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Detection of the gaze direction of a driver using the time-varying image processing

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Abstract

To realize driving support systems friendly to drivers, it is important to detect the driver states (consciousness degradation, inattention etc.). This paper describes the development of a technique to detect the gaze direction of a driver during driving by the time-varying image processing. In this method, the facial direction and the gaze direction can be detected separately. The verification experiments proved that the developed method is applicable for the detection of inattention.

1. Introduction

Driving support systems are the most popular among many ITS systems. Examples of such systems include distance detection systems for vehicles ahead and lane departure detection systems [1, 2]. These systems give warning information depending on the urgency level. To realize driving support systems excellent in human interface, it is essential to change the method or the timing to give warning information depending on the driver states [3–5].

This paper describes the detection technique of the gaze direction that has been developed to detect inattention of a driver during driving among driver states. The eye areas are extracted and tracked from the facial images captured by a camera installed in an instrument panel. The facial direction and the gaze direction are detected separately from the extracted eye areas. It is also shown from verification experiments that this method is applicable to the inattention detection. Studies concerning detection of the gaze direction have been performed mostly as a part of human interface studies or as one of the display visibility evaluation methods. Studies of this kind for inattention detection are few [5–8]. This paper describes the above-mentioned contents in detail.

2. Driver status monitor

2.1. Role of driver status monitor

Driver status monitor detects degradation of consciousness or attention of a driver during driving, and the objects to be detected are drowsiness, inattention, excessive concentration through cellular phone use, intoxication or drugs, fatigue and so on [4]. The detection object of the developed driver status monitor is drowsiness and inattention.

Fig. 1 shows the role of the driver status monitor. In this system, the method or the timing for offering information to a driver is changed according to the level of the consciousness or the attention of a driver, and the media or its method to offer information is changed according to assent or urgency level of the information. The purpose of this study is to realize a system that wins driver's confidence by the method mentioned above.

This system detects drowsiness from the change in the duration of eye closure during blinking of a driver and inattention from the change in the gaze direction. This paper describes the detection method of the gaze direction for detecting inattention.

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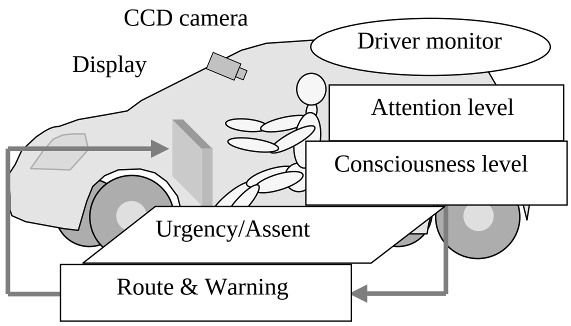

Fig. 1. The role of driver status monitor.

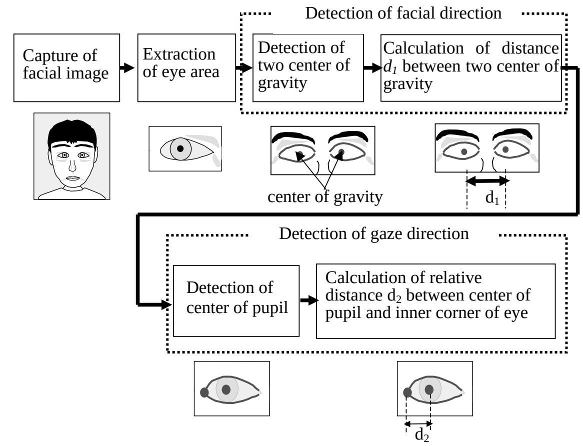

Fig. 2. Flow chart for detection of gaze direction.

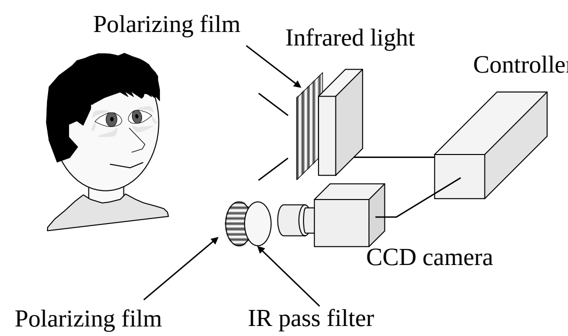

Fig. 3. Composition of image capture part.

2.2. *Technical problems in detecting gaze direction*

The technical problems in detecting the gaze direction of a driver during driving are the following: (1) a capturing method robust against the illumination changes; (2) an image capture part that enables capturing an image of a driver with glasses or sunglasses; (3) image processing to be able to deal with the movement of face or eyes; (4) separated detection of facial direction and gaze direction for detecting inattention.

An example of problem (1) includes the illumination changes that vary widely from low illumination condition at night up to exposure to direct sunlight, and examples of problem (2) include positive reflection from the surface of glasses or capture of the eye of a driver with sunglasses. Both of them are problems of the capturing method. Problems (3) and (4) are about image processing and recognition, and therefore it is essential to develop a method for tracking and recognizing an object by the time-varying image processing.

3. Detection of gaze direction

The eye area is extracted from the facial images obtained by a CCD camera installed in the instrument panel, and then gaze direction is calculated from the eyeball movement.

Fig. 2 shows the whole flow chart for detection of gaze direction. In the detection of gaze direction, it is essential to detect facial direction and gaze direction separately. The reason is that when a driver turns 30° to the left and the eyeball turns 30° to the right, the person continues to look to the front. Therefore the center of gravity of left eye and that of right eye are detected from the extracted eye area, and facial direction is detected from the distance d_1 between the two centers of gravity. Next the center of pupil and inner corner of eye are detected, and the gaze direction is detected from the relative distance d_2 between them.

3.1. *Method for capturing image*

Fig. 3 shows the composition of the image capture system utilizing the pulsed infrared light projection method that is adopted to solve the above-mentioned technical problem [5]. In this method, because a pulsed infrared light is projected only for the capturing period, it is able to capture facial images stably independent of the change in surrounding illumination conditions. To prevent positive reflection from the surface of glasses, polarizing films with a polarization angle of 90° are set in front of the pulsed light source and the camera.

Fig. 4 shows examples of facial images captured by this method along with images captured by a conventional method (conventional CCD camera) for reference. This method enables us to obtain stable with detailed information from low illumination conditions at night up to high illumination conditions in direct sunlight.

3.2. *Detection method for gaze direction*

3.2.1. *Extraction of eye areas*

Fig. 5 shows the flow chart for extracting automatically eye areas from obtained facial images. Candidates for the eye areas are segmented from the captured facial

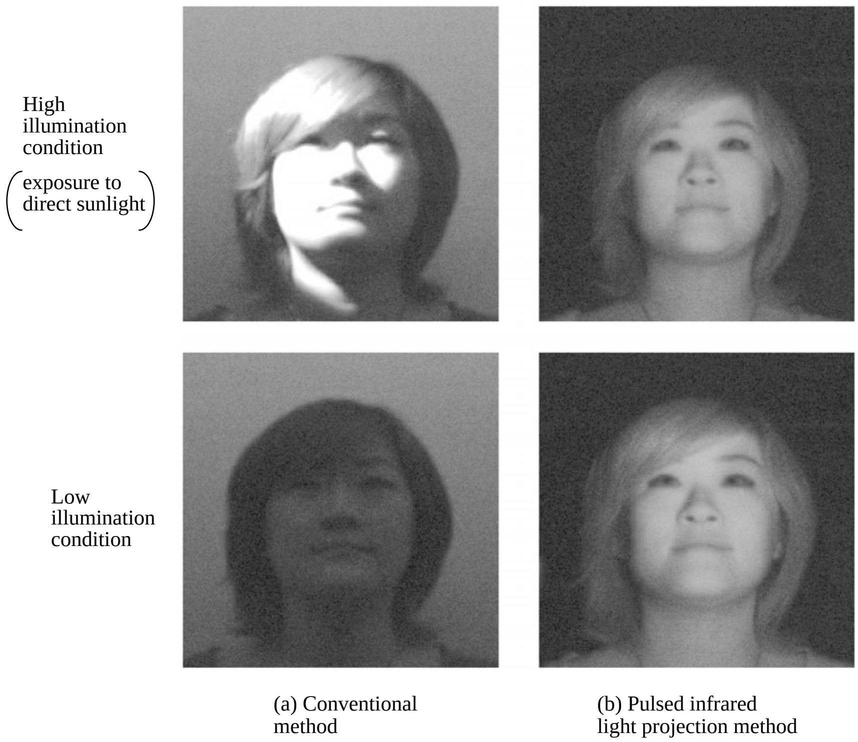

Fig. 4. Examples of captured images.

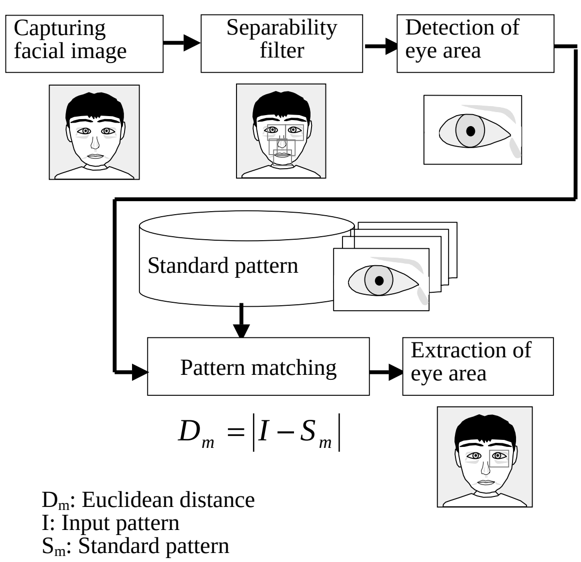

Fig. 5. Flow chart of eye area extraction.

images using a separability filter. The degree of similarity between the segmented candidate for the eye area and the standard pattern of the eye area on subspace made in advance is calculated.

The standard patterns of the eye areas used here are made in advance for ten subjects as follows: the images of the eye areas are made for the facial direction from left 40° to right 40° and from up 30° to down 30°, and after pre-processing the images standard patterns are made by KL expansion in each classes of up and down or right and left. Here, KL expansion is a method used as a dimensionality reduction method for pattern recognition, and is an expansion for approximating a pattern set. This method is utilized to find the eye area efficiently by keeping features of original image and reducing dimensionality as much as possible.

Here, Euclidean distance on the feature space is used to calculate the degree of similarity between the produced standard pattern and the candidate of the eye area. After candidates of the eye areas segmented by separability filter are projected on the subspace of each class, Euclidean distance between the images of the eye areas projected on the subspace in advance and the projected candidate are compared, and then the eye area is extracted as the one that has the minimum distance.

3.2.2. Detection of facial direction

Fig. 6 shows the principle of the detection of facial direction. The direction and the angle of a face are calculated from the center of gravity of left eye, that of right eye and the middle point of nose. First, the distance d_{eye} between the center of gravity of left eye and that of right eye is calculated when the facial angle is zero (looking to the front), and then the distance d'_{eye} between the center of gravity of left eye and that of right eye is calculated in the case of an arbitrary facial angle θ. The facial angle θ is obtained as

$$\theta = \cos^{1}(d'_{eye}/d_{eye}). \quad (1)$$

Here, the facial direction is detected from the distance D_{right} between the center of gravity of right eye and the middle point of the nose, and the distance D_{left} between the center of gravity of left eye and the middle point of the nose. For example, if $D_{\mathrm{right}} > D_{\mathrm{left}}$, the face looks to the left, and if $D_{\mathrm{right}} < D_{\mathrm{left}}$, the face looks to the right. Here, nostrils are detected by separability filter and the center of both nostrils is set as the middle point of the nose.

Fig. 7 shows examples of detected facial direction in the case of right 20° and left 20° respectively. It can be seen from these results that the facial angle is obtained from the detected right and left eyes and also the nose using the above-mentioned method.

3.2.3. Detection of gaze direction

Fig. 8 shows the processing flow of detection of gaze direction. The positions of the pupil and the inner corner of the eye are detected from the extracted image of the eye area, and then the gaze direction is calculated from the relative distance between the two positions.

Fig. 9 shows examples of detected gaze direction. Fig. 9(1) shows the detected gaze direction when the direction of eye ball is fixed to the front toward the facial direction and only the facial direction is moved, and Fig. 9(2) shows the detected gaze direction when the facial direction is fixed to the front and only the eye ball is moved. It can be seen from Fig. 9(1) that the position of inner corner of the eye is detected properly independent of facial direction, and from Fig. 9(2) that the center position of the pupil and the position of the inner corner of the eye are detected correctly when the eye looks in each direction.

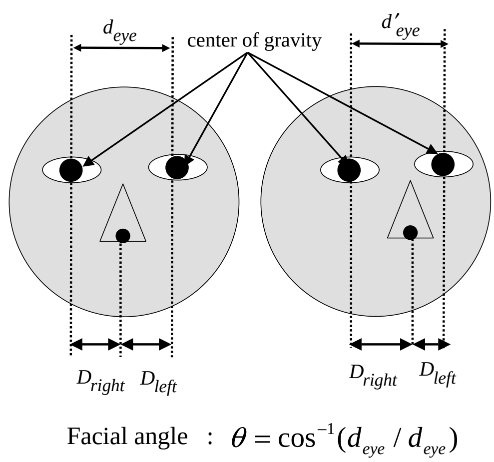

Fig. 6. Principle of detection of facial direction.

4. Verification experiments

The following experiments were conducted to verify the effectiveness of the developed detection method of gaze direction by the time-varying image processing.

Verification experiments are as follows:

1. experiment 1: extraction of eye area,
2. experiment 2: measurement of gaze direction.

Experiment 1 studied whether the eye areas, which are essential to detect gaze direction could be extracted stably from captured facial images, and in

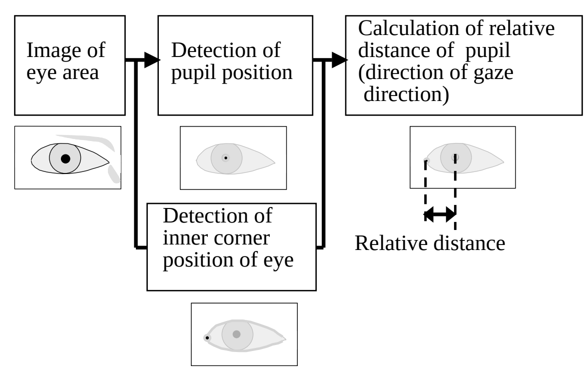

Fig. 8. Processing flow of detection of gaze direction.

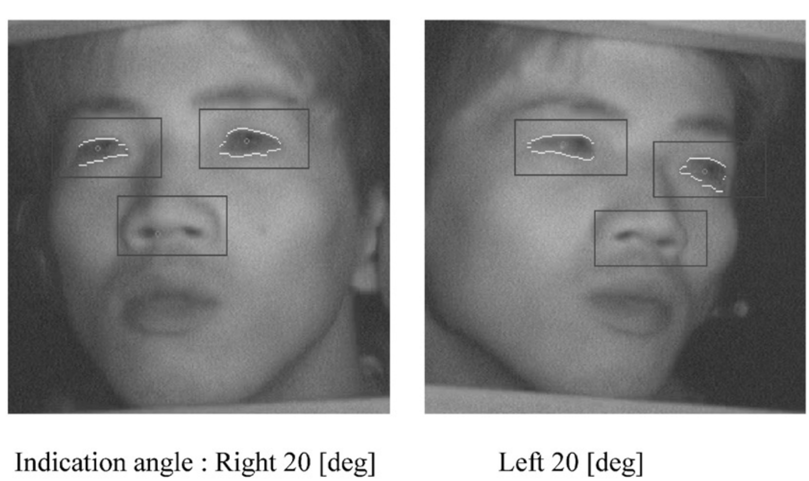

Fig. 7. Examples of detected facial direction.

experiment 2 measurement accuracy of gaze detection was measured.

4.1. *Experiment 1: extraction of eye area*

4.1.1. *Experimental method*

The experiment in extraction of eye area was carried out in a laboratory using the experimental set-up shown in Fig. 10. The subjects were ten men (all subjects had standard patterns of eye areas) in their twenties who were not wearing glasses. The subjects were requested to watch the light spot on the screen by moving the facial direction every 10° from left 40° to right 40°, and whether the eye area could be extracted at each spot was verified. The standard patterns of eye areas for the experiment are produced from the patterns of eye areas at this time.

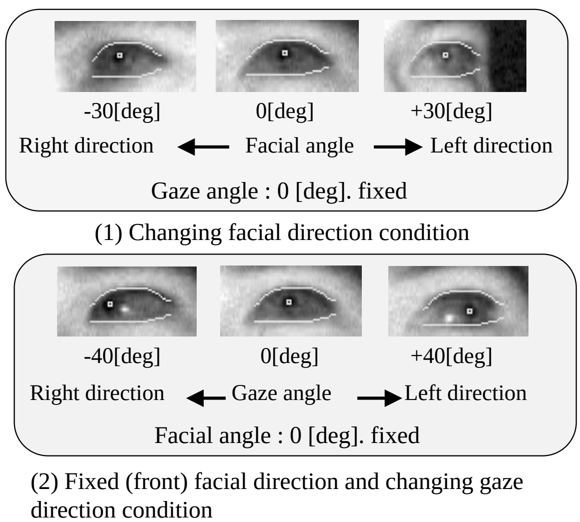

Fig. 9. Examples of detected gaze directions.

4.1.2. *Experimental results*

Table 1 shows the experimental results of extraction of eye areas for 10 subjects. In this experiment, "the success in segmenting the eye area" indicates that eye areas which could be tracked in the latter tracking processing of eye area can be extracted.

As shown in Table 1, eye areas are correctly extracted for the subjects whose standard patterns of eye areas were made in advance except for two subjects at left 30°.

The reason why eye areas were not extracted correctly is that areas like eyebrow etc. were mis-recognized as eye areas, because the number of standard patterns was not enough.

4.2. *Experiment 2: measurement of gaze direction*

4.2.1. *Experimental method*

This experiment was performed to obtain measurement accuracy of the developed detection method of gaze direction. The subjects were four men in their twenties who were not wearing glasses. The experiment was carried out using the experimental set-up shown in Fig. 11. In the experiment, the head of the subject was

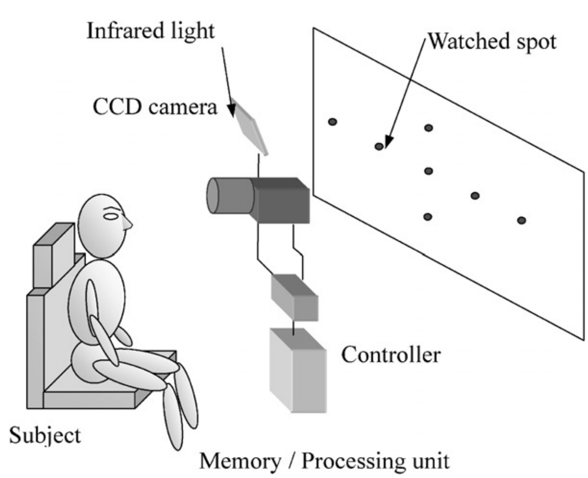

Fig. 10. Experimental set-up for extraction of eye area.

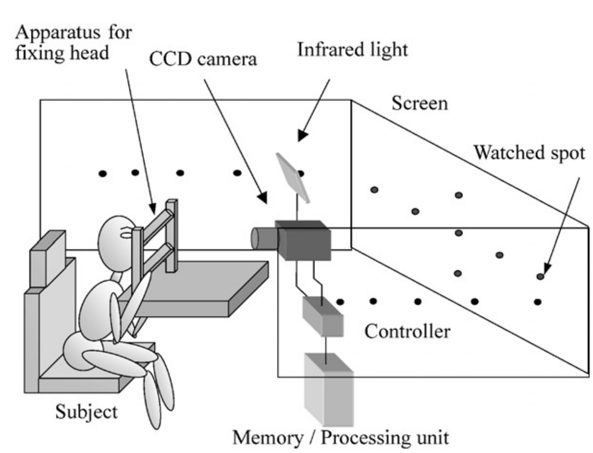

Fig. 11. Experimental set-up for extraction of gaze direction.

Table 1
Experimental results of extraction of eye area

	Front (deg)	Left (deg)			Right (deg)			Up (deg)			Down (deg)		
	0	10	20	30	10	20	30	10	20	30	10	20	30
Extraction rate (%)	100	100	100	80	100	100	100	100	100	100	100	100	100

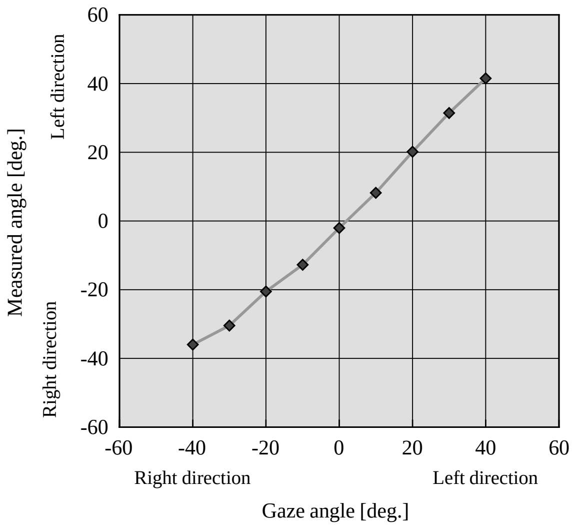

Fig. 12. Example of experimental result of gaze direction (facial direction: 0°).

fixed by an apparatus for fixing the head to measure the gaze direction at a settled facial angle.

The subjects were requested to watch the light spot on the screen by the instructions of the experimenter and to move the eyeball every 10° from left 40° to right 40°, and the gaze angle at each time was measured. The true value is set as the fixed angle and the measurement value is set as the one measured by this system. In the same way, the gaze angle was measured when facial direction was changed every 10° from left 30° to right 30°.

4.2.2. Experimental results

Fig. 12 shows the measured angles of a subject whose facial direction was fixed at the front and only gaze direction was changed from left 40° to right 40°. The gaze angle was measured properly from right 40° to left 40°, and the measurement accuracy is $\pm 1.6°$ in this range. The measurement accuracy of the other three subjects is $\pm 3.5°$, $\pm 2.7°$, and $\pm 1.4°$ respectively in the same measurement range, and it can be said that good measurement accuracy is obtained.

Fig. 13 shows the measured angles of gaze direction at each facial direction for a subject. The average of measurement error at the facial angle from left 30° to right 30° is $\pm 4.21°$, $\pm 2.86°$, $\pm 2.74°$, $\pm 2.68°$, $\pm 2.77°$, $\pm 1.35°$, and $\pm 3.97°$ respectively. The obtained gaze direction was within the error range as indicated by bold lines at each facial direction. These results prove that gaze direction can be measured properly.

Table 2 shows the average accuracy of measured angles at a fixed facial angle. Each value means the average of the values when gaze direction is changed from left 40° to right 40° at a fixed facial angle (from left 30° to right 30°). Although the measurement accuracy deteriorates slightly when the facial angle becomes large,

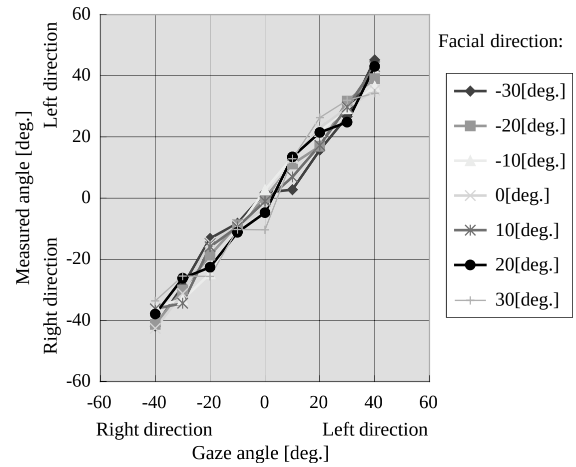

Fig. 13. Example of experimental result of gaze direction (facial direction: left 30° ~ right 30°).

Table 2
Experimental results for all subjects

Facial angle (deg)	Accuracy (deg.)			
	Subject 1	Subject 2	Subject 3	Subject 4
30	2.83	12.93	4.21	4.15
20	3.71	5.57	2.86	3.85
10	4.51	4.98	2.74	3.83
0	1.62	3.51	2.68	1.40
−10	1.96	3.53	2.77	4.21
−20	2.08	5.00	1.35	3.88
−30	3.02	4.65	3.97	4.31

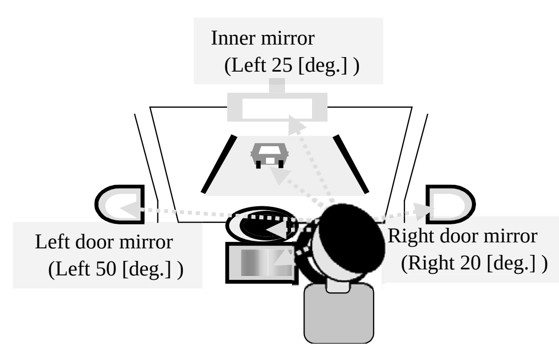

Fig. 14. Example of gaze direction while watching right and left door mirrors and inner mirror of a sedan.

it can be said that good measurement accuracy ± 3.8 deg. is obtained on the whole.

4.3. Examination of the application to the inattention detection

Inattention means that the gaze is off from ahead watching for a moment during driving and some difficulties arise in safe driving. Therefore to apply this detection system of the gaze direction to the inattention detection, it is necessary to be able to measure the detection range of gaze of a subject, its accuracy and staying time of gaze about the system.

Fig. 14 shows the typical angles viewed from the front when a driver sitting on the right driving seat of a sedan turns the face to the front and watches the right door mirror, the left door mirror and the inner mirror. When a driver watches the inner mirror in a state of the face fixed to the front, the gaze direction becomes about left 25°, in the case of watching the right door mirror it becomes about right 20°, and also in the case of watching the left door mirror it becomes about left 50°. Though these are the values when the face is fixed to the front, a driver compensates the movement of gaze by shifting the facial direction in actual driving. Therefore, this detection system of the gaze direction is applicable to the inattention detection from the measurement range and accuracy view.

Considering the staying time of the gaze, the time that one can leave the gaze from the front is within 1.5 s, and a subject is allowed to repeat this action up to two or three times [9]. Accordingly, as the watching time at one point is within 1.5 s per one action and this action is limited within three times, we make this time (4.5 s) as one indication of the staying time.

To make the detection of inattention possible, it is necessary to be able to measure the gaze direction and its staying time mentioned above. Although there is a little room for improvement in the detection range and accuracy, it is shown that the detection system of the gaze direction presented in this paper is applicable well to the inattention detection.

5. Conclusions

To realize a driving support system that has a human-friendly, superior human interface, it is essential to detect the driver states during driving. This paper has described the detection method of the gaze direction to detect the inattention that is one of the driver states. In this method, eye areas are extracted from the facial images captured by the image capture part installed in an instrument panel, and then facial direction and gaze direction are detected separately from the eye areas. The measurement accuracy for detecting facial direction and gaze direction was obtained by the experiments, and it was shown that this technique is effective to detect inattention during driving.

The subject for the future is to recognize the eye areas and to measure the gaze direction using the images captured by a camera installed in an inner mirror.

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