Human-Computer Interaction Using Eye-Glasses Shape Information by 3-D Computer Vision Techniques*

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ABSTRACT

An approach to human-computer interaction using eye-glasses shape information by 3-D computer vision techniques is proposed. The direction of sight is estimated by the pose of a pair of eye glasses worn on the user. The eye-glasses shape used in this study is composed of two parallel lines and two circles. A monocular image of the eye-glasses shape is captured by a camera mounted on the computer monitor. Then image processing and curve fi t-ting techniques are employed to obtain the equations of lines and circles. The pose of the eye glasses with respect to the camera can be computed using the derived analytical solution in terms of the coefficients of the lines and the circles. In addition, an approach to calibrating the geome t-ric relation between the camera and the computer monitor is proposed. After knowing the pose of the eye glasses and the monitor plane equation in the image coordinate s s-tem, the intersection of the direction line of the eye glasses and the monitor can be used as input for some human-computer interaction applications. An advantage of this method is that the solution can be uniquely and an a-lytically determined without iterative computation. E x-perimental results of image processing and pose estimation show the effectiveness of the proposed approach.

Keyword: human-computer interaction, eye-glasses shape, pose estimation, computer vision.

1. Introduction

As computers are more and more popular in various applications, the interactions between humans and computers become more frequent and more important. In recent years, a number of human -computer interaction (HCI) techniques have been pr oposed to extend the simple interaction facilities of the keyboard and the mouse. Some researches focus on the topic of automatic speech recogn i-tion and several commercially successful speech interfaces have been developed [1]. A lot of other studies are about using hand gestures as HCI techniques [2]. Two groups of techniques, i.e., glove-based devices and video-based noncontact techniques, are discussed. In addition, there is a third class of interaction tool, called gaze-driven interaction, which utilizes the user's direction of gaze as the i n-put [3, 4]. In Hutchinson et al. [3], the gaze-interaction tools are data-helmets with some embedded infrared s s-tem, which evaluates the current pupil position by ex-ploiting the di fferences in infrared reflectivities between the pupil and the surrounding iris and sclera. In C olombo and Bimbo [4], only the camera is used to capture images. The user's eyes are continuously tracked by means of computer vision, and image information is used to infer the user action.

One application of the third class of interaction tool mentioned above is to use the eye gaze as a mouse to point a certain spot on the screen for the handicapped. The tools were not shown to work well for a man with glasses. If a shortsighted user wants to use the interaction tools, he must wear contact lenses. This seems impractical. In this study, the location of glasses is used instead of the eye gaze. This is especially useful for a man with glasses. In our system, a camera is mounted on the monitor. An illustration of the camera setup is shown in Fig 1.

In our approach, the user's glasses are tracked b means of computer vision. A standard eye-glasses shape is designed, which is composed of two parallel lines and two circles. To get the eye glasses direction, an image of the eye glasses is taken first. The two lines of nosepiece and the two circles are detected by the Hough Transform and curve fitting. After the image equations of the two lines and the two circles are determined, the pose of the eye glasses can be obtained b substituting the coefficients of equations into the formula derived in this study. After the direction of the eye glasses is obtained, the intersection of the monitor and the eye direction can be computed and used as input to other applications. In add ition, the geometric relation between the camera and the monitor must be calibrated first, when the camera is set up. An effective calibration a pproach is also proposed is this study. It is easy to use because no special equipment is needed.

The remainder of this paper is orga nized as follows. In Section 2, the proposed analytical method to l o-cate the eye glasses is described. In Section 3, the pr o-posed method to relate the pose of the eye -glasses shape to a corresponding point on the computer monitor is pr e-sented. In Section 4, experimental results are included.

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Finally, conclusions and some suggested future works are given in Section 5.

2. Locating Eye-Glasses Shape

In Section 2.1, three coordinate s stems and coordinate transformations used in this study are defined. Next, the formulation of the problem of 3-D location of an eye-glasses shape is described and the analytical solution of 3-D location of the eye glasses with respect to the ca mera coordinate system is derived in Section 2.2.

2.1 Coordinate Systems and Transformations

Given the image of a pair of eye glasses whose shape (including the equ ations of the two parallel lines and the two circles) in the object coordinate system is known advance, we want to derive the camera parameters with respect to the eye glasses. The camera parameters are composed of the position parameters X_C, Y_C, and Z_C, and the orientation parameters ψ, θ, and δ (pan, tilt, and swing angles). These parameters may be considered to fully determine the location and the direction of the eye glasses with respect to the camera, where the origin G of the eye glasses is the middle point of the nos epiece.

Figure 2 shows the relation of a standard eye-glasses shape and the coordinate systems used. For an eye-glasses shape, let C_1 and C_2, O_1 and O_2, and L_1 and L_2 represent the left and the right circles, their ce nters, and the parallel line segments of the nosepiece, respectively. The length of L_1 is $2L$ and the radius of either circle is R. Three coordinate systems are used in this study, as d escribed in the following.

1. The object coordinate system (OCS), denoted as X-Y-Z, is attached to the middle point G of the line segment $_2$ of the nosepiece. The X-axis is along the line $_2$ and goes through G, O_1 and O_2. The Z-axis is parallel to the normal vector of either circle and goes through the origin G. The line segment $_1$ are parall el to the X-axis. Note that the Z coordinates of all the points on the eye-glasses shape are equal to zero.
2. The camera coordinate system (CCS), denoted as x-y-z, is attached to its lens center C. The z-axis is along the optical axis and the x -y plane is parallel to the image plane.
3. The image coordinate system (ICS) is denoted as u-v. The image plane is located at $z = f$ in CCS, where f is the focus length of the camera.

The transformation between the CCS and the VCS can be written as [5]

$$(x \;\; y \;\; z \;\; 1)=(X \;\; Y \;\; Z \;\; 1)\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -X_c & -Y_c & -Z_c & 1 \end{bmatrix}\begin{bmatrix} r_{11} & r_{12} & r_{13} & 0 \\ r_{21} & r_{22} & r_{23} & 0 \\ r_{31} & r_{32} & r_{33} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad (1)$$

where

$$\begin{aligned} r_{11} &= \cos\psi\cos\delta \\ r_{12} &= -\cos\psi\sin\delta \\ r_{13} &= \sin\psi \\ r_{21} &= \sin\theta\sin\psi\cos\delta+\cos\theta\sin\delta \\ r_{22} &= -\sin\theta\sin\psi\sin\delta+\cos\theta\cos\delta \\ r_{23} &= -\sin\theta\cos\psi \\ r_{31} &= -\cos\theta\sin\psi\cos\delta+\sin\theta\sin\delta \\ r_{32} &= \cos\theta\sin\psi\sin\delta+\sin\theta\cos\delta \\ r_{33} &= \cos\theta\cos\psi \end{aligned} \quad (2)$$

and ψ is the pan angle, θ is the tilt angle, δ is the swing angle, and (X_C, Y_C, Z_C) is the translation vector from the origin of the OCS to the origin of the CCS. Let (u,v) be the coordinates of the perspective projection of a 3-D point (x, y, z) on the image plane. The perspective transformation from the CCS to the ICS can be written as [5]

$$\begin{pmatrix} u \\ v \end{pmatrix} = \frac{-f}{z}\begin{pmatrix} x \\ y \end{pmatrix}. \quad (3)$$

2.2 Analytical Solution of Camera Parameters

Let the equations of the perspective projection of line $_1$ and L_2 be expressed as

$$a_1 u + b_1 v + c_1 = 0, \quad (4)$$

$$a_2 u + b_2 v + c_2 = 0, \quad (5)$$

where (u,v) are the image coordinates of the projection of any point on L_i, and a_i, b_i, and c_i, i=1 or 2, represent the coefficients of the line equations, which can be obtained by the use of the Hough transform and least-mean-square line fitting. By combining Eq. (1) through Eq. (5), the orientation parameter ψ and δ can be obtained. The details are described as follows.

Since line $_1$ is parallel to the X-axis, (X, Y_1, Z_1) are the coordinates of any point on $_1$ in the OCS, where X represents a free variable and Y_1 and Z_1 are two fixed values. Substitute the expressions of x, y, and z of Eq. (1) into Eq. (3) to obtain the following equ ations

$$u=-f\left[\frac{r_{11}(X-X_C)+r_{21}(Y_1-Y_C)+r_{31}(Z_1-Z_C)}{r_{13}(X-X_C)+r_{23}(Y_1-Y_C)+r_{33}(Z_1-Z_C)}\right], \quad (6)$$

$$v=-f\left[\frac{r_{12}(X-X_C)+r_{22}(Y_1-Y_C)+r_{32}(Z_1-Z_C)}{r_{13}(X-X_C)+r_{23}(Y_1-Y_C)+r_{33}(Z_1-Z_C)}\right]. \quad (7)$$

By eliminating the (X- X_C) term, the above two equations can be reduced into

$$\begin{aligned} &u[(Y_1-Y_C)r_{31}-(Z_1-Z_C)r_{21}]+ \\ &v[(Y_1-Y_C)r_{32}-(Z_1-Z_C)r_{22}]+ \\ &f[(Z_1-Z_C)r_{23}-(Y_1-Y_C)r_{33}]=0. \end{aligned} \quad (8)$$

Eq. (8) is the form of Eq. (4), so that we have the following equations

$$\frac{a_1}{(Y_1-Y_C)r_{31}-(Z_1-Z_C)r_{21}}=\frac{b_1}{(Y_1-Y_C)r_{32}-(Z_1-Z_C)r_{22}}=\frac{c_1}{f[(Z_1-Z_C)r_{23}-(Y_1-Y_C)r_{33}]} \quad (9)$$

From Eq. (9), the following equations are obtained:

$$\frac{Y_1-Y_C}{Z_1-Z_C}=\frac{b_1 r_{21}-a_1 r_{22}}{b_1 r_{31}-a_1 r_{32}}=\frac{c_1 r_{21}+a_1 r_{23} f}{c_1 r_{31}+a_1 r_{33} f}. \quad (10)$$

By eliminating the Y_C and the Z_C terms in Eq. (10), we can get the following equation

$$a_1 f(r_{22}r_{33}-r_{32}r_{23})+b_1 f(r_{23}r_{31}-r_{21}r_{33})-c_1(r_{r21}r_{32}-r_{22}r_{31})=0$$

, which can be reduced to be

$$r_{11}a_1 f + r_{12}b_1 f - r_{13}c_1 = 0\,, \qquad (11)$$

according to the relations of the orthogonal rotation matrix elements [5]:

$$r_{11}=r_{22}r_{33}-r_{32}r_{23},$$
$$r_{12}=r_{23}r_{31}-r_{21}r_{23},$$
$$r_{13}=r_{21}r_{32}-r_{22}r_{31}.$$

Since L_2 is parallel to the X -axis too, and the equation of the image of L_2 is Eq. (5). In a similar way, we can get another equation

$$r_{11}a_2 f + r_{12}b_2 f - r_{13}c_2 = 0\,. \qquad (12)$$

From Eqs. (11) and (12) and the condition [5] $r_{11}^2+r_{12}^2+r_{13}^2=1$,

we can obtain

$$r_{11}=Q_1 r_{13},\ r_{12}=P_1 r_{13},\ r_{13}=\pm\frac{1}{\sqrt{(1+P_1^2+Q_1^2)}}, \quad (11)$$

where

$$P_1=\frac{c_1a_2-c_2a_1}{(b_1a_2-b_2a_1)f}, \text{ and } Q_1=\frac{c_2b_1-c_1b_2}{(b_1a_2-b_2a_1)f}.$$

Then from Eq. (2), the orientation angles ψ and δ can be solved as follows

$$\psi=\sin^{-1}(r_{13})\,, \qquad (12)$$

$$\delta=\tan^{-1}(-r_{12}/r_{11})\,. \qquad (13)$$

Next, the tilt angle θ can be derived from the coeff i-cients of either circle of the eye -glasses shape. Let the equation of the left circle in the 3 -D OCS be expressed as

$$(X+L)^2+Y^2=R^2\,, \qquad (14)$$

$$Z=0\,. \qquad (15)$$

Since the projection of a circle in the image plane is an ellipse, let the ellipse equation, which is assumed to have been obtained by some image processing techniques, be described by:

$$Au^2+Buv+Cv^2+Du+Ev+F=0\,. \qquad (16)$$

By combining Eqs. (1) through (3), and (13) through (15), the orientation parameter θ can be obtained. The details are as follows.

First, the image coordinates of u and v of Eq. (16) can be replaced by the orthogonal matrix elements r_{ij}, the position par ameters X_c, Y_c, and Z_c, and the object coordinates X, Y, and Z, according to Eqs. (1) through (3) and Eq. (14). The result is the following equ ation

$$A'f^2X^2+B'f^2XY+C'f^2Y^2+D'fX+E'fY+F'=0, \qquad (17)$$

where

$$A'=Af^2r_{11}^2+Bf^2r_{11}r_{12}+Cf^2r_{12}^2-Dfr_{11}r_{13}-Efr_{12}r_{13}+Fr_{13}^2 \qquad (18)$$

$$B'=2Af^2r_{11}r_{21}+Bf^2(r_{11}r_{22}+r_{21}r_{12})+2Cf^2r_{12}r_{22}$$
$$-Df(r_{11}r_{23}+r_{21}r_{13})-Ef(r_{12}r_{23}+r_{22}r_{13})+2Fr_{13}r_{23}, \qquad (19)$$

$$C'=Af^2r_{21}^2+Bf^2r_{21}r_{22}+Cf^2r_{22}^2-Dfr_{21}r_{23}-Efr_{22}r_{23}+Fr_{23}^2 \qquad (20)$$

$$D'=-(2X_cA'+Y_cB'+Z_cM_1)\,, \qquad (21)$$

$$E'=-(2Y_cC'+X_cB'+Z_cM_2) \qquad (22)$$

$$F'=X_C^2A'+X_CY_CB'+Y_C^2C'+X_CZ_CM_1+Y_CZ_CM_2+Z_C^2M_3\,, \qquad (23)$$

$$M_1=2Af^2r_{11}r_{31}+Bf^2(r_{11}r_{32}+r_{31}r_{12})+2Cf^2r_{12}r_{32}$$
$$-Df(r_{11}r_{33}+r_{31}r_{33})-Ef(r_{12}r_{33}+r_{32}r_{13})+2Fr_{13}r_{33}, \qquad (24)$$

$$M_2=2Af^2r_{31}r_{21}+Bf^2(r_{31}r_{22}+r_{21}r_{32})+2Cf^2r_{32}r_{22}$$
$$-Df(r_{31}r_{23}+r_{21}r_{33})-Ef(r_{32}r_{23}+r_{22}r_{33})+2Fr_{33}r_{23}, \qquad (25)$$

$$M_3=Af^2r_{31}^2+Bf^2r_{31}r_{22}+Cf^2r_{32}^2-Dfr_{31}r_{33}-Efr_{32}r_{33}+Fr_{33}^2 \qquad (26)$$

Since Eq. (14) and Eq. (17) both describe the same circle in the OCS, by co mparing the coefficients of two equations, we obtain

$$B'=0\,,$$

which can be rewritten as

$$r_{21}a_3+r_{22}b_3+r_{23}c_3=0\,, \qquad (27)$$

where

$$a_3=2Af^2r_{11}+Bf^2r_{12}-Dfr_{13},$$
$$b_3=bf^2r_{11}+2f^2r_{12}-Ef_{13},$$
$$c_3=-Dfr_{11}-Efr_{12}+2Fr_{13}.$$

By Eq. (27) and the conditions $r_{21}r_{11}+r_{22}r_{12}+r_{23}r_{13}=0$ and $r_{21}^2+r_{22}^2+r_{23}^2=1$, the elements r_{21}, r_{22}, and r_{23} can be solved as follows

$$r_{21}=Q_2r_{23},\quad r_{22}=P_2r_{23},\quad r_{23}=\pm\frac{1}{\sqrt{(1+P_2^2+Q_2^2)}}, \quad (29)$$

where

$$P_2=\frac{a_3r_{13}-c_3r_{11}}{b_3r_{11}-a_3r_{12}}, \text{ and } Q_2=\frac{a_3r_{12}-b_3r_{13}}{b_3r_{11}-a_3r_{12}}.$$

From the relation of the orthogonal orientation matrix elements, the extra three matrix elements are o b-tained:

$$r_{31}=r_{12}r_{23}-r_{13}r_{22},$$
$$r_{32}=r_{21}r_{13}-r_{11}r_{23}, \qquad (30)$$
$$r_{33}=r_{11}r_{22}-r_{12}r_{21}.$$

After the nine elements of the rotation matrix in Eq.(1) are solved (Eqs. (11), (29), and (30)), the tilt angle θ can be derived, according to (2), to be

$$\theta=\tan^{-1}(-r_{23}/r_{33})\,. \qquad (31)$$

In addition, the position parameters X_C, Y_C, and Z_C can be derived from the coefficients A' through F' in Eq. (17). By comparing the coefficients of Eq. (14) with those of Eq. (17), we obtain:

$$2X_CA'+Z_CM_1=2LA'\,, \qquad (32)$$

$$2Y_CC'+Z_CM_2=0\,, \qquad (33)$$

$$X_C^2A'+Y_C^2C'+X_CZ_CM_1+Y_CZ_CM_2+Z_C^2M_3=A'(L^2-R^2) \qquad (34)$$

.

From Eq. (32) through Eq. (34), the position parameters are solved as follows

$$X_C = -\frac{M_1 Z_C}{2A'} + L, \quad (41)$$

$$Y_C = -\frac{M_2 Z_C}{2C'}, \quad (42)$$

$$Z_C = \sqrt{\frac{A' R^2}{\frac{M_1^2}{4A'} + \frac{M_2^2}{4C'} - M_3}}. \quad (43)$$

3. Relating Pose of Eye-Glasses Shape to Corr e-sponding Point on Computer Monitor

The point on the computer monitor which the user looks at is the intersection of the direction line of the eye-glasses shape and the monitor plane. In this study, we assume that the surface of a monitor is planar. The situ a-tion is shown in Figure 3. Since the pose of an ey -glasses shape can be obtained by the analytical solution in Section 2, if the equation of the monitor plane in the CCS is known, the intersection of the direction line of the eye-glasses shape and the plane of the monitor can be d e-rived by geometry. However, this requires that an initial calibration be performed to get the geometric relation between the camera and the computer monitor. One way for this purpose is proposed in this study, and is described in the following.

Because the equation of a plane can be obtained from three distinct points on it, three points are chosen as predefined locations where the user is prompted to follow by his/her view with the eye glasses. As shown in Figure 4, the first point, P_1, is placed at the center of the upper line of the monitor, and the other two points, P_2 and P_3, are at the lower-left and lower-right corners of the monitor, respectively. An icon is placed at the three predefined points su ccessively. The user's eye -glasses image is captured when the user looks at the icon at the first location, say X_1. Then the user moves to another location, say X_2, and the above process of capturing an image is r e-peated, and so on. For each point, its coord inates in the CCS can be solved by the inte rsection of the direction lines of the eye glasses at two different locations. After the coordinates of P_1, P_2 and P_3 are obtained, the equation of the monitor plane can be derived by geometry. Let (x_i, y_i, z_i) be the coordinates of point P_i in the CCS, i = 1, 2, and 3. The equation of the monitor plane in the CCS could be expressed as

$$ax + by + cz = 1, \quad (44)$$

where $\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{bmatrix}^{-1} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$

The detail of the calibration process is d escribed in Algorithm 1 below.

Algorithm 1 : Calibrating the geo metric relation b e-tween the camera and the co mputer monitor. The situation is shown in Figure 4.

Step 1 Move to a location X_1, and while looking at each of the three pre -selected points, P_1, P_2 and P_3, capture an eye-glasses image.

Step 2 Move to another location X_2 and do the same as in the last step.

Step 3 Computer the nearest point P_i for each pair of $\overrightarrow{X_1P_i}$ and $\overrightarrow{X_2P_i}$, where i=1, 2 and 3. The equations of $\overrightarrow{X_1P_i}$ and $\overrightarrow{X_2P_i}$ are the direction lines of the eye -glasses shape at X_1 and X_2, respectively.

Step 4 Compute the equation of the monitor plane b the coordinates of P_1, P_2 and P_3 in the CCS.

Now, we have the parametric equation of the d i-rection line of the eye glasses in the CCS a s follows

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} p \\ q \\ r \end{bmatrix} t + \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix}, -\infty < t < \infty, \quad (45)$$

where (x_c, y_c, z_c) are the coordinates of the origin of the eye glasses in the CCS. The (x_c, y_c, z_c) can be obtained by Eq. (1) and the camera parameters. The 3 -tuple (p, q, r) is the direction vector of the direction line of the eye glasses at a location. Substitute the expressions of x, y, and z of Eq. (45) into Eq. (44) to o btain

$$t = \frac{1 - ax_c - by_c - cz_c}{ap + bq + cr}. \quad (46)$$

Substituting t in Eq. (46) into Eq. (45), we can obtain the expressions of x, y and z, which are the coordinates of the intersection of the direction line of eye glasses and the monitor plane. The situation is shown in Figure 3. The obtained point then can be used as input to other applic a-tions.

4. Experimental Results

Experiments have been performed on a Pentium PC including a image board connected to a CCD camera with 8mm lenses for capturing images. The image size is 640x480x8 bits. The eye glasses used in the experiments were artificial o nes made of pasteboard and the size is shown in Figure 5.

To extract the ellipses and line se gments of the eye glasses, image and numerical analysis techniques were used. Thresholding is first applied to segment the shape of the eye glasses. By computing t he ho izontal projection, the regions and the centers of the ellipses are detected. Then the boundaries of the ellipses are detected. The least-median-of-squares (LMeds) method [6] was applied for conic fitting. At last, the line segments of nosepiece are detected by the Hough transform [7]. Examples of image processing are shown in Figure 6.

The eye glasses was imaged ten times at two di f-ferent locations for testing. The camera was set up from a distance of about 320 mm to capture images of the eye glasses. All the computed location param eters are listed in Table 1. In Table 1, the row 'M' is measured manually and was used as a reference to test the precision of the corr e-sponding location result. The row 'm' was the av erage value of computed position parameters from the ten i m-ages. At last, the row 'e' specifies the error rate which is defined as the ratio of the difference between row 'M' and row 'm' to the value of 'M'. As shown in Table 1, the error rate values are a ll smaller than 5%, so the proposed method is feasible for locating the eye glasses.

5. Conclusions and Future Works

An approach to human-computer interaction using eye-glasses shape information by 3-D computer vision techniques is proposed. Firstly, a method to estimate the direction of sight by eye-glasses shapes has been proposed. An analytical solution for pose determination of the eye glasses have been derived without iterative operations. In addition, an approach to calibrating the geometric relation between the camera and the monitor is proposed. The merit of this method is the ease to use with no requir ement of additional equipment. By combining the resulting i n-formation oh the two approaches, the direction of sight can be obtained and applied to some human-computer interaction applications.

One future work is to improve the a ccuracy of the point we look at and to implement real interaction application, such as eye-gaze word processing, eye writing proc-ess, etc.

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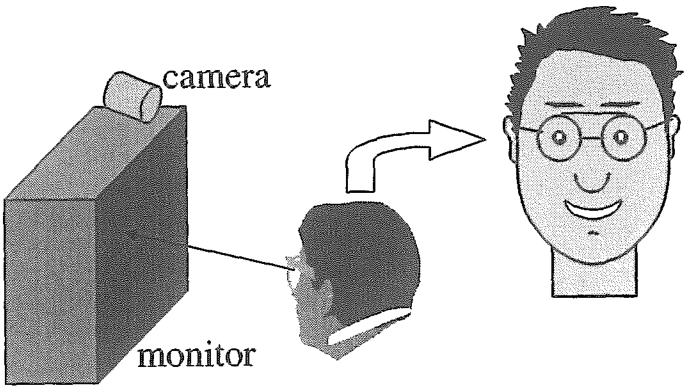


Figure 1. Illustration of the interaction between a computer and a user with a pair of eye glasses.

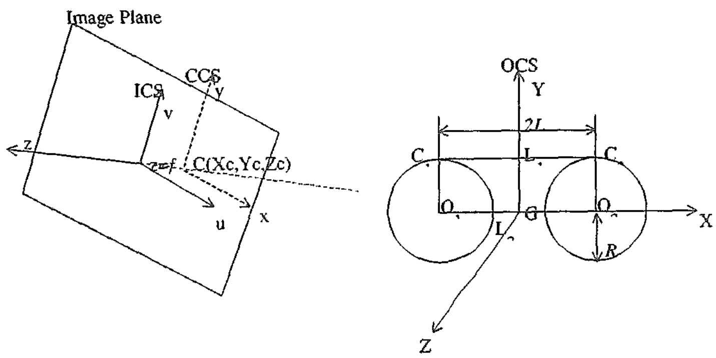


Figure 2. The relation of the object coordinate system XYZ(OCS), the camera coordinate system xyz(CCS) and the image coordinate system uv(ICS).

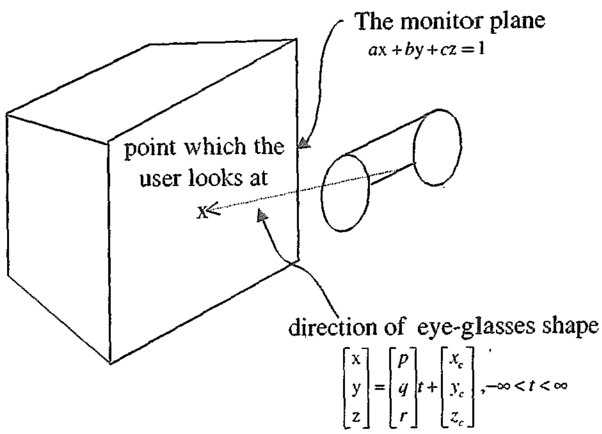


Figure 3. The relation of a point that the user looks at and the eye gl asses shape.

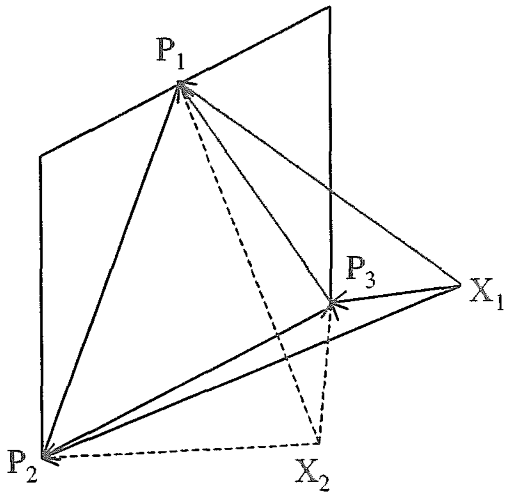


Figure 4. Three predefined points on computer monitor, P_1, P_2 and P_3, and two locations X_1 and X_2 where the user looks at the three points above.

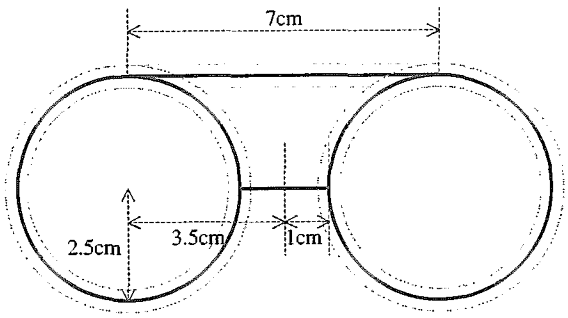
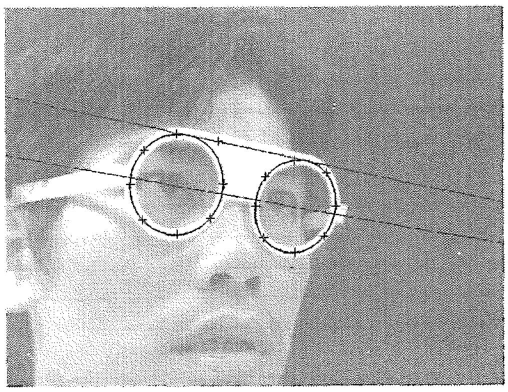
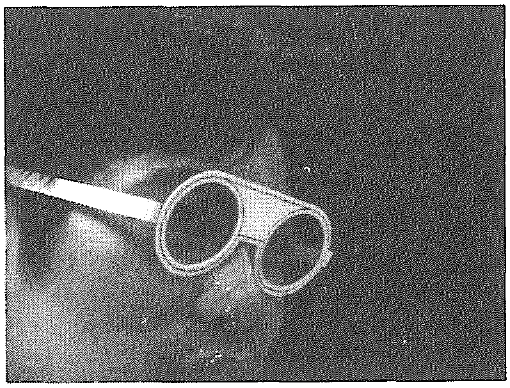


Figure 5. The dimensions of eye glasses used in the experiments.

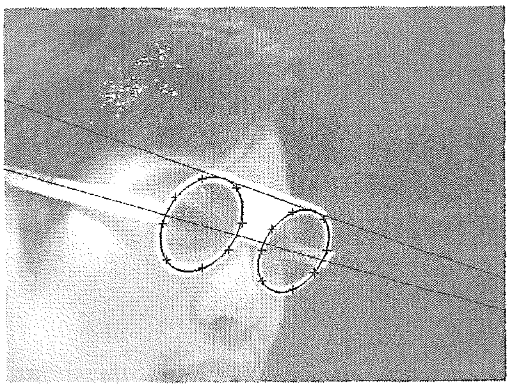
(a)



(b)



(c)



(d)

Figure 6. Artificial eye glasses used in the experiment. (a) An image of the eye glasses at a location. (b)The image processing result of (a). (c) An image of the eye glasses at another location. (d) The image processing result of (c).

Table 1. The location results of eye glasses.

Place		X_C (mm)
1	M	-46.000
	m	-48.209
	e	4.80%
2	M	56.000
	m	53.463
	e	4.53%

Place		Y_C (mm)
1	M	81.000
	m	83.494
	e	3.08%
2	M	74.000
	m	71.873
	e	2.87%

Place		Z_C (mm)
1	M	302.000
	m	311.543
	e	3.16%
2	M	315.000
	m	308.605
	e	2.03%