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INTELLIGENT MIRROR ADJUSTMENT SYSTEM USING A DRIVER'S PUPILS

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ABSTRACT−This paper describes an intelligent mirror adjustment system that rotates a pair of side mirrors and the room mirror of a car to the optimal position for a driver by using the location of the driver's pupils. A stereo vision system measures the three-dimensional coordinates of a pair of pupils by analyzing the input images of stereo B/W CCD cameras mounted on the instrument panel. This system determines the position angle of each mirror on the basis of information about the location of the pupils and rotates each mirror to the appropriate position by mirror actuators. The vision system can detect the driver's pupils regardless of whether it is daytime or nighttime by virtue of an infrared light source. Information about the pair of nostrils is used to improve the correctness of pupil detection. This system can adjust side mirrors and the room mirror automatically and rapidly by a simple interface regardless of driver replacement or driver's posture. Experiment has shown this to be a new mirror adjustment system that can make up for the weak points of previous mirror adjustment systems.

KEY WORDS : Intelligent mirror adjustment system, Pupil and nostril detection, Infrared light source, Stereo-vision

1. INTRODUCTION

In recent years, there have been numerous studies for development of intelligent products to improve a driver's convenience and safety. A pair of side mirrors and the room mirror of a car are indispensable equipment for safe driving because they provide a driver information about obstacles which are located to side and rear directions of a car and, on the basis of obstacle information, a driver determines when he will change lanes and accelerate or decelerate. The driver adjusts mirrors optimally for his physique and driving posture before driving or while driving. If the driver drives a car with mirrors that are not adjusted optimally, he does it under stress in regard to safe driving and it may cause an accident. Therefore, the driver usually adjusts the mirrors before driving a car.

The method of adjusting mirrors has been changed for the purpose of improving driver's convenience. The first improved method was a manual adjustment method using a lever mounted in the car for the side mirrors and the hands for the room mirror. Adjusting the mirrors using this method is a very troublesome process, especially when the driver wants to adjust the far side mirror, and he generally has to try several times to adjust them optimally. The second method is an automatic adjust-ment method using a mirror motor control button that is located near the driver. The driver can control the pair of side mirrors by use of one button. This method is more convenient than the first one, but the driver still has to use his hands to adjust the room mirror and has to try several times to adjust the side mirrors. Currently, a number of cars use this method. The most advanced method is a memory setting method by which the driver can record a memory of the optimal position angle of each mirror obtained by means of the second method and adjust the mirrors automatically by pressing a button whenever he wants. This method has been applied to high grade cars. However, this method usually memorizes only a small amount of drivers's data. The common disadvantages of the previous methods are that adjusting mirrors in this way is irritating work where several drivers with different physiques use the same car and, moreover, difficult and dangerous work where the driver wants to adjust mirrors while driving when the driving posture is changed. Therefore, an intelligent mirror adjustment method has to be able to adjust side mirrors and room mirror automatically and rapidly by means of a simple interface regardless of driver replacement and posture.

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Though many drivers are not aware of it, there are many cases in which a driver has to adjust mirrors, for example, where a driver sometimes changes his posture during a long drive, where drivers that have different physiques operate the same car, where the position angle of a mirror is changed by pedestrian contact or other reasons, where a woman driver uses a mirror as a makeup mirror, etc. Some drivers adjust mirrors when the car is stopped at a crossroads or is running on the road. These cases inhibit safe driving and may cause an accident. Therefore, a safer, easier and more convenient mirror adjustment method is needed.

In this paper, we describe a new mirror adjustment system that can make up for the weak points of previous mirror adjustment systems. This system determines the optimal position angle of side mirrors and the room mirror regardless of driver replacement and posture by measuring 3-D coordinates of a pair of pupils by means of a stereo vision system, and each mirror is rotated to the target position by means of a mirror actuation system. Since all processes are performed automatically as soon as the driver pushes a command button on the steering wheel while gazing to the road, this system is very easy, convenient and safe to use, and it is possible to adjust mirrors safely while driving. This system can be integrated with a driver drowsiness and carelessness warning system without any additional hardware.

The most important technique used to implement this system is that of detection of a pair of driver's pupils and measurement of their 3-D coordinates. The reason for detecting the pupils to determine the position angle of each mirror is that a driver usually adjusts the mirrors on the basis of the 3-D coordinates of the pupils.

Research about eye detection and tracking started in the early 90s and recently has been performed for application to a driver drowsiness detection system and a Human-Machine Interface system. Many traffic accidents are caused by drowsiness and careless driving. To prevent such accidents, most car makers are developing a drowsiness warning system. To recognize driver drowsiness, most of the methods have used a computer vision technique for detecting location of the eyes and eye blinking by analyzing a sequential image inputted by a CCD camera mounted in the car. They have a little difference in the methods for detecting eyes, but most of them use the gray-level gradient of the region surrounding the eye in a 2-D image and an infrared light source to obtain a bright enough image at night.

Several studies have proposed various methods of driver drowsiness detection. Shunji (Katahara *et al.*, 1995) used the inner corners of left and right eye for detecting eye region candidates and extracted the eyelid by curve fitting and the iris by Hough transform. Kazuhiko (Sugiyama *et al.*, 1996) and Hideo (Obara *et al.*, 1996) detected the location of the eyes using the characteristic that there are edges at upper eyelid and lower eyelid. Kenji (Ogawa and Shimotni, 1997) used a max-min filter for detecting the eye in the daytime and an inverse max-min filter for detecting a pupil brightened by infrared light at night. Sarbjit (Singh and Papanikolopoulos, 1999) determined the face region by using face skin color and detected the pupils by analyzing an edge map of the face region. Michinori (Ando *et al.*, 1999) detected the driver's bridge of the nose in an image obtained from a vision system installed on the room mirror and determined eye region on the basis of the bridge of the nose, detecting the eye by using average gray-level difference between the eyelid region and the area surrounding the pupils. Morimoto (Morimoto *et al.*, 2000) detected the eye by using the difference between two images. One image contains the pupils brightened by reflected infrared light, and the other contains dark pupils. Some of the previous work concerned with pupil detection used the feature that the pupils are reflected under an infrared light source (Ogawa and Shimotni, 1997; Morimoto *et al.*, 2000). This phenomenon provides a good clue in detecting pupils under specific illumination such as indoors or in a car without external light at nighttime. But, when it is daytime or there is some light source at nighttime, the reflection does not occur. Therefore, this phenomenon is not pertinent to use for detecting a driver's pupils under various illumination conditions.

Previous studies were generally focused on eye detection, tracking and blinking for development of a drowsiness detection system and Human-Machine Interface. However, this paper is focused on measuring the location of a pair of pupils in a 3-D system. The unique characteristic of the proposed pupil detection algorithm is use of a pair of nostrils. The pair of nostrils is easier to detect than the pupils and all drivers have them in unveiled status. Section 2 describes the overall system configuration, section 3 develops a pupil and nostril detection algorithm, section 4 presents measurement of 3-D location of pupils using a stereo vision model, section 5 describes the method of determination of optimal mirror position, and section 6 describes experimental results from real-time implementation of the pupil and nostril detection and section 7 concludes the paper.

2. SYSTEM CONFIGURATION

The intelligent mirror adjustment system consists of two CCD B&W cameras, infrared LEDs, a quad-splitter, an image processing board, a PC and a mirror actuation system. The system configuration is shown in Figure 1. The stereo CCD cameras with infrared LEDs were mounted on the instrument panel in front of the driver

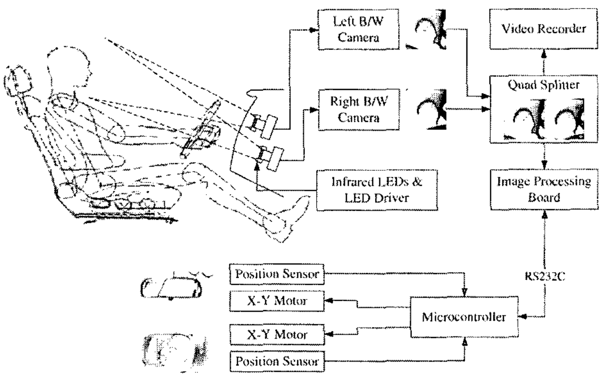

Figure 1. System configuration.

and obtain the driver's face image. The quad-splitter integrates the two videos into one video. The integrated video is transmitted to an image processing board or video recorder. By analyzing the driver's image using the proposed computer vision algorithm, the driver's pupils are detected, their 3-D coordinates are measured, and optimal position angle of each mirror is determined. Target angle values are transmitted to a microcontroller via serial communication, and the controller actuates mirror control motors until mirrors rotate to each target position angle.

2.1. Infrared Light Source and Vision System

To detect the driver's pupils regardless of whether it is daytime or nighttime, the vision system has to receive a sufficiently bright driver's image. An infrared light source is used to compensate for insufficient light during daytime driving, as in a tunnel, or nighttime driving. It is invisible to the driver but a general B&W camera perceives infrared light with 700~950 nm wavelength. In the experiment, we have used 8 infrared LEDs for each camera, and the peak emission wavelength of the infrared LED is 880 nm, with a beam angle of ±20°. The direction of the infrared light is parallel to the optical axis of the camera, and the infrared light is directed toward the driver's face. Figure 2 shows the stereo camera with infrared LEDs in the instrument panel.

The stereo vision system consists of stereo cameras, a quad splitter and a frame grabber. The quad splitter is connected to the four cameras as input channel, converts each video signal to digital image, integrates the four digital images into one image and has an output channel for displaying an analog video signal which includes the four images. This equipment is used in security systems for observing and storing sequential scenes of different places simultaneously. There are two advantages of using the quad splitter. The first is that we can use a general image processing board for implementing a stereo vision system. Generally, to implement a stereo vision system, a special frame grabber that can obtain two real-time images without switching video channels is needed. If we use a quad-splitter, because it provides an image which includes stereo images, it is possible to use a frame grabber with a single input channel. The second advantage is that a stereo vision system can record and redisplay stereo images easily by using a quad-splitter. For an experiment with stereo vision, the vision system has to be able to record and replay two images synchronously. Thus, a general stereo vision system is more complicated compared with a single vision system in regard to system configuration. But, by using a quad splitter, a stereo vision system is simplified and, moreover, a multi-vision system that can use 3 or 4 synchronous images can be implemented.

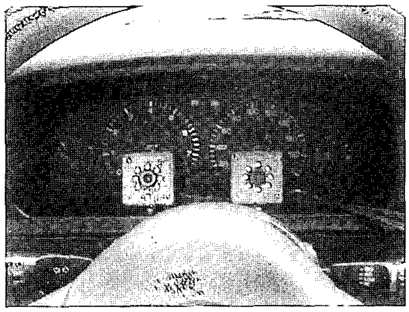

Figure 2. Stereo cameras with infrared LEDs.

2.2. Mirror Adjustment System

To implement an intelligent mirror adjustment system, the IMS (Integrated Memory System) of EQUUS, a passenger car made by Hyundai Motor Company, was used. It memorizes the precise position of side and rear mirrors, driver's seat as well as the steering wheel for up to two drivers. This equipment rotates each mirror to a memorized position at the press of a button. Each mirror of IMS is equipped with two DC motors for rotating the mirror and two potentiometers for sensing the up-and-down and right-and-left position angle of the mirror. The position angle value of each potentiometer is digitized between 0 and 255. By using this mirror adjustment system of IMS, an intelligent mirror adjustment system can rotate each mirror to the optimal position angle that is determined by the stereo vision system.

2.3. Preprocessing of a Driver's Face Image

For successful detection of the driver's pupils, the driver's face image should be bright enough for use of the computer vision algorithm. But, according to the location of the sun and the car, the brightness of a driver's face image is variable. If illumination of the driver's seat is completely absent, we can acquire a bright driver face image by using infrared light. However, in Figure 3(a),

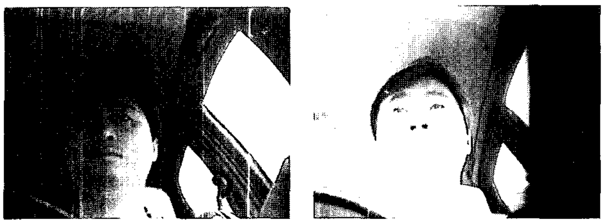
(a) (b)

Figure 3. (a) Dark and (b) bright driver face images. The gray-level of the face region is brightened.


(a) (b) (c)

Figure 4. (a) Daytime and (b), (c) nighttime images of a driver's face under the infrared light source.

though the driver's face image was obtained in the daytime, it may be difficult to detect the pupils by using a gray-level gradient because the driver's face region is quite dark. This phenomenon is caused by AE (Automatic Exposure) among the camera functions, which controls shutter speed automatically according to the brightness of the object. In cases where there is light in front of the object, this is not a problem, but in cases where there is bright sunshine or a lamp to the rear of the object, it is darkened by an exposure insufficiency phenomenon even if infrared light is used during the daytime. Because the large area of the car window near the driver is bright in Figure 3(a), the driver's face is darkened. To overcome this problem, the part of the CCD cell where the image of the car window near the driver is made is intercepted by means of an opaque material. Figure 3(b) shows the result of this operation. A part of the white window area was completely darkened and the area of the driver's face was whitened. The gray-level of pupil, eyelid and nostril is relatively darkened. Therefore, their detection becomes easier. Figure 3 is an image of the left-side camera, but an image of the right-side camera also contains white widow area. Thus, a part of the CCD cell of the right-side camera was also intercepted. If we increase the focal length of the camera, we can obtain a magnified driver's image without white window area. We can then get a bright driver's face image, but, in this situation, if the driver's have different physiques or move their faces, the face could be partially or completely missing in the field of view of the camera. Therefore, acquiring an image in which a driver's face is magnified is not pertinent to this system.

Figure 4 shows driver's images at daytime and nighttime. In the daytime, the infrared light source has no effect on brightness of image, as in Figure 4(a), except when the car is running in a very dark area. But, at nighttime or in a tunnel, by using infrared light, we can acquire a bright enough image that pupils and nostrils can be extracted, as in Figure 4(b), (c). There is a significant difference in the gray-level of pupil between the two night images. If the infrared light source is installed very close to the optical axis of the camera and there is no lamp to light the driver's face, such as a street lamp, headlights of approaching cars, etc, the pupil is reflected in the infrared light and it is whitened. Thus, this phenomenon has been used for detecting pupils, and a method using this feature is robust in the case of indoor application. However, since there are many kinds of lamps on the road at nighttime, such a phenomenon may not occur. Therefore, this feature is not pertinent for detecting driver's pupils at night. For this reason, the proposed method does not use this feature but uses an infrared light source to brighten the face image at night, and the same algorithm for detecting black pupils is applied to the daytime image and the nighttime image.

3. DRIVER'S PUPIL DETECTION ALGORITHM

In this research, a pair of pupils along with the nostrils is used for detecting a driver's eyes. The location of the eye is defined as the center point of the pupil, and nostril information is used for improving the correctness of pupil detection. The average gray-level of the pupil and nostril regions is darker than that of the neighboring regions, the shape of their regions is similar to a circle, and the size is pretty small. The detection algorithm of pupil and nostril is performed for each image inputted by two cameras, and the process flow is shown in Figure 5.

All pixels in the search window are scanned by a

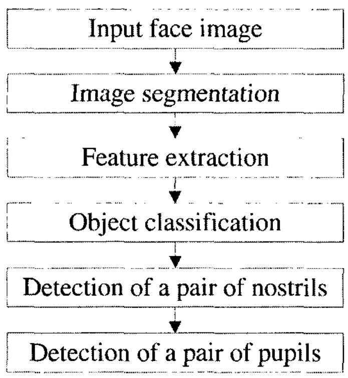

Figure 5. Process flow for detecting a driver's pupils.

special window pattern to segment an image into small and dark objects to be candidates for pupils or nostrils, and they are binarized. The boundary of objects in the window is described by a chain code method. Some measurements that characterize each object are calculated to discriminate pupils and nostrils among the candidate objects, and only a few objects that may be pupil or nostril remain. A pair of nostrils and a pair of pupils are detected sequentially by using a driver face model composed of two nostrils and two pupils.

3.1. Search Window

The detection algorithm of pupils and nostrils does not have to be applied to the whole image because the location of the driver's face is confined to a specific area of the image even if each driver has a different physique and moves his head slightly. Therefore, it is more efficient for the detection algorithm to be performed to a specific area that is designated as a search window in the view of processing time. The resolution of an input image is 320× 240 and the resolution of the search window is determined as 160× 160. This resolution is space enough to contain each driver's face in normal driving conditions. The center point of the search window is defined as an average of four points, a pair of pupils and a pair of nostrils, and is updated whenever the pupils and nostrils are newly detected. After a pair of nostrils is detected in the search window, a pupil search window is established for detecting a pair of pupils. The width, height, and location of the window are determined using information from the pair of nostrils.

3.2. Image Segmentation

To detect a pair of pupils and a pair of nostrils in the search window, the characteristics of pupil and nostril used are that the value of gray-level of their region is lower than that of the surrounding region, their size is quite small, and the shape is similar to a circle. To segment the image into small and dark objects that could be pupils or nostrils, a special window pattern was designed. It has three regions ranged along its length, as shown in Figure 6(a), and each grid in the window corresponds to one pixel. By scanning this window pattern in the input image $f(i, j)$ by using (1), a binary image $g(i, j)$ is obtained. T is the threshold and avg_U, avg_C, avg_L are the mean values of gray-levels of upper region, central region and lower region, respectively. If the mean value of the gray-level of a central region is less than that of the upper region and lower region by a specific value, the central region is considered to be a candidate region for pupil or nostril. Figure 6(b) shows the case that the window pattern is located on the pupil exactly. The reason for adding some empty grids between the central region and the other regions in the window

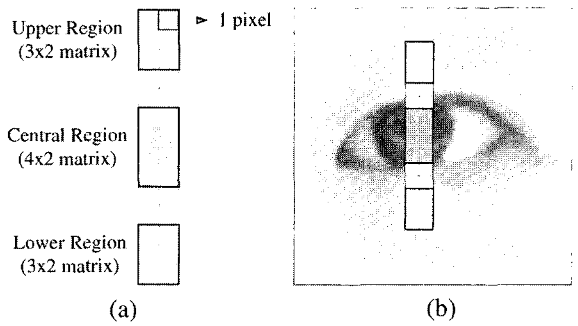

Figure 6. (a) Window pattern designed for detecting candidate regions of pupil and nostril. (b) Shows window pattern being matched with pupil.

pattern Figure 6(a) is that the size of the driver's pupil varies according to the location of the driver's face and the size of the driver's eye. In the experiment, the height of driver's pupil was between approximately 4 and 7 pixels with our vision system within a car. The height of the central region is 4 pixels, and the interval between the upper region and lower region is 8 pixels for discriminating a small and dark isolated region such as pupil and nostril regions. This method is robust for the thickness of the eye.

$$g(i,j) = \begin{cases} 255 \text{ if}(avg_U - avg_C) > T \text{ and} \\ \quad (avg_L - avg_C) > T \\ 0 \quad \text{otherwise} \end{cases}, (i,j) \in R \quad (1)$$

where R is a set of central region pixcels

The image segmentation breaks an image into individual objects. In the first stage, the window pattern is scanned to the search window of an input image, and we can get a binary image which is a white pixel group that represents a small dark region in the original image. In the second stage, individual white pixels are separated into objects by means of a chain code. Figure 7(b) shows the result of image segmentation of Figure 7(a). Pupils, nostrils, sections of hair, etc, which are small and dark objects compared with the surrounding region in a vertical direction, are extracted.

3.3. Feature Extraction

In this step, the individual features of each object are measured. We used three measurements: area, center point and roundness of each object. The first measurement is area of the object. It is computed as the total number of pixels inside, and including, the object boundary. It is defined as N and can be easily computed by adding a simple expression to the chain code. The second measurement is the center point of the object. The third measurement is roundness of the object, which is a ratio based on the area and perimeter measures of the object. The greater the ratio, the rounder the object. As the ratio decreases from 1, the object departs from circular form. Because a pupil and a nostril are close to circular form, this measurement is a good measurement. In (2), the perimeter is the pixel distance around the circumference of the object.

$$Roundness = (4\pi \times N)/Perimeter^2 \quad (2)$$

3.4. Object Classification

For an object to be a candidate for a pupil or a nostril, the size of the object area needs to be fall within a specific range, roundness needs to be close to 1, and the center point needs to be located in a pertinent region in a search window. Therefore, some objects that do not satisfy the above three measurements are discarded. This step is object classification, and Figure 7(c) shows that only objects having a shape similar to a pupil and a nostril remain.

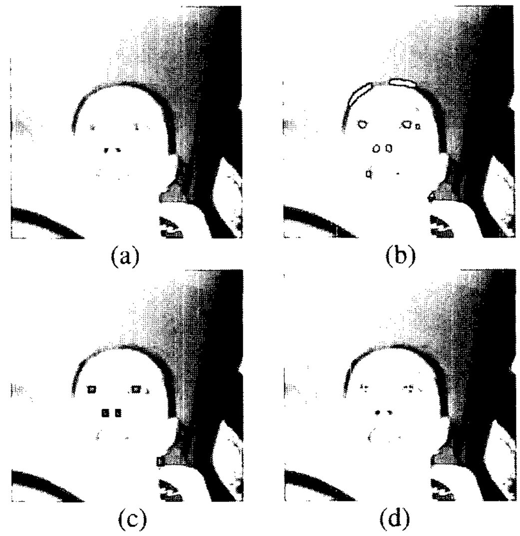

Figure 7. (a) Input image (b) image segmentation (c) object classification (d) detection of a pair of pupils. Process for detecting a pair of pupils.

3.5. Detection of a Pair of Nostrils

There are some cases in which it is difficult to detect a pair of pupils, for example, where the brightness of the area around the eyes is whitened by external light, a driver wears a pair of opaque glasses, a driver's hair hides one eye, etc. But there are few cases in which it is not possible to detect a pair of nostrils since the brightness of a pair of nostrils is seldom affected by external light, and thus the pair of nostrils always exists in detectable status. Therefore, the proposed method detects a pair of nostrils prior to detecting a pair of pupils. Among several objects, a pair of nostrils is detected by use of two properties. The first is that the nostrils in the pair have a similar shape and size, and the second is that the pair of nostrils is located very close together and horizontally.

3.6. Detection of a Pair of Pupils

The final step is to detect the pair of pupils. By using the location information of the pair of nostrils, we can guess where the pair of pupils is located in the search window. On the basis of the location information of the pair of nostrils and a driver face model, the proposed method establishes a pupil search window and detects a pair of pupils in this window by using a driver face model. The definition of this model composed of a pair of pupils and a pair of nostrils is as follows:

- A pupil and nostril are approximately circular.
- A pair of nostrils is below a pair of pupils.
- The distance between nostrils is shorter than the distance between pupils.
- The range of the distance between nostrils is obtained by multiplication of the width of one nostril.
- The range of the distance between pupils is obtained by multiplication of the distance between nostrils.
- A quadrangle that consists of a pair of nostrils and a pair of pupils is approximately an isosceles trapezoid.
- The line connecting two pupils is parallel to the line connecting two nostrils and their slope is approximately horizontal.

The location and size of the pupil search window are determined by using the center point of the pair of nostrils and the distance between the pair of nostrils. Detecting a pair of pupils in a pupil search window makes it possible to decrease the error ratio of pupil detection and measure the location of the pupils approximately even if the driver closes his eyes or wears sunglasses. If a pair of objects in the pupil search window satisfies all of the conditions of the driver face model, it is considered a pair of pupils. Figure 7(d) shows that a pair of pupils has been detected, and a white cross mark represents the center of each pupil.

4. MEASUREMENT OF THE 3-D COORDINATES OF A PAIR OF PUPILS

After the stereo vision system detects a pair of pupils, the 3-D coordinates of the left and right pupils are measured. The position of each pupil is obtained by using the relationship between the 3-D coordinates of the center point of each pupil and the corresponding coordinates of the left and right images representing the projection of the points through a stereo camera model.

Let $P(X, Y, Z)$ represent the 3-D coordinates of the center point of a pupil with respect to an original midway point between the lens centers as shown in Figure 8. For a

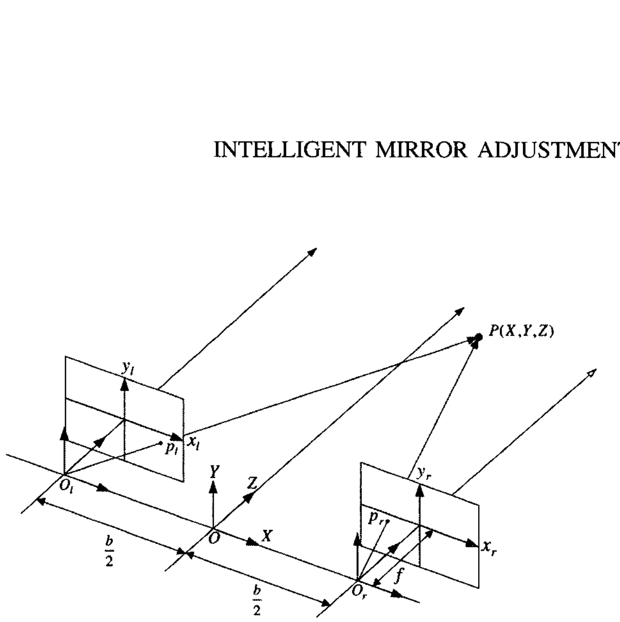

Figure 8. Stereo vision geometry.

parallel-looking stereo camera model, the point $P(X, Y, Z)$ and its corresponding left and right image points $p_l(x_l, y_l)$ and $p_r(x, y_r)$ are related by (3).

$$X = \frac{bx_l + x_r}{2x_l - x_r}\ Y = \frac{by_l + y_r}{2x_l - x_r}\ Z = \frac{bf}{x_l - x_r} \tag{3}$$

where b denotes the baseline distance and f the focal length.

After measuring the 3-D coordinates of the left and right pupils, the feature point to be used for determining the position angle of the mirrors is measured. The feature point is defined as the center point between the two 3-D coordinates of the left and right pupils.

5. DETERMINATION OF THE POSITION ANGLE OF MIRRORS

The position angles of side mirrors and the room mirror for the left-and-right direction and the up-and-down direction of each mirror are determined by (4). (P_x, P_y, P_z) is a feature point.

M_{lsx}, M_{lsy} are the left-and-right and the up-and-down direction position angle of a left side mirror respectively, M_{rsx}, M_{rsy} are of the right side mirror, M_{rx}, M_{ry} are of the room mirror. (b_{lsx}, b_{lsy}), (b_{rsx}, b_{rsy}), (b_{rx}, b_{ry}) are basis for the left-and-right and the up-and-down direction position angles of the three mirrors, (P'_x, P'_y, P'_z) is a basis feature point, and k_1, k_2 are constant.

$$\begin{pmatrix} M_{lsx} & M_{lsy} \\ M_{rsx} & M_{rsy} \\ M_{rx} & M_{ry} \end{pmatrix} = \begin{pmatrix} b_{lsx} & b_{lsy} \\ b_{rsx} & b_{lsy} \\ b_{rx} & b_{ry} \end{pmatrix} +$$

$$k_1 \begin{pmatrix} (P_x - P'_x) & (P_y - P'_y) \\ (P'_x - P_x) & (P_y - P'_y) \\ (P_x - P'_x) & (P_y - P'_y) \end{pmatrix} + k_2 \begin{pmatrix} (P_z - P'_z) & (P_z - P'_z) \\ (P'_z - P_z) & (P_z - P'_z) \\ (P_z - P'_z) & (P_z - P'_z) \end{pmatrix} \tag{4}$$

An optimal mirror position angle is defined as a mirror position angle that allow the driver to see visual markers that are installed on rear-side positions of the car in the center of each mirror. Each parameter in (4) was determined by experiment. (4) represents the function that for the location value of a driver's pupil, a change of the x coordinate effects a change of the left-and-right direction position angle of each mirror, a change of the y coordinate effects a change of up-and-down direction position angle of each mirror, and a change of the z coordinate effects a change of all directions in the position angle of each mirror. Communication between the image processing computer and the microcontroller is conducted by RS232C serial communication. If a driver pushes the mirror adjustment button installed on the steering wheel while gazing at the road to the front, the microcontroller recognizes the command and transmits one byte (0xFF) to the PC. As soon as the PC receives a command signal, the proposed vision algorithm is executed, detects a pair of pupils, measures the 3-D coordinates of the pupils, determines the position angle of each mirror and transmits 7 bytes to the microcontroller. The 7 bytes consist of a header (1 byte), up-and-down direction for the position angle of the two side mirrors and the room mirror and left-and-right direction for their position angles. The controller that receives the 7 bytes actuates firstly, the three DC motors for rotating the up-and-down direction position angle of the three mirrors and, secondly, the three DC motors for rotating the left-and-right direction position angle of the three mirrors until the position angle value of each mirror reaches the target angle value.

6. EXPERIMENTAL RESULTS

In the experiment, real-time implementation of the pupil detection system is run at 12 frames/s on a single processor Pentium-II 350 machine. The images are of resolution 320×240×8 bits. A PCI frame-grabber with no on-board processing capabilities is used for image acquisition. One of the computers serial communication ports is used to transmit the target position angle of each mirror to a controller. The current implementation uses two 1/3" CCD B&W board cameras with 8 mm lens. The current prototype is able to detect pupils up to 80 cm from the camera.

In testing the proposed method on 20 driver's in a group composed of men and women with different physiques in the daytime and nighttime, driver's pupils were successfully detected with stereo images. The detection ratio for nostrils was 95% and the detection ratio for pupils was 85%. Figure 9 shows the resulting images. The white cross mark represents the center of each pupil. The pupil detection error is classified in two categories. The first is caused by nostril detection error,

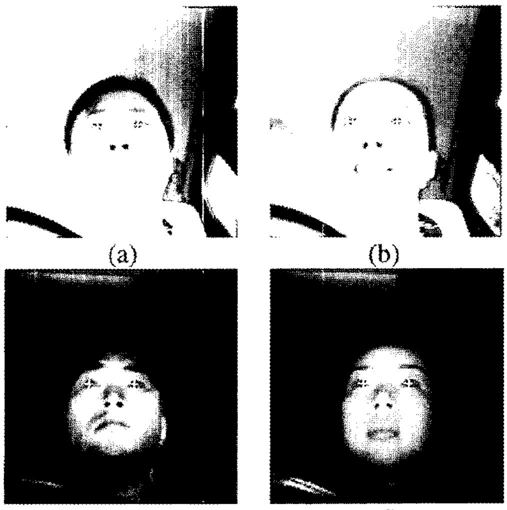

Figure 9. (a) Man driver (b) woman driver in the daytime (c) man driver (d) woman driver at nighttime. Experimental results for detecting a pair of pupils.

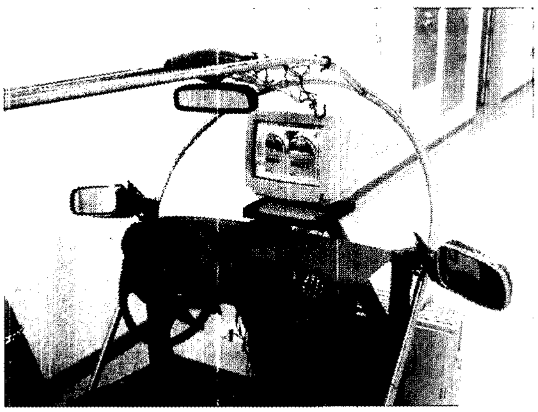

Figure 10. Intelligent mirror adjustment system simulator.

and the second is caused by pupil detection error after the nostril was detected. The pair of pupils of a few driver's wearing glasses was not detected since the darkness of the pupils was brightened a little by the effect of a lens. But, whenever the nostril is detected, where it is difficult to detect the pupil, for example, if a driver closes eyes or a driver wears a pair of sunglasses, the proposed method can measure the position of the pupils approximately.

The experiment of measuring the 3-D coordinates of a driver's pupils was executed on an intelligent mirror adjustment system simulator, shown in Figure 10. Since it was difficult to compare the real 3-D position of pupils with the 3-D position of pupils measured by the proposed method, we made a simulator that could do all functions of an intelligent mirror adjustment system for experimental convenience.

The distance between the focal point of the camera and the driver's pupils generally ranged from 60 cm to 80 cm. Thus, we placed the driver's pupils at 27 different locations for which we knew the 3-D coordinates and measured the position value by means of the proposed stereo vision method.

In the results, the average position error of X, Y and Z coordinates was 0.87 cm, 0.92 cm and 1.03 cm, respectively. These errors were caused by the low resolution of an input image and a small displacement of the pupil center point. This amount of error was not critical in determining the optimal position angle of each mirror because generally drivers adjust a mirror roughly and are not concerned about fine adjustment. Most of the experimental drivers were satisfied with the result of the intelligent mirror adjustment.

If this system could get vehicle speed data from an ECU or other device, it could take on the role of accident warning system as well as intelligent mirror adjustment system. This system basically can track the position of the driver's face. Therefore, if it could not detect the driver's nostril in driving, it is evident that the situation is very dangerous and may cause an accident.

7. CONCLUSION

We have proposed an intelligent mirror adjustment system that can adjust the side mirrors and the room mirror to an optimal location automatically. The system detects a pair of pupils and a pair of nostrils, measures the 3-D coordinates of the driver's pupils, determines the optimal position angle of each mirror, and rotates them to target position. By using an infrared light source, the system can detect the driver's pupils whether it is daytime or nighttime. A stereo vision system measures the location of a pair of pupils. The robustness of the technique is demonstrated by a real-time implementation, which was run at 12 frames/sec, using images of resolution 320×240 ×8 bits.

This system can make up for the weak points of previous mirror adjustment systems and adjust side mirrors and room mirror automatically and rapidly using a simple interface regardless of driver replacement and posture at any time. The system has been tested successfully for 20 drivers, and it has proven to be very useful. The system is inexpensive and very compact, and we are confident that this method would be an appropriate mirror adjustment system for an intelligent vehicle. Future extensions of this work will be to integrate it with a driver drowsiness and carelessness detection system and a voice recognition system to make it a more convenient system.

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