

An eye-tracking and head-control system using movement increment-coordinate method

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Abstract

In this paper a novel design which combines an eye-tracking device with a head gesture control module is discussed. In the eye-tracking mode, the user wears goggles, and two tiny CCD cameras capture the eye image from the screen with the help of a video capture card. In the head gesture control mode, a light source projector is turned on, and the CCD camera detects the position of the light source. The locations of the spots on the screen and on the image pupil of the eye image are calculated, compared with the previous point and are subsequently mapped to the point on the screen. The movement increment-coordinate control is also discussed, which could improve the ease of use of the computer.

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1. Introduction

There are many algorithms and configurations for eye-tracking devices. The remote-type of eye tracking method requires the user's head to remain totally motionless; otherwise the point of the regarding information will be lost. If very large eye movements are involved, even the eye will be out of focus [1]. Our eye-tracking device was initially developed as a non-contact optical eye blink measuring system. In this experiment, we used a diagonal-box checker search [2,3]. It can achieve a higher rate for the correcting pupil position identification by analyzing a sample eye image obtained from the CCD. Using a 950 nm IR LED with output power distribution of $2 \mu\text{W}/\text{cm}^2$ this system will not cause contact injury or discomfort to the eyes. The essential core of the eyeball tracking technology is the eye feature extraction system.

In this paper, a new human-machine interface system (Fig. 1) is developed. It is a novel design which combines an

eye-tracking device with a head gesture control module. In the eye-tracking mode, the user wears goggles (Fig. 2), and miniature CCD cameras capture the eye's image with the help of a video capture card. The computer program locates the center-points of each pupil in the image, and records the information of the moving trace and pupil diameter. The system does not use the conventional bright/dark pupil-corneal reflection method in which the vector (between pupil center and glint center) on the image is mapped to screen coordinates. This technique responds more quickly and can provide more precise information of pupil diameter variation data. In the head gesture control mode, a light source projector is turned on. The CCD camera, which has a 16.0 focal ratio, is used to detect the position of light source without the influence of the background. Head movements can also be linked with the position of the cursor, and the user can control the mouse cursor with his head.

With a four channel color quad video box, this system can combine the eye tracking and head gesture control system for use in virtual reality systems or it can operate as

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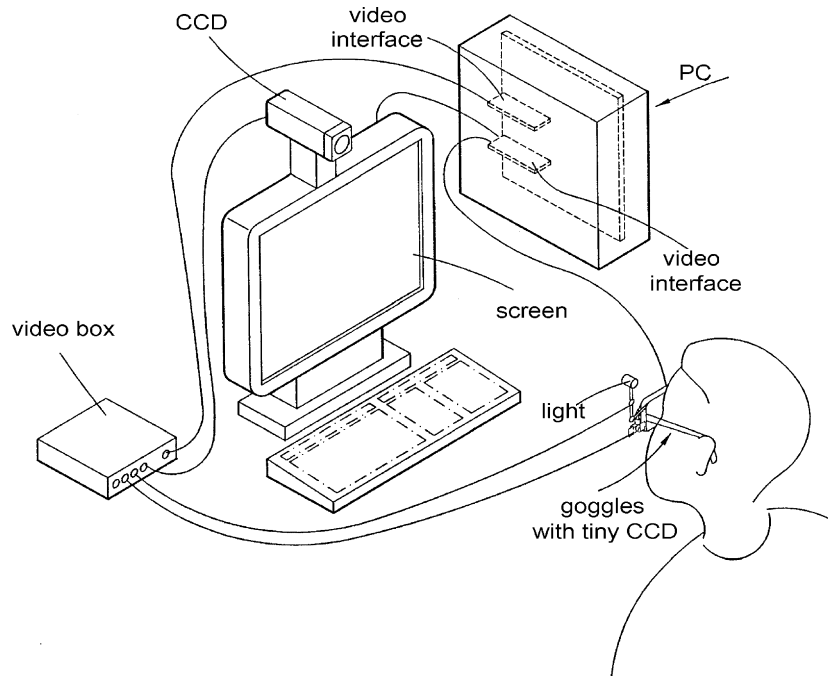


Fig. 1. The novel human-machine interface design which combines the eye tracking device and the head gesture control module.

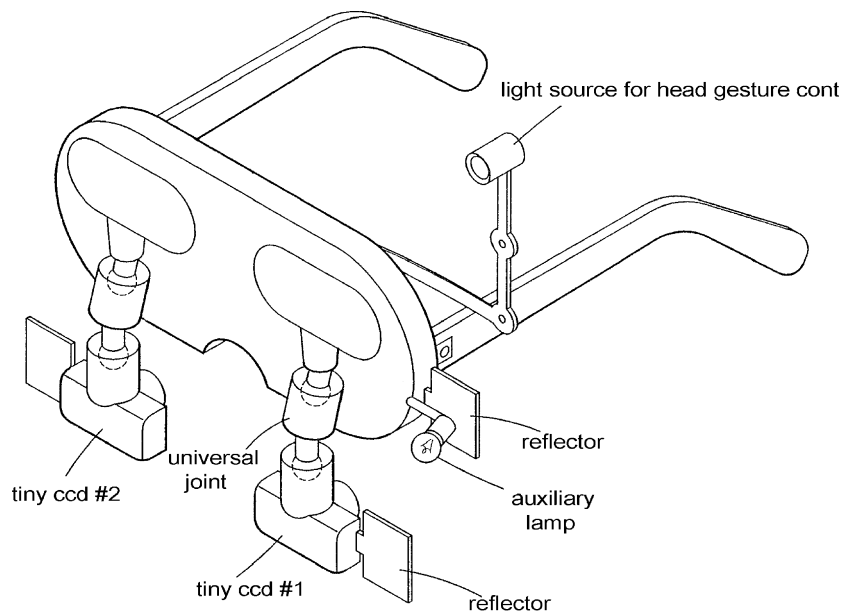


Fig. 2. Goggles for eye tracking and head gesture control.

a medical instrument for the doctor to analyze the condition of the eyes in clinical tests. After the system transfers the coordinates of the pupil center or the bright spots on the images to the display coordinate, it will determine the point at which the user focused on the display, and then transfer that location to the game subroutine program.

In many eye-tracking devices, the position calibration step of the pupil is the most important part, such as in

spatially dynamic calibration [4] or where the statistical and vague assemblage concepts were adopted to correctly judge the gazing position of the pupil [5]. The location of the pupil is calculated, compared with the previous point and mapped to the point of the screen. Here a fast calibration method develops a human-machine interface that operates simply and easily allowing the user to operate a computer with the eye and head [6–8] together or separately.

2. The multi-functional human-machine interface system

A binary process on the eye image obtained by the CCD is used to distinguish the light spot and the eye. After thresholding, the eye-tracking system searches the pixels of the grey level 0 and the head gesture control system searches the pixels of the grey level 255 as the target object.

We can obtain the center point coordinate (Xe, Ye) of the eye using the gravity method.

$$(Xe, Ye) = \left(\frac{1}{k} \sum_{n=1}^k i_n, \frac{1}{k} \sum_{n=1}^k j_n \right), \quad (1)$$

where, k is the total number of points for which the grey level value satisfies zero, and (i_n, j_n) is the corresponding coordinate.

The first step to control the mouse with the eye or neck is to gaze at the center point of the screen, then move the mouse after a few minutes. We can calculate the mouse coordinate (Xm_n, Ym_n) of n th mapping using Eqs. (2)–(5).

$$\Delta X_n = Xe_n - Xe_{(n-1)}, \quad (2)$$

$$\Delta Y_n = Ye_n - Ye_{(n-1)}, \quad (3)$$

where $(\Delta X_n, \Delta Y_n)$ is the coordinate variation between $(n - 1)$ th and n th location. From a basically vector (2D) system, we can transform the locations of the eye image onto screen coordinates with mapping ratios and rotation angle. The coordinate with the correct ratio and mapping angles can be written as

$$(Xm'_n, Ym'_n) = (\alpha \Delta X_n + Xm_{n-1}, \beta \Delta Y_n + Ym_{n-1}), \quad (4)$$

where α and β are the ratio mapping values that will transform what is measured on the eye image onto the screen coordinate. The initial values are set to 2.

Then the coordinate with correct rotation angle can be written as

$$\begin{bmatrix} Xm_n \\ Ym_n \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} Xm'_n \\ Ym'_n \end{bmatrix}, \quad (5)$$

where θ is the rotation mapping angle of the system, and the initial value is set to 0° . Fig. 3 shows the transformation relationship between the coordinates. Whenever the eye moves to a different position, the mouse will move to the corresponding position determined by the above equations. This allows the user to control the mouse by means of the eye or head.

3. Increment-coordinate system

The increment-coordinate system is entirely different from the rectangle coordinate system. This system can use the deviation distance in which the eye or head deviates from the image center to control the movement velocity of the cursor. The greater the distance, the faster the movement of the cursor. The diagram of this system is shown in Fig. 4.

The user gazes at center point O as a start point in the beginning, (Xe_0, Ye_0) is the center coordinate of the eye image and (Xm_0, Ym_0) is the center coordinate of the mouse on the screen. When the eye moves to another point O' (Xe_n, Ye_n) , the mouse will move to (Xm_n, Ym_n) as shown in Eq. (6). The next point of the mouse is determined by the

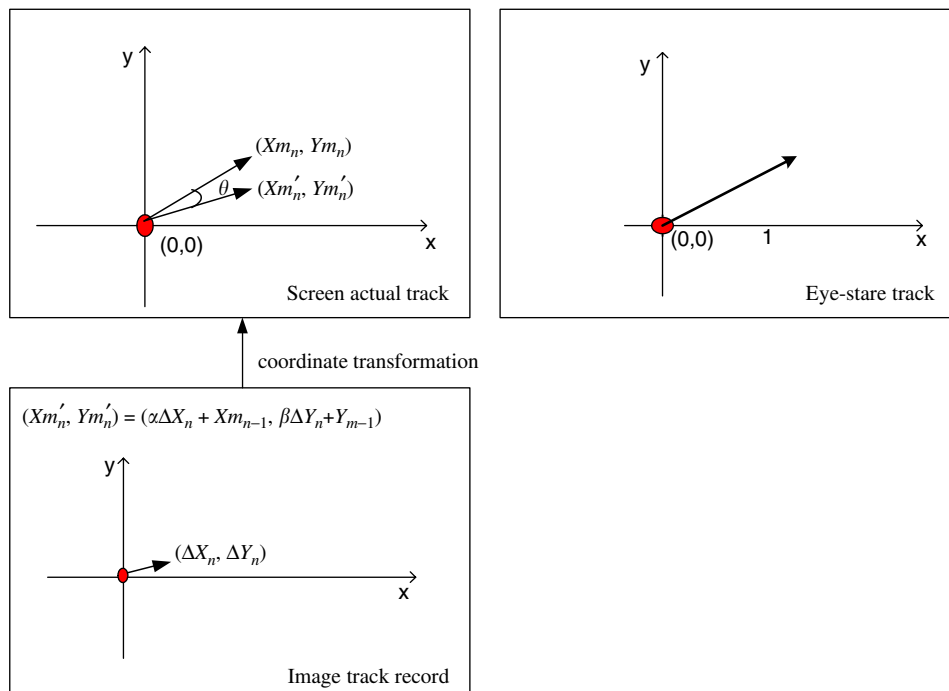


Fig. 3. The transformation relationship between coordinates when the eye moves.

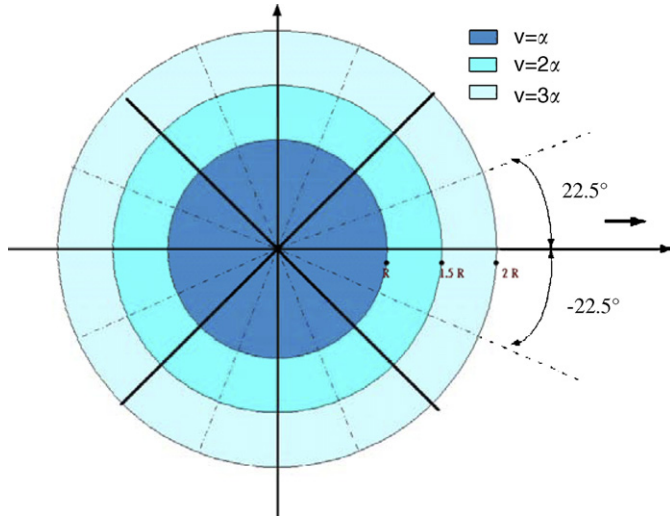


Fig. 4. Diagram of the increment-coordinate system.

former coordinate of the mouse. This becomes an increment-coordinate system.

$$(Xm_n, Ym_n) = V \times \vec{M} + (Xm_{n-1}, Ym_{n-1}), \tag{6}$$

where V is the velocity parameter, defined by

$$|\vec{OO'}| < R, \quad V = 0,$$

$$R < |\vec{OO'}| < 1.5R, \quad V = \alpha,$$

$$1.5R < |\vec{OO'}| < 2R, \quad V = 2\alpha,$$

$$|\vec{OO'}| > 2R, \quad V = 3\alpha,$$

where α is the unit of moving velocity. Changes in the vector parameter \vec{M} depend on different districts (Table 1).

4. Experiments and discussion

In order to engage in the research of the eye-tracking system, the image capture card and machine vision software components were selected. A new machine vision component was developed on VCL framework using Microsoft's DirectShow. The component could be used on the USB PC cameras, 1394 DV devices, image capture devices, TV video card and multiple video streams support. A high-speed and high-sensitivity machine vision component on QImaging Retiga 1300 Camera using Intel MMX/SSE/SSE2 technology was also developed. This software technology ensures the component has high capacity and high performance. It provides complete functions for the user to control color adjustment with the program, including brightness, contrast, hue, saturation, sharpness, gamma, color enable, white balance, gain, backlight compensation etc. In the meantime, it can deal with more

Table 1
Setting table of the vector parameter \vec{M}

Region	Angle define	\vec{M}
1	$337.5^\circ < \angle \vec{OO'} < 22.5^\circ$	(1, 0)
2	$22.50^\circ < \angle \vec{OO'} < 67.5^\circ$	(1, 1)
3	$67.50^\circ < \angle \vec{OO'} < 112.5^\circ$	(0, 1)
4	$112.5^\circ < \angle \vec{OO'} < 157.5^\circ$	(-1, 1)
5	$157.5^\circ < \angle \vec{OO'} < 202.5^\circ$	(-1, 0)
6	$202.5^\circ < \angle \vec{OO'} < 247.5^\circ$	(-1, -1)
7	$247.5^\circ < \angle \vec{OO'} < 292.5^\circ$	(0, -1)
8	$292.5^\circ < \angle \vec{OO'} < 337.5^\circ$	(1, -1)

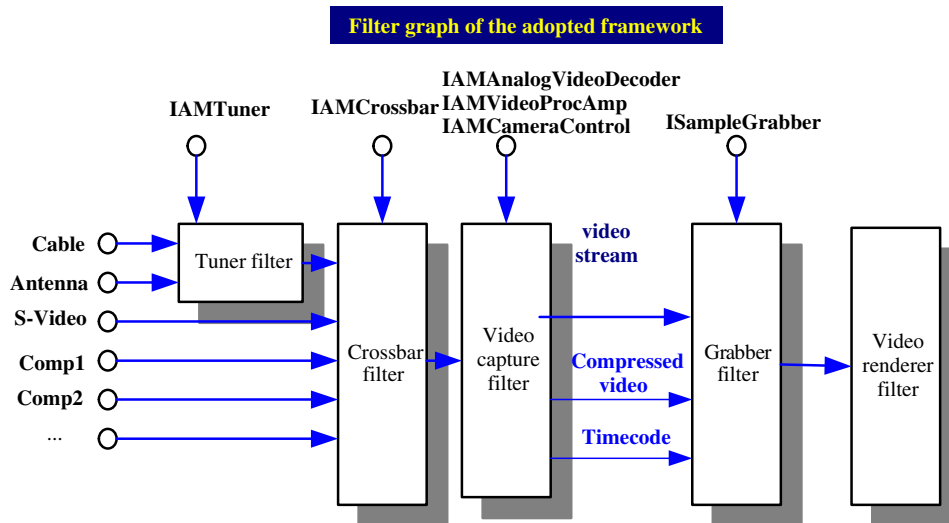


Fig. 5. The framework of extensive type core model for machine vision component.

capture equipment to proceed with multiplex image processing. Its upper limit depends on the amount of hardware.

The practical design structure is divided into two stages. The first stage designs a block chart which is based on the DirectShow structure (Fig. 5). The second stage is to design a component model, which is based on the VCL structure, with C++ Builder (Fig. 6). To make use of the VC++, we must ensure the functional interaction correlation between the components of DirectShow and VCL can smoothly operate. The follow-up program can be developed by means of this VCL component. It can be

completely accomplished with machine vision component because it includes the complete method, attribution and event functions. The attribution functions include the capture card of the driver image, image width, color adjustment and dialogue frame. The method functions include the dialogue frame for the start, stop and call, in-built color procession, character display, drafting and can obtain all of the capture card attribution. The event functions include a callback capability that can give feedback concerning an event as it receives every image, and mouse response element fundamental attribution.

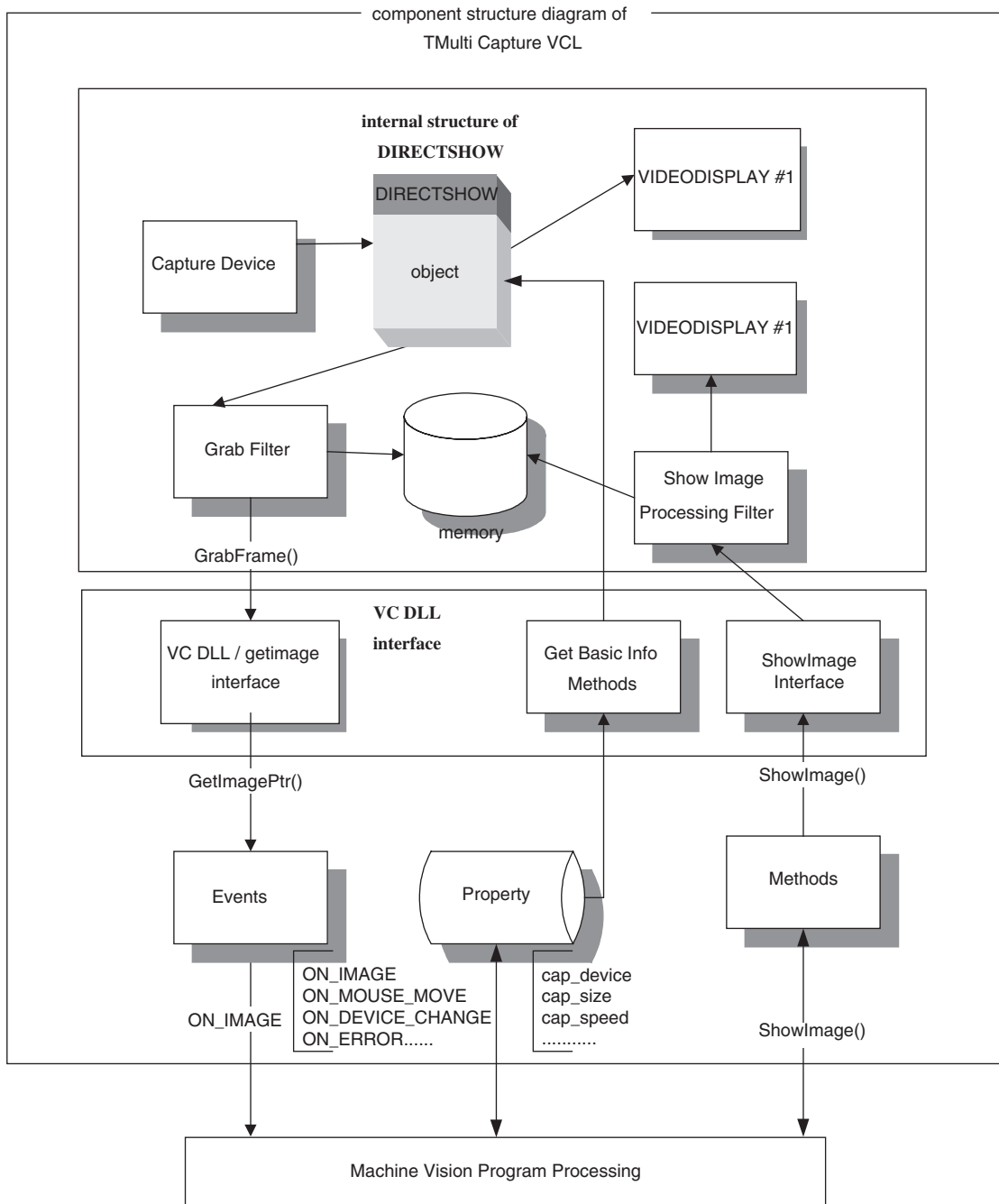


Fig. 6. The framework of extensive type machine vision model.

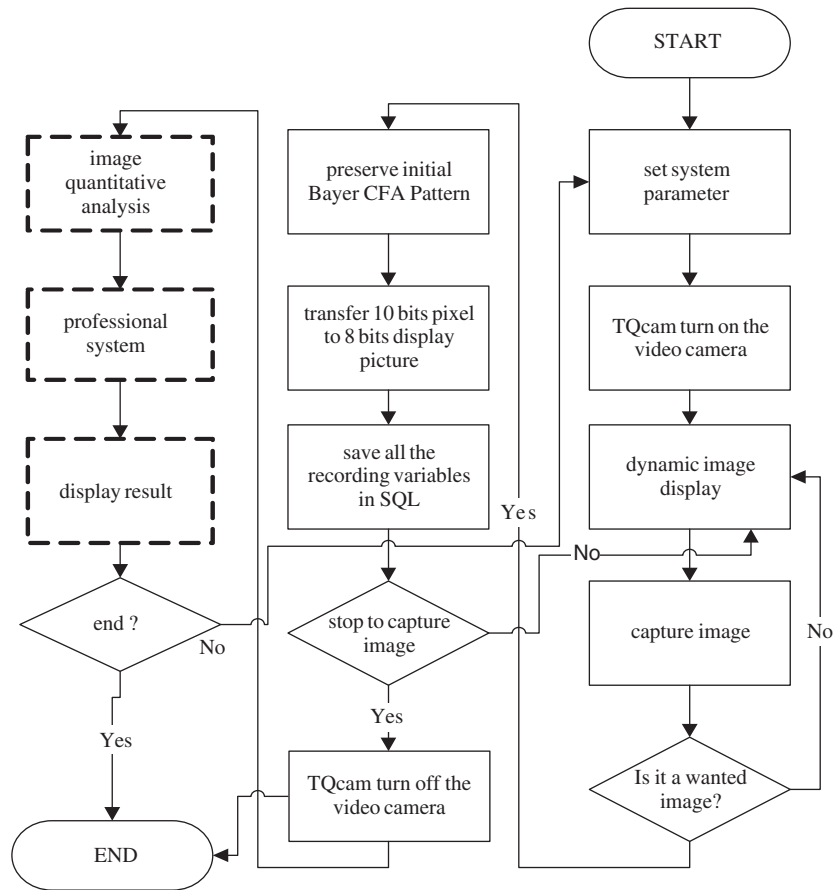


Fig. 7. The programming flow chart.

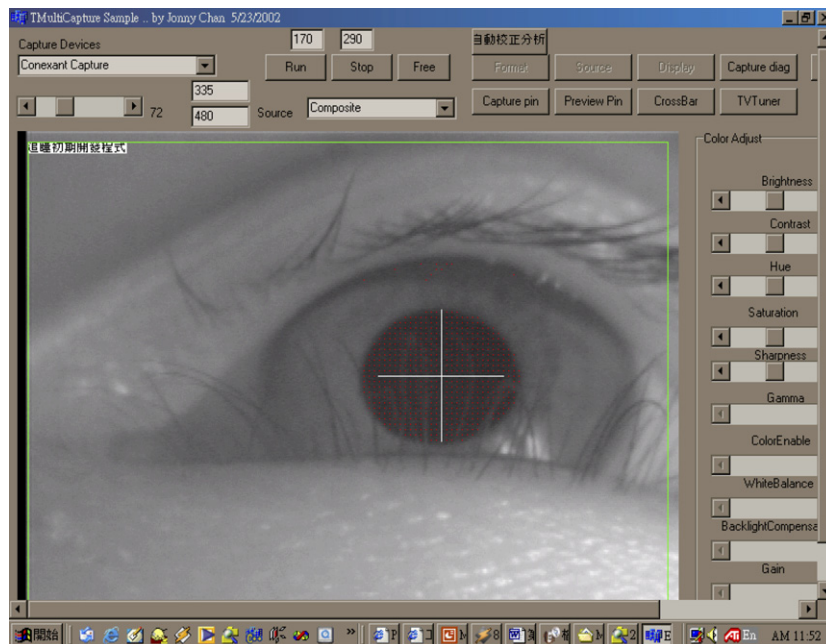


Fig. 8. Testing pattern of the pupil image tracking

The programming framework and the operation flow-chart is shown in Fig. 7. The key point of the entire system is that it can record the detailed capture data of the

databank so as to be used in the future. The completeness of the system parameter is also the important setting point as it captures the image.

Table 2
The comparison between the former and novel eye-tracking systems

Type/comparison	Former research for pupil tracking [9–11]	Our research
Correction time	Average 30 s	10–15 s
Feedback correction	No	Yes
Image processing number	20 frames/s	30 frames/s

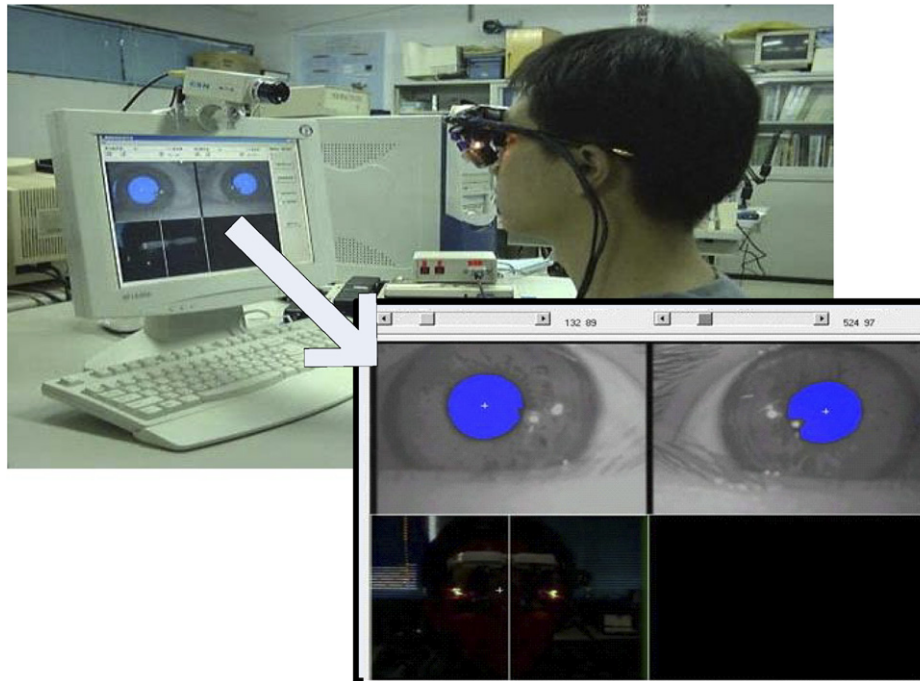


Fig. 9. The combination of the eye controlled and head controlled human–machine interface system.

Fig. 8 is the testing pattern of the pupil image tracing. At first, the user gazes at the center point and then presses the space bar, so that he can control mouse by eye. The applied development of this system is the improvement in mouse coordinate control, and hardware selection, which is a simple application to enhance the new capabilities of eye-tracking system, as shown in Table 2. The combination of the eye controlled and head controlled human–machine interface system is shown in Fig. 9. There are three cameras in this system, one is for head-light tracing, and the other two are for eye tracing, but they are separately in four channel color quad image.

5. Conclusion

The main technology of eye tracking is modified and makes use of the head gesture control system. In this system, the user only wears a light source device and sits in front of a computer. Then, the CCD camera on the monitor can capture the user's image and calculate the position of the light by real-time digital image processing technology. Based on this, the user can control the mouse cursor by moving his head.

We can also use this system as a joystick to play a game with an application program in a multimedia environment. The main technology of the head gesture control system is modified from eye tracking. In the eye-tracking device, the system searches for pupil center in the black parts of the image. In contrast, the head gesture control system searches for the bright spots in light sources image.

Disabled people can easily operate a computer by using eye tracking or head gesture control device. In addition, this device has many applications employing complex and economical equipment, as confirmed by its use in entertainment and virtual reality. We hope our eye and head controlled devices can become more useful for human–machine interfaces in future.

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