Color-banded hand tracking system based on fuzzy logic concept

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Abstract

This paper introduces a color-banded hand tracking system (CbHTS) based on fuzzy logic concept. Human-computer interaction interface is a rising field of research in recent years. Among them, the hand tracking method based on image processing holds the most advantages. This research applied fuzzy logic on image processing to recognize the color bands pre-banded on user’s fingers. By analyzing the coordinate of the color bands, CbHTS can then be used to obtain the effect of hand tracking. If the tracking performance of our system could be promoted to increase the frame rate and the precision of detection in the near future, it would be possible to substitute CbHTS for the function of traditional mouse to offer a more intuitive operation environment in human-computer interaction interface.

Key words: Fuzzy theory, Hand tracking

1. Introduction

Human computer interaction (HCI) interface is a rising field of research in recent years. The HCI devices had changed rapidly from keyboards and mice to touching screens and gesture recognition devices (including motion sensors), and the latest approach of applying image processing has also been significantly noticed. The changes of the improving devices had sent us a message of how important the role that intuition plays not only in operating environment but also in the communication between human and computers.

Recent development in touching screens and gesture recognition devices have terminated the era of traditional HCI devices such as keyboard and mouse, and the interest of research has also been shifted to focus on the intuition and feedback during operating period. Thus, the inherent habit of users which is used to existing devices would be facing a major impact in near future.
Due to the trend mentioned above, the development of hand tracking systems attracts the most interests in related fields, simply because the operations of such systems are most similar to the behavior of daily life. Table 1 shows the comparison of existing HCI devices. As the Table 1 indicates, the hand tracking system by image processing holds the most advantages. Our system (Color-banded hand tracking system, CbHTS) focuses on the development of hand tracking ability by analyzing images captured from single camera to obtain the coordinate of the particular point on user’s hand. And for the purpose of fluent operating experience, CbHTS has to paste 2 color bands on user’s fingers (one blue and one red) in order to ‘mark’ the finger positions for the computer. Another feature of CbHTS is by applying fuzzy logic on dynamic scan zone and color separation, we can reduce the complication of the processing and increase the efficient of the system.

2. System overview

CbHTS applied fuzzy logic on image processing in order to develop a system capable of detecting and recognizing human hand. First, we introduce the operating environment of CbHTS. Then a flowchart of CbHTS will be given, followed by introduction of proposed method. Finally, the detailed operating steps are showed.

2.1. Operating environment

CbHTS is a brand new interface for communication between human and computer, initially designed for personal computer users. The basic operating environment of CbHTS is similar to common PC operating environment. Two major preparations must be done before operating CbHTS- one is to set up video camera (webcam...etc) near the displayer (LCD monitor...etc) for capturing image streams of user’s hand, the other is to paste (or strip) two color bands on user’s fingers (red band for index finger and blue band for thumb). The operating environment for CbHTS is showed on Fig.1.

<table>
<thead>
<tr>
<th>Table 1. Comparison of existing HCI devices</th>
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<td>Operating Intuition</td>
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<td>Touching screen</td>
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<td>Hand Encumbrance</td>
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<td>High</td>
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<tr>
<td>Low</td>
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<tr>
<td>Mid</td>
</tr>
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<td>None</td>
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<td>Portability</td>
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<td>High</td>
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<tr>
<td>Low</td>
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<tr>
<td>Mid**</td>
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*Including motion sensor devices, such as Wii remote controller...etc.

**Possible to be integrated into monitor
The operating logic of CbHTS is slightly different from traditional mouse. The user’s index fingertip is referred to the mouse cursor, and single click is defined as the contact of index and thumb (similar to the action of ‘pinch’). Double click is defined as continuous two single clicks in time period T1, and right click is defined as the contact and hold of index and thumb for time period T2. T1 and T2 are given constant of time. The operating logic of CbHTS is showed as Table 2.

2.2. System flowchart

The flowchart of CbHTS is showed as Fig.2. After capturing image streams, users must perform the function of initial color recognition (correction of color nulling operation) in order to adapt CbHTS to different environmental color lights. For each image in the stream, CbHTS is set to automatically proceed to determine dynamic scan zone, color separation, centroid determination, and the logic of judging clicks. The result is returned to user as a mouse cursor before the next image processes.

![Operating environment for CbHTS](image1)

![Fig.2. Operating environment for CbHTS](image2)

### Table 2. The operating logic of CbHTS

<table>
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<tr>
<th>Traditional mouse</th>
<th>CbHTS</th>
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<td>Moving cursor</td>
<td>Moving index finger</td>
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<td>Single click</td>
<td>Contact of index and thumb</td>
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<tr>
<td>Double click</td>
<td>Continuous 2 clicks during T1</td>
</tr>
<tr>
<td>Right click</td>
<td>Contact and hold of index and thumb for T2</td>
</tr>
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</table>
2.3. Methodology introduction

The methodology of CbHTS is based on the followings: a. determination of dynamic scan zone, b. color separation, c. centroid determination, and d. judgment of clicks, which are introduced below.

a. Determination of dynamic scan zone

For the reason of higher image detecting rate and better noise filtering ability, CbHTS applied dynamic scan zone technique instead of scanning the whole pixels on the captured image. CbHTS scans specific zone for color bands, and the dimension of scan zone is determined by applying fuzzy logic on cursor speed of previous image. Basically, as the cursor speed gets fast, the dimension of scan zone grows large, so the color band won’t fall out of the zone, and vice versa.

The function of determining the dimension of scan zone is given as:

\[
\text{MaskSize} = (500 \times \mu_L) + (200 \times \mu_N) + (50 \times \mu_S) \quad \text{(unit: pixels)}
\]

\[
\mu_L(V) = \begin{cases} 
    1 & , V_f < V \\
    \frac{V - V_m}{V_f - V_m} & , V_m < V < V_f \\
    0 & , V < V_m 
\end{cases}
\]

\[
\mu_N(V) = \begin{cases} 
    \frac{V - V_f}{V_m - V_f} & , V_m < V < V_f \\
    \frac{V - V_s}{V_m - V_s} & , V_s < V < V_m \\
    0 & , V_f < V \text{ or } V < V_s 
\end{cases}
\]
\[ \mu_s(V) = \begin{cases} \frac{V - V_m}{V_s - V_m}, & V_s < V < V_m \\ 1, & V < V_s \\ 0, & V_m < V \end{cases} \]

V, Vs, Vm, and Vf are cursor speeds which are defined as the displacement of the cursor during two continuous images. The value of Vs, Vm, and Vf are determinate by the size of image captured, as an example, the size of captured image in CbHTS is 640 by 480 (pixels), and the Vs, Vm, and Vf are chosen as 10, 20, and 30. The membership function of Vs, Vm, and Vf are shown as Fig. 3.

b. Color separation

For better adaption of different environmental lights, CbHTS must perform the correction of color nulling operation for blue and red color bands. This operation requires user to put the fingertip color bands onto the blocks shown on the screen separately. After scanning the RGB value on user’s thumb and index finger, CbHTS determines the threshold value for color separation by applying fuzzy multi-factor judgment.

The algorithm of color separation in CbHTS is based on fuzzy logic. By applying fuzzy multi-factor judgment, CbHTS can get the optimum threshold value. The detailed steps are described as below.

i. Establish fuzzy element set

Establish fuzzy element set \( U = \{ R, G, B \} \)  R, G, and B are the color value of scanned pixels.

ii. Establish fuzzy weight set

Establish fuzzy weight set for red band,
\[ A = 0.8, 0.2, 0.2 \]

For blue band \[ A = 0.2, 0.2, 0.8 \]

iii. Establish fuzzy evaluate set

Establish fuzzy evaluate set,
\[ V = \{ \text{High}(V_p > 200), \text{MidHigh}(200 \geq V_p > 150), \text{Mid}(150 \geq V_p > 100), \text{MidLow}(100 \geq V_p > 50), \text{Low}(50 \geq V_p) \} \]

\( V_p \) is the RGB value of the pixel, the fuzzy evaluate set is showed as Fig. 4.
iv. Single-factor judgment

Perform single-factor judgment on scanned RGB values by following equations,

\[ H = \begin{cases} 1 & ,225<V_p \\ \frac{V_p-175}{50} & ,175\leq V_p \leq 225 \\ 0 & ,V_p<175 \end{cases} \]

\[ MH = \begin{cases} \frac{V_p-225}{50} & ,175< V_p <225 \\ -50 & ,175\leq V_p \leq 225 \\ 0 & ,V_p<175 \end{cases} \]

\[ M = \begin{cases} \frac{V_p-175}{50} & ,125< V_p <175 \\ -50 & ,125\leq V_p \leq 175 \\ 0 & ,V_p<125 \ or \ 225<V_p \end{cases} \]

\[ ML = \begin{cases} \frac{V_p-125}{50} & ,75< V_p <125 \\ -50 & ,75\leq V_p \leq 125 \\ 0 & ,V_p<75 \ or \ 175<V_p \end{cases} \]
\[ L = \begin{cases} 
0 & ,75 < V_p \\
V_p - 25 & 50 \leq V_p \leq 75 \\
50 & V_p < 25 \\
1 & V_p \geq 75
\end{cases} \]

v. Fuzzy multi-factor judgment for threshold value

Then perform fuzzy multi-factor judgment, \( B = A \circ R \), the result \( B \) is the required fuzzy set. From fuzzy set \( B \), CbHTS can obtain the truth value of element set \( U \) which can be used as the basis of color separation.

c. Determination of center of colored pixels

CbHTS applied minimum bounding box method for determining the center of colored pixels. The method determines the minimum square box ‘A’ that contains the whole colored pixels, and then replaces the center of colored pixels by the centroid of the square \( A \). The method of minimum bounding box is showed as Fig. 5.

d. Judgment of clicks

After CbHTS concludes the center of red finger band and blue thumb band, it proceeds to the judgment of clicks. The flow chart of judgment is showed in Fig. 6. CbHTS is currently capable for the single click, and the other features are under progressing.

2.4. Operating steps

The interface of CbHTS is showed as Fig. 7. First, click on the ‘ShowIM’ button and press ‘play’ to enable the capturing of the CbHTS. The capturing image is showed as Fig. 8. Second, click on ‘PreR’ and ‘PreB’ and moving the color bands into the block showed on the screen individually for red and blue color nulling operation. Then click ‘capture’ while the color bands fill the entire block. The step is showed as Fig. 9. Finally, the virtual mouse is ready for operation.
Fig. 6. The algorithm of click judgment
3. Results of CbHTS

The results of CbHTS are showed below. Fig. 10 and Fig.11 show the result of tracking and dynamic scan area. The red hollowed circle is the center of the red color band pixels which is refer to the mouse cursor and the zone of detection is showed as the green box.

Fig. 12 showed the capability of CbHTS to operating in various moving background and without the influences of the skin color. Fig. 13 showed the results of single click judgment. The cursor turned to red filled circle which refers to the single click when the distance of both centers is under a given threshold. Fig. 14 showed both red and blue bands on the screen. Because the distance between two centers on Fig.14 are still above the threshold value, the single click is not triggered and the circle is still hollowed.
4. Conclusion and discussion

The most difficulty currently for CbHTS is to perform a more fluently operating experience by increasing computer calculation efficient. The frame rate of CbHTS is currently below 20 fps, and other algorithm could be considered for improving the frame rate such as Kalmen filter...etc.

Further works of tracking without color band could be considered such as the applying of edge detection. Thus, the operation experience could be more flexible and convenience.

The improving of the above issue could lead the tracking systems to a more intuitive human-computer interaction interface and may be capable to replace the old time using mouse.
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