n - Sn| < R\) /*The difference in two coordinates is smaller than \(R^*/

\[
z = z + 1 \quad /*Count*/
\]

\[
Sm = Dm, \quad Sn = Dn
\]

END \cdot IF

IF \(z \cdot = \cdot = \cdot T\) /*The mouse stays in the fixed range for the threshold limit frequency*/

mouse \cdot click \quad /*Click the mouse’s left button*/

ELSE

no \cdot click \quad /*Not to click mouse’s left button*/

END \cdot IF.

5. Experimental results and discussion

The head-control system with a red–green dual light source for the distance between the user and monitor is an important factor in the accuracy of the system. After analyzing the user’s position and the distance of the camera under the condition of the system working properly, and further tracing the position of the light source with correct calculation of the center of the user’s head, we processed several tests for tracing the user’s head for different specific distances. This system creates the head’s dynamic motional space by the relative positions of dual light sources that project it onto the full screen. If the user is closer to the monitor, the user will obtain a better system performance with large head movements. On the contrary, the greater distances between the user and the screen would decrease the sensibility of the system performance because small actions after projection will cause small deviations. Users may operate by small actions, but the operation of the system is still sensitive.
The shifting angles of the user's head become smaller when the distance between the user and screen becomes longer (Table 1). Taking a distance of 120 cm for example, the operation angle is only ±2.4° in the horizontal and ±1.73° in the vertical. Although the system could still detect the center of the user's head and translate the correct coordinates, a tiny movement of the user's head would cause huge displacement in the monitor under these conditions. The stability of the system would therefore drop. If the user is too far from the camera, the detection of the images would be easily interfered with by the background light field. This will lead to an erroneous judgment of the system.

Therefore, the objective of this research is to detect the swinging angles of the user's head to solve the distance problem mentioned above, since the distances have no relation with the swinging angles. Initial operation would acquire some adjustments, so we must compare the initial adjustments with the previous head-control system. Table 2 shows the comparison for various adjusting times and the probability of completing adjustments for different distances.

In Table 2, we can see that longer distances will require more time and lower probabilities to complete system adjustments. The background light field will influence the CCD for receiving the light that originates from the light source. This will cause the system to make an erroneous judgment. We must change the two parameters “TLV of color” and “TLV of brightness” during the frequent system adjustments because the brightness and direction of the light source would be abated due to the increasing distance. Here we recommend that the best operation distance is between 40 cm and 100 cm.

Once the user has finished system adjustment and remained at the same distance, the user can precisely direct the mouse to any position at any distance. This is a great improvement on the inaccuracy of the previous head-control system and clicking icon time. The angles of user’s head movement can control the speed of the cursor. In other words, the greater angles would cause a greater speed of the cursor, but smaller angles will cause a smaller speed of the cursor. Thus, the system control is more precise and has better performance, especially in for icon clicking during a computer operation.

6. Conclusion

This image-based head-control system would not be affected by the background brightness. All the users have to do is to adjust the diaphragm of CCD and the TLV of brightness and color, and then they can use the computer easily by moving their head. This will be of great help those. It would be more effective than the old eye-track system. Even some interfaces have been improved to help them, but they are still far away from totally convenient. For this reason, we propose this new head-control system to provide a non-handicap computer envi-

| Table 1 |
The relationship between the operation distance and the user’s head movement

<table>
<thead>
<tr>
<th>The operation distance (cm)</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max warping distance (cm)</td>
<td>Max warping degree (deg.)</td>
</tr>
<tr>
<td>40</td>
<td>±14.64</td>
<td>±21.60</td>
</tr>
<tr>
<td>60</td>
<td>±10.72</td>
<td>±10.38</td>
</tr>
<tr>
<td>80</td>
<td>±7.10</td>
<td>±5.14</td>
</tr>
<tr>
<td>100</td>
<td>±5.98</td>
<td>±3.45</td>
</tr>
<tr>
<td>120</td>
<td>±5.00</td>
<td>±2.40</td>
</tr>
</tbody>
</table>

| Table 2 |
The relation between operation distance and system adjustments

<table>
<thead>
<tr>
<th>Distance</th>
<th>40 cm</th>
<th>60 cm</th>
<th>80 cm</th>
<th>100 cm</th>
<th>120 cm</th>
<th>140 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for adjustment</td>
<td>10</td>
<td>12</td>
<td>15</td>
<td>20</td>
<td>27</td>
<td>38</td>
</tr>
<tr>
<td>Probability of completing adjustments (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>90</td>
<td>80</td>
</tr>
</tbody>
</table>
environment for people who have spinal injury (above C5, C6 degree) or uncontrollable finger movement. Also, it can provide the information to doctors for research on curing neck slant or patient rehabilitation situation.

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