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Tracking Telescope Aiming Point for Bioptic Driving Surveillance

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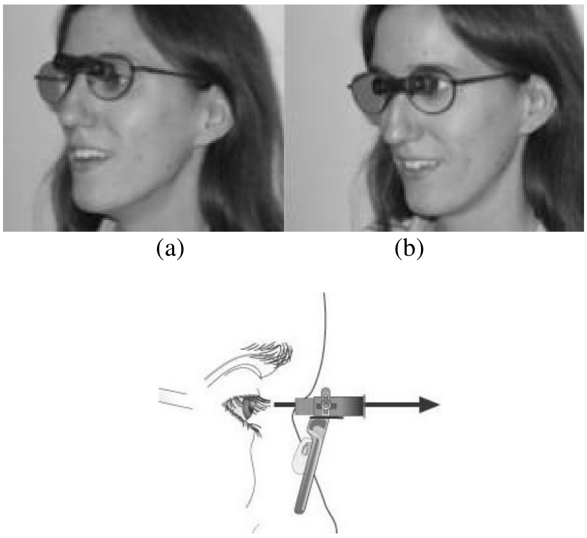
Abstract - *Bioptic telescope is a visual aid used by some people with impaired vision for driving and to qualify for licensing. Data on how and when bioptic drivers use the telescope and what they look at with it are important in bioptic driving studies. A video-based technique to track bioptic drivers' spectacle frames, which represent telescope aiming point, is presented in this paper. With three retro-reflective markers pasted on the bioptic spectacles frame, aiming point is determined from the angles formed by the three markers. Telescope aiming points projected on a scene camera image is calculated by means of interpolation based on a novel calibration method in which a laser pointer is mounted on the spectacle frame. A large number of calibration points are sampled automatically when the driver scans across the scene. Preliminary experiment demonstrated that the average error over a 65°×48° field was only 0.89 degree.*

Keywords: Bioptic driving, In-car camera system, Tracking, Telescope aiming point.

1 Introduction

The spectacle-mounted bioptic telescopes were introduced in the early 1950s as a visual aid for people with impaired vision (Figure 1) and have been used as driving aid since the 1960s. The magnification provided by the telescope compensates for reduced visual acuity. Currently, people with moderate impaired vision can drive with bioptic telescope in 38 US states [1]. Most of the time the users view and scan the environment through the carrier spectacle lenses, with an unrestricted field of vision (Figure 1a). They spot intermittently through the telescope, achieved by a slight downward tilt of the head (Figure 1b) to read road signs, determine the status of traffic lights, or scan ahead for road hazards. At this point, the pupil is aligned with the tube of telescope (Figure 1c). A brief examination (1 to 2 sec.) through the telescope provides the user with the required high-resolution information needed to recognize the details.

Whether the use of bioptic telescopes results in better (or worse) driving performance remains controversial [2]. It is not known whether accidents of bioptic drivers occurred when looking through narrow field of the telescope (which might obscure relevant traffic), or occurred because of failure to look through the telescope (which might result in poor perception of important traffic sign or other detailed information). Collecting data on what bioptic drivers view through the telescope in actual daily driving activities is crucial to find answers to these questions in bioptic driving studies [3]. Estimation of telescope aiming point may help with such data collection.


(a) (b)

(c)

Figure 1 Bioptic telescope used for driving. (a) Most of the time the wearer views through the carrier lens (under the telescope) without any effect of the telescope. (b) With a slight downward tilt of the head, the telescope is brought into the line of sight, enabling a magnified view of the object of interest. (c) The line of sight and tube of telescope are aligned when driver look through telescope. *(Figure from http://www.biopticdriving. org)*

Many video-based head tracking techniques have been developed [4-8], typically based on a head or face model determined from facial features. Facial features extraction is a crucial step in these methods, but it is hard to extract facial features under varying illumination conditions, and the extraction can be easily affected by expressions, for example laughing, talking, crying, as well as change of hair or whiskers style, or wearing spectacles etc. Therefore there is no effective solution which can be applied to unconditioned scenarios. Instead of tracking facial features, fiducial marker tracking is used in some applications [9]. In spite of possible inconvenience and restriction imposed by the use of fiducial markers, such tracking methods are usually more robust in real world situations where illumination and shading may dramatically change. We therefore use infrared retro-reflectors markers in this study.

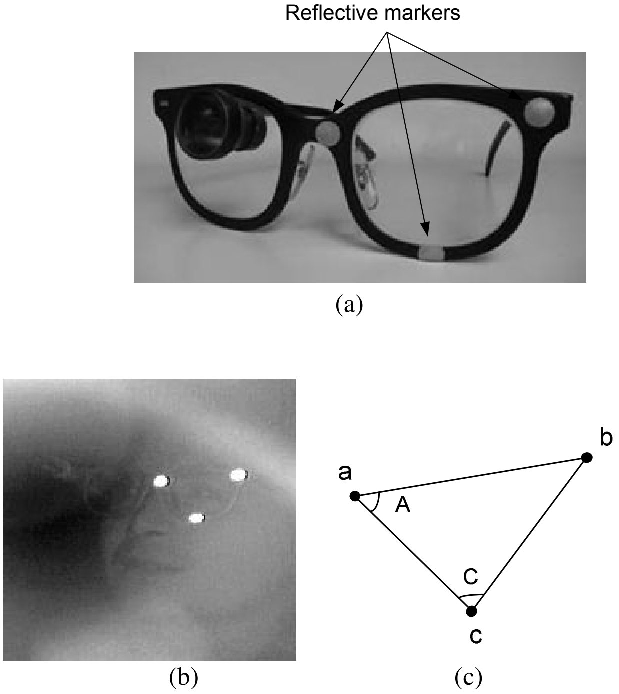
Head position calculation methods include photogrammetry, interpolation, and neural network. Unlike model-based methods that extract face and eye features, appearance-based methods treat an image as point in a high-dimensional space. These methods usually use linear interpolation [10] or neural network [11]. In our application, we only need to solve for head yaw and pitch associated with the 2-D scene images that usually are of highly distorted due to the use of wide field cameras. For this situation direct interpolation based on scene images provides an easier solution.

In our bioptic driving application head tracking is actually achieved by tracking the frame of bioptic spectacles. The spectacle frame tracking provides information about head movement and aiming point through the telescope. Frame shifting and sliding on the nose can be tolerated when we examine the head movement. The aiming point through the telescope needs to be precise, but it is not affected by the frame sliding because the telescope aiming point is only associated with the frame but not the head. We define the aiming point as the intersection point between the line of sight through the telescope tube center and the scene image plane. Note each pixel of the scene camera image corresponds to a direction of the field-of-view of telescope.

2 In-car head movement recording

We developed an in-car recording system of bioptic driving behaviors that is comprised of a mobile DVR system recording multiple video channels including road scene image and head image (Figure 2) in addition to various other car and road parameters. There are three cameras in the system. A wide field camera is mounted in the middle of windshield in front of the rearview mirror for the traffic scene, a band-pass infrared camera is mounted on the driver's side of the windshield for telescope aiming point tracking, and a third camera is mounted on the right side of the windshield to enable monitoring the driver's head and body behaviors by human reviewers. This third camera is not used for telescope aiming tracking in this paper.

Figure 2 The digital in-car surveillance system is comprised of one scene camera aimed at the road ahead and two cameras aimed at the driver.



(a)

(b) (c)

Figure 3 (a) Reflective markers mounted on the bioptic spectacles. (b) Infrared image of a bioptic driver's head showing the high contrast of the reflective markers. (c) Head yaw and pitch can be represented by the shape of the triangle formed by the markers. Specifically we used angles A and C to represent the telescope aiming point.

In order to acquire stable video images in the real world driving situations, where light level changes dramatically, we are using a near-IR camera with 890nm band-pass filter to capture videos of the driver's frontal head view. Three retro-reflective markers were pasted on the driver's bioptic spectacle frame (Figure 3a). These reflectors are illuminated by IR LEDs mounted on the camera box. This imaging system suppresses changes in the ambient light. The near-IR illumination is not visible to the driver and therefore does not interfere with the driving. The infrared image of a bioptic driver's head with reflective markers is shown in Figure3b. The three markers in such IR images can be detected robustly. The telescope aiming point position is represented by the triangle formed by the three markers (Figure 3c). The geometric shape is not sensitive to lateral head movement, but it changes with head yaw (left-right) and pitch (up-down). Small head lateral shift (e.g. 5cm) can be ignored relative to the large distance from the head to the scene plane (e.g. 500cm or much more).

3 Telescope aiming point estimation

An estimation method of aiming point based on two internal angles of the marker triangle, A and C, is presented in this paper. Figure 4 illustrates the relationship between the different shapes of the marker triangle and 9 different telescope aiming points in the scene image. Based on the correspondence between multiple known aiming points and the values of angle pairs A and C for each point, the aiming point corresponding to a given angle pair (a, c) can be estimated by means of interpolation. Similar empirical interpolation approach is being used in many head or eye gaze tracking systems [10]. The advantages are that the analytic function of telescope aiming point is not required, and the distortion of scene image does not affect the correspondence.

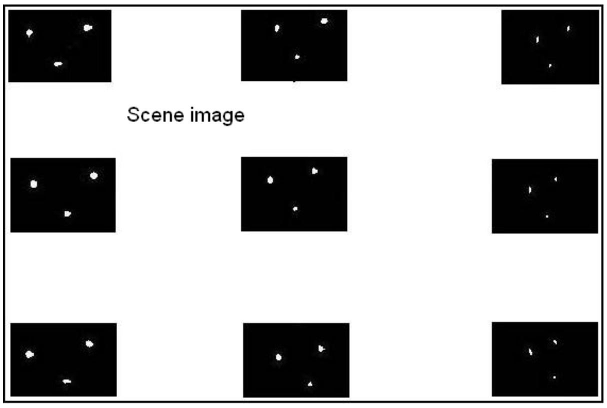


Figure 4 Relationship of telescope aiming point position on scene image to the marker triangle shape. Different triangle shapes correspond to different aiming points on scene image. The aiming point position is centered at the location of the triangle shown.

A calibration procedure establishes the correspondence mapping. Typically the person needs to aim at some indicated points that are called calibrators across the scene, while at the same time the features or markers are recorded. Usually, calibration is performed in indoor and the calibrators are on a screen.

In most calibration procedures of interpolation approaches, the number of calibrators is limited, e.g. 8, 9 or 16. Otherwise the calibration procedure becomes lengthy. For some complex system (with multi camera or multi IR illuminations), the calibrators number can be reduced to 2 or a "moving target" on screen [12]. However, in our application, the system in the car cannot be very complex, and limited calibrators are not sufficient to ensure accuracy for a wide range head movement, especially when the scene image is highly distorted. Below we propose a full-field calibration method in which large number of calibrators in high density can be easily obtained and applied to estimate the aiming point.

4 Full-field calibration with floating calibrators

The calibration method is illustrated in Figure 5. The IR head camera is placed to the left of the head and outside the range of aiming to be tracked (to avoid sign reversal). The IR camera captures images of three retro-reflective markers pasted on the bioptic glasses frame. A wide angle scene camera (65°×48°) is placed in front of the rear view mirror. A bright laser pointer is mounted on the telescope-side temple of the spectacles to project a light spot on a wall. During the calibration, the bioptic wearer freely moves his head to scan the scene field visible through the windshield. The videos of head and scene are recorded in sync. Thus, the light spot position on the scene image and markers position are paired for each video frame. In this scanning process, the projected laser spot in each video frame can serve as a calibrator. The advantage of the floating calibrators is that they are not fixed, and therefore the subject's accuracy in following instruction does not affect the calibration. Numerous calibrators located in almost every section of scene can be collected quickly. We used an optical flow method [13] to detect the laser light spot. An adaptive threshold method is used to detect the reflective markers.

Our calibration process does not require that the line of sight through the telescope is coinciding with the light spot in the scene. The angular offset of the light spot from the heading direction can be approximated as a constant across the scene field. The offset can be determined by scene camera parameter or by a single point calibration, and then be compensated.

Because it is the spectacle frame that is tracked, the full-field calibration can be completed by any person when the recording system is set up. For other subjects, it is a calibration free tracking system.

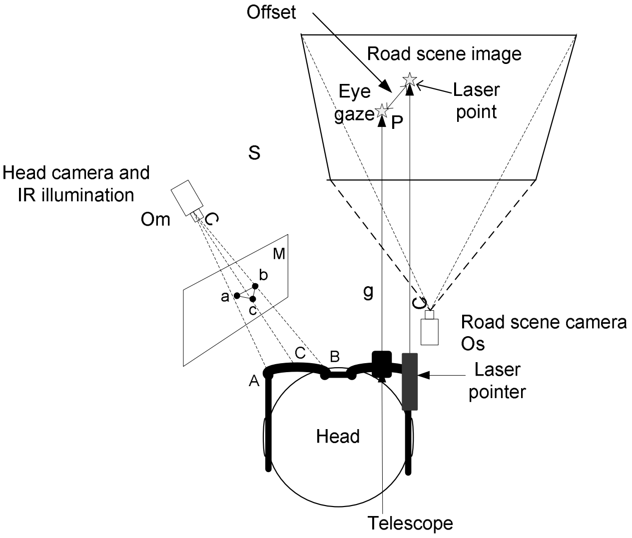


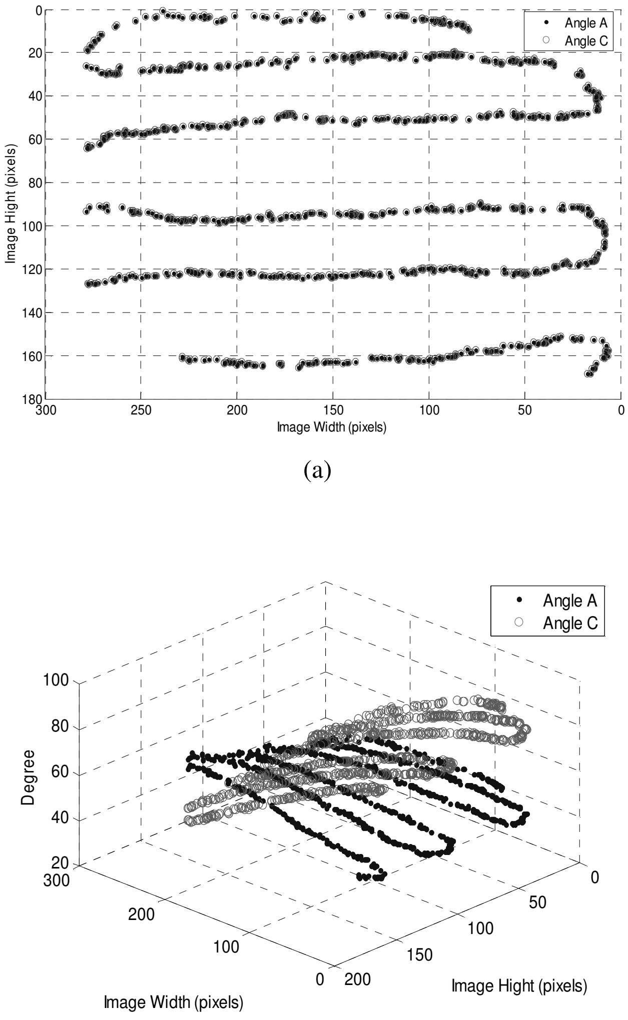
Figure 5 Illustration of full-field calibration with floating calibrators. The laser light spot on the scene image serves as the calibrator. When the person scan the full field by moving head, spot follow the moving and a large number of calibrators can be obtained.

5 Verification experiment

An experiment was conducted to verify the proposed methods. During the calibration, a subject freely moved his head to scan the scene field so that the laser light spot moved across the full field. In order to simplify the detection of the laser light spot, the laser spot was projected on a white wall in a garage.

Figure 6a show the trajectory of the laser light spot on the scene image during this full-filed calibration. The values of angle A and C measured for each of those light spots are shown in Figure 6b.

Based on the data of those floating calibrators, the coordinates (X, Y) of every telescope aiming point in the scene can be estimated by interpolation. This interpolation approach requires that the mapping between the shape of the triangle formed by the markers and the telescope aiming point is unique and that it behaves smoothly locally. This unique mapping will be proved in our future work. Figure 7a shows the results of such a interpolation. Note the same surface profile as in Figure 6b. To calculate telescope aiming point from pair angle A and C, an interpolation from angle pair to coordinates (X, Y) is used (see Figure 7b).

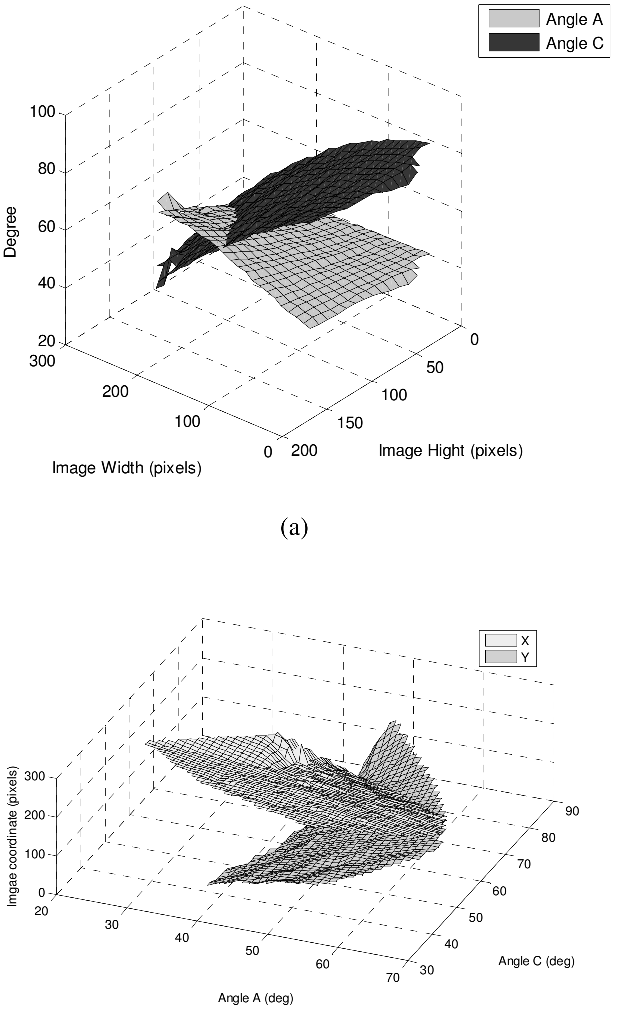


(a)

(b)

Figure 6 (a) Trajectory of laser light spot measured by the scene camera during the full-field calibration. (b) Angle pair A and C as functions of coordinates of light spots for every laser spot location measured.

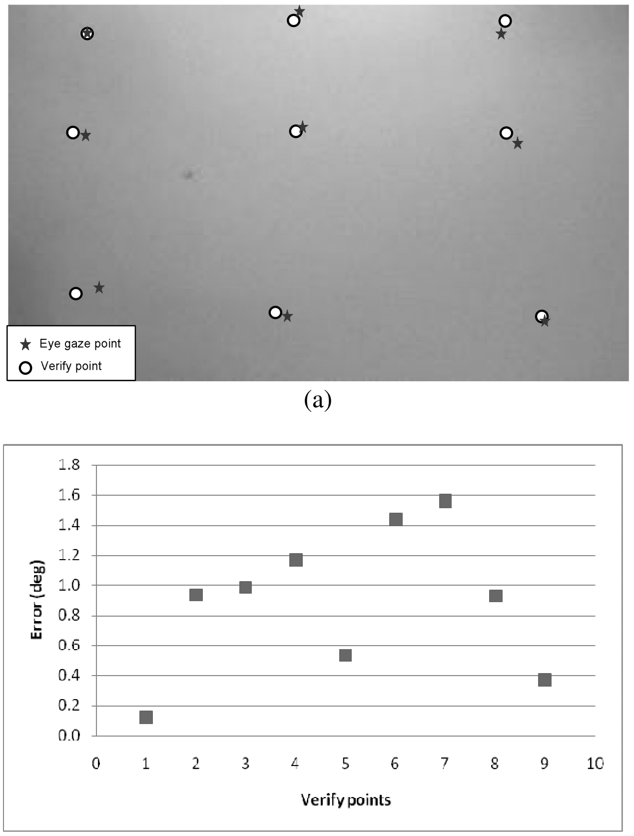
After the full-field calibration, we placed 9 stickers (circles in Figure 8a) on the wall at arbitrary locations to test the accuracy of telescope aiming point estimation. The subject looked at these points through the telescope centering the sticker in the field-of-view of the telescope. The markers were recorded for each location and the results computed from the shape of the marker triangles are shown as red stars in Figure 8a. The computed errors for each sticker location are shown in Figure 8b. The maximum error of the 9 points is 1.56 degree, the minimum error is 0.12 degree, and the average error is 0.89 degree. These errors may include random alignment error of the subject, i.e. he did not always look through the telescope center exactly. The largest error at point 7 is probably due to the lack of calibrators at the lowerleft corner. In this experiment, the size of head and scene video image is 350×240 pixels, and the field of view of scene camera is 65°×48°.



(a)

(b)

Figure 7 Projection relationships between telescope aiming point and angle pair (A, C). (a) Each aiming point (X, Y) on scene image corresponds to a unique pair of angle A and C. (b) Aiming point (X, Y) can be determined according to angle A and C (same data as in (a)).



(a)

(b)

Figure 8 Verification of telescope aiming point tracking. (a) 9 verification points in the scene image (circles) and tracking results (stars). (b) Tracking errors for the 9 points. The average of error is 0.89 degree.

6 Conclusions

Methods for wide-range head tracking is presented in this paper, including a telescope aiming point estimation method based on geometric shape of triangle and a full-field calibration method with floating calibrators. The accuracy of this tracking method meets the needs of bioptic driving studies. Our telescope aiming point tracking approach has several advantages. The system only need single camera to track telescope aiming points in real world driving environment and the cameras calibration for wide road scene is avoided. The system is calibration target free and the bioptic wearer does not need to follow any calibrators and the head is allowed to move freely. The system is robust against illumination change. These techniques are developed for our bioptic driving studies, but they can be applied in many other real world applications. Our calibration can be easily performed in outdoor and result in high accuracy. Because the telescope aiming points are projected on the scene image, image distortion, which usually accompanies wide-angle scene cameras, does not affect the accuracy. These advantages make our system suitable for driving behavior studies.

7 Acknowledgement

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