

ESTIMATION OF DRIVER INATTENTION TO FORWARD OBJECTS USING FACIAL DIRECTION WITH APPLICATION TO FORWARD COLLISION AVOIDANCE SYSTEMS

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Summary: In forward collision avoidance systems, warnings may be provided more effectively if the underlying timing is set earlier than normal when the driver's attention is not in the forward direction of the vehicle. In this regard, we determined the following driver characteristics: (1) the amount of horizontal facial rotation needed to keep track of a moving object in the driver's field of view increases significantly when the horizontal viewing angle of that target object exceeds 20 degrees, (2) when the driver's face is oriented in the forward direction, the horizontal angle of facial rotation falls within 15 degrees, and (3) the reaction time to warning lengthens in accordance with the increase in the horizontal viewing angle. In the context of forward collision warning systems, we have determined the difference in the distribution of the driver's horizontal facial rotation angle, for cases when the driver's attention was and was not directed to objects in the forward direction of the vehicle. Furthermore, we have measured the reaction time to warning when the driver's face was not directed forward. Last, our findings were successfully applied to issue the onset timing of a forward collision warning system.

INTRODUCTION

Driver perception error is recognized as a factor in a large proportion of automobile accidents. Driving support based on the state of driver attention or awareness is therefore regarded as an effective way of further reducing the number of accidents, rather than simply focusing on external conditions such as the distance to the preceding vehicle. Although errors in driver perception consist of various aspects, a significant proportion of automobile accidents are the result of extrinsic factors causing driver inattention to forward objects, such as glances toward a passenger, or distraction by outside scenery (Takubo, 2005). For this reason, if the vehicle is approaching a forward hazard while the driver's attention is not in that direction, providing early notification of the hazard is likely to be an effective safety measure. This paper describes the efforts to develop a system for estimating driver inattention to forward objects by detecting facial direction, which is considered to be comparatively easier to research than detecting the line of sight. It also describes an investigation into delays in driver reaction to warnings of inattention to forward objects, and the setting of an early warning timing when the vehicle is approaching a forward object.

RESEARCH APPROACH

Research into the extrinsic factors causing driver inattention to forward objects has already indicated that fixation point movement occurs frequently in the horizontal direction (Takubo, 2005). Consequently, this study focused on horizontal movement of the fixation point. In this

regard, the study closely followed the three steps described hereafter.

Relationship between eye movement and head rotational movement. Research has already shown that the range of comfortable eye movement is within 15° to the right and left sides (SAE J985 DEC2002). Beyond this range, fixation point movement accompanied by changes in facial direction become clear. The first step of this study was to verify the relationship between eye movements and facial direction when the fixation point moves horizontally. The purpose of this step was to examine the possibility of using facial direction to estimate driver inattention to forward objects.

Estimating inattention to forward objects using facial angle. Differences between two driver states corresponding respectively to when the driver's attention is and is not in the forward direction were examined, based on the facial angle distribution, to study how to differentiate the two states.

Warning reaction times when driver's attention is not in forward direction. Warning reaction times are likely to be slower when the driver's attention is not in the forward direction. For this reason, the reaction time between the driver hearing the warning and operating the brake pedal was examined when the driver's attention is not in the forward direction, and the possibility of setting the warning timing earlier was studied.

RELATIONSHIP BETWEEN EYE MOVEMENTS AND FACIAL DIRECTION

Method

A visual target was projected onto a screen in front of a test subject, whose eye movements and head horizontal rotational angle (i.e., facial angle) were then measured when the fixation point shifted from a position directly in front of the subject to the visual target. The subject's eye movements were measured using an eye mark recorder, and the facial angle was calculated by reading the position of a pointer attached to the subject's head using images taken by an overhead camera. The visual target and operation were selected in order to achieve natural fixation-point movement as similar as possible to that during driving. The visual target consisted of random two-digit numbers displayed at one-second intervals, and the subject was required to shift the fixation point from a position directly in front to the visual target after a signal, read the number, and then return it to the front. Ten human subjects aged between 24 and 52 years old participated in the experiment. The visual target was positioned as follows. Position directly in front of the subject: 0°; left and right: 5°, 10°, 15°, 20°, 30°, 40°, 50°, and 60°; vertical angle: 0°.

Experimental Results

Figure 1 shows an example of measurement results for eye movements and facial angle obtained at 20° on the right side. The stable angles after movement of the fixation point (θ_f and θ_e in Figure 1) were obtained from this data and transferred to Figure 2, which shows the average value for the 10 subjects at each visual target position. Since no difference was found between left and right, the values for both sides are shown collectively. These results show that when the horizontal angle to the visual target is more than 20°, the facial angle exceeds the eye movement,

and there is a clear tendency of facial movement by the subject. According to existing research, the fixation point distribution when the driver's attention is in the forward direction during urban driving is within approximately 20° (Inuzuka et al., 1991). Thus, there is a clear facial movement when the fixation point moves beyond this range in urban driving, which validates the possibility of using facial direction to estimate driver inattention to forward objects.

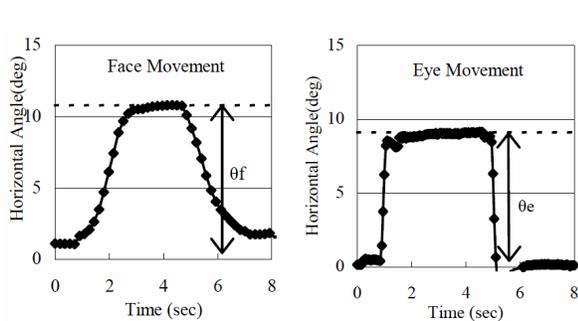


Figure 1. Examples of face and eye movements

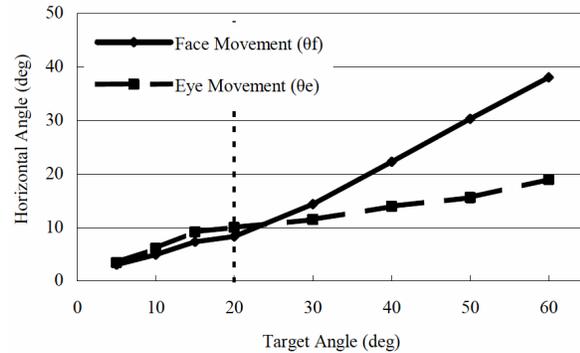


Figure 2. Horizontal angle of face and eye movements

ESTIMATING FORWARD INATTENTION USING FACIAL ANGLE

Method

As in the previously described experiment, 10 subjects participated, but their ages ranged between 20 and 56 years old. The subjects were asked to drive at approximately 50 km/h on a straight road and fix their attention on various visual targets based on instructions from the person conducting the test. The facial angle was calculated from images of the subject's face (Figure 3). In the same way as shown in Figure 1, the angle obtained was a stable value after movement of the fixation point. Several visual targets were used to move the driver's attention away from the forward direction. These visual targets were: a map shown on the in-vehicle display, the inner mirror, the outer door mirrors (left and right), and scenery on the side of the vehicle (left and right). The timing for returning the fixation point to the forward direction after shifting it to the visual target was left to the subject.



Figure 3. Image samples with different face angles

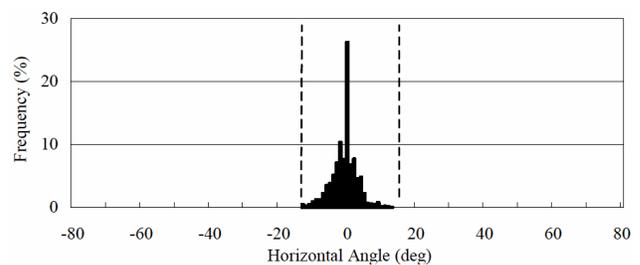


Figure 4. Horizontal angle of face movement with driver's attention in the forward direction

Experimental Results

Figure 4 shows the facial angle distribution when the driver's attention is in the forward direction.

It shows that at least 99% of the facial angles in this study are within a 15° range to the right and left. In contrast, when the driver’s attention is on the visual targets, it was found that the facial angle exceeds 15° for most of the targets, although angles at or below 15° were obtained for some particular targets in some cases (Figure 5). Consequently, when the facial angle is 15° or more, there is a higher possibility that the driver’s attention is not in the forward direction.

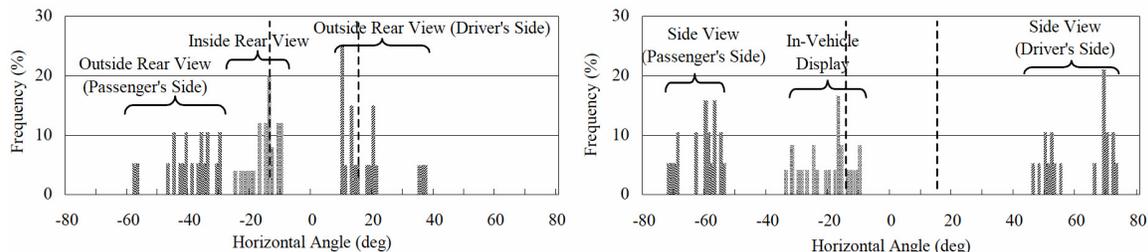


Figure 5. Horizontal angle of face movement with driver’s attention not in forward direction

WARNING REACTION TIMES DURING DRIVER’S INATTENTION

Method

Subjects were asked to drive at approximately 50 km/h on a straight road and instructed to fix their attention on various visual targets after the person conducting the test verified that the road ahead was safe. The subjects and visual targets were the same as those described in the facial angle experiments. While the driver’s attention was on the visual target, a warning was sounded accompanied by simultaneous illumination of a red warning LED lamp located on the hood of the driver’s vehicle. However, in some cases, the LED lamp was not illuminated when the warning sound was issued. The purpose of this LED lamp was to simulate the brake lamps of a preceding vehicle. The driver was instructed to operate the brake pedal if the LED lamp was illuminated, and the time between the auditory warning and brake pedal operation was measured. For comparison, the same kind of measurement was made with the driver’s attention in the forward direction. In this case, the LED lamp was switched randomly between red and no illumination, to study selective reaction of brake pedal operation to the warning sound.

Experimental Results

Figure 6 shows reaction times from issuing the warning sound to operating the brake pedal when the driver’s attention is on the visual target. It shows that the reaction time between the driver hearing the warning and operating the brake pedal is longer than when the driver’s attention is in the forward direction. Consequently, the warning may be issued earlier when the driver’s attention is not in the forward direction.

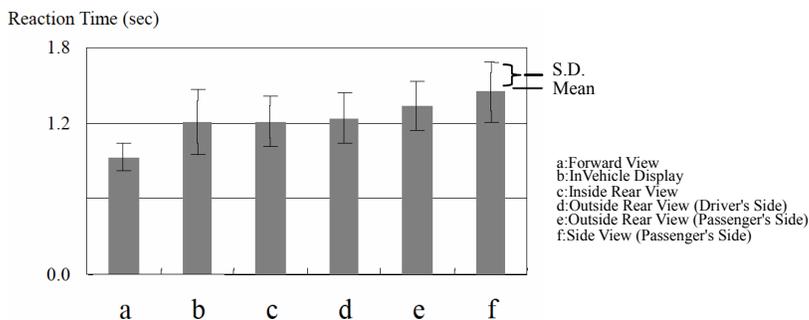


Figure 6. Reaction time to warning

DISCUSSION

Facial Angle when Driver’s Attention is Not in Forward Direction

In Figure 7, the overall facial angle data (see Figure 2) shows that there are individual differences in facial movement: from drivers with a large amount of facial movement to others with virtually none. Figure 8 shows the facial angle distribution when the horizontal angle to the visual target is within 20°, based on a fixation point distribution within 20° in urban driving (Inuzuka et al., 1991). These results indicate that most facial angles are within 15° (Figure 8). Accordingly, a facial angle of within 15° may be considered as an angle where the driver’s attention is in the forward direction.

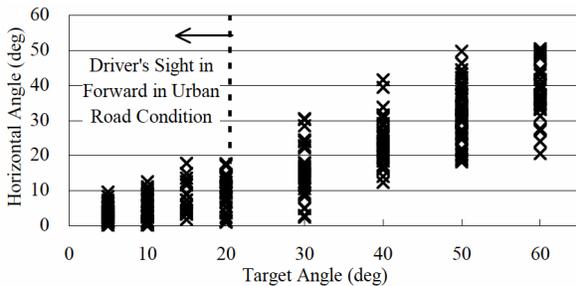


Figure 7. Horizontal angle of face movement

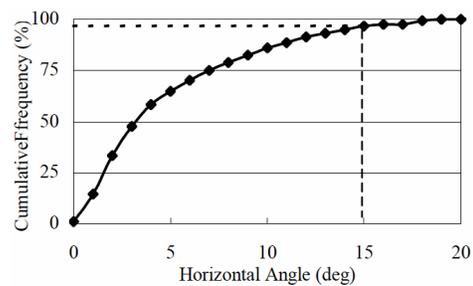


Figure 8. Distribution of face movement

Duration of Inattention when Driver’s Attention is Not in Forward Direction

The study examined the duration of forward direction inattention (also referred to as the “glance time”) when the driver’s attention was on a non-forward visual target. When the driver’s attention is on a visual target, the duration of forward direction inattention is defined as the period from the start of facial movement to the point of return (Figure 9), and the corresponding distribution is shown in Figure 10 (Nakagoshi et al., 2006). These results show that most periods of inattention last at least 1 second. Previous research has also revealed that the duration of inattention in rear-end collisions, in which lack of attention to the forward direction is a factor, exceeds 1 second in most cases (Takubo & Fujioka, 2003). Therefore, the danger of an accident is likely to increase if the facial angle exceeds 15° for an extended period of time.

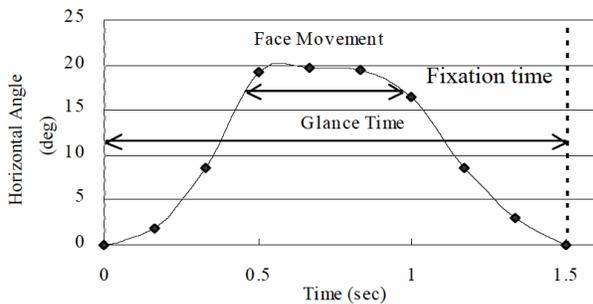


Figure 9. Definition of glance time using face movement

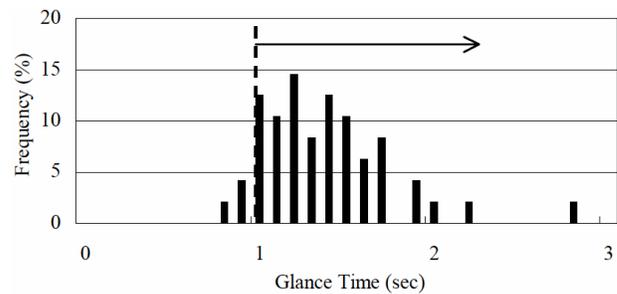


Figure 10. Distribution of glance time

Defining Forward Direction Inattention

Based on the results described above, it could be said that the driver’s attention is not in the forward direction if the facial angle exceeds 15°. If this state continues for an extended period,

there is a greater possibility that the vehicle will encounter a hazard in the forward direction, and reaction times to warnings of forward inattention will increase. Consequently, when the vehicle is approaching a forward hazard during an extended period of driver inattention to that direction, setting the warning timing earlier could be an effective safety measure. For this reason, in order to define the state of forward direction inattention from the facial angle, this study investigated the relationship between the fixation time and facial angle when the driver's attention is fixed on an object not in the forward direction (Figure 11).

These results show that the facial angle starts to exceed 15° after a fixation time of approximately 0.3 seconds, and then converges once more toward 15° beyond a fixation time of 1 second. It is thought that this is because drivers are aware that long periods of inattention are dangerous, which creates resistance to large facial movements. Consequently, forward direction inattention is defined as a state in which the facial angle exceeds 15° for at least 0.3 seconds, and the extent of inattention can be defined as large when the duration reaches 1.0 second or more.

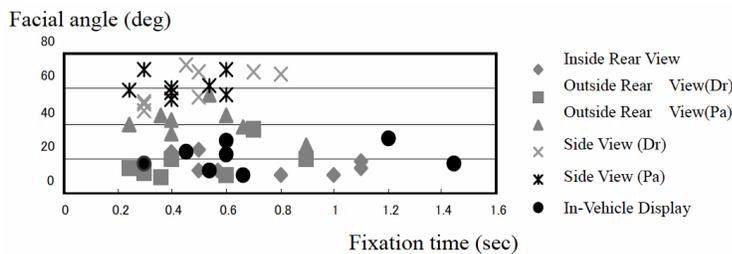


Figure 11. Relationship between fixation time and facial angle

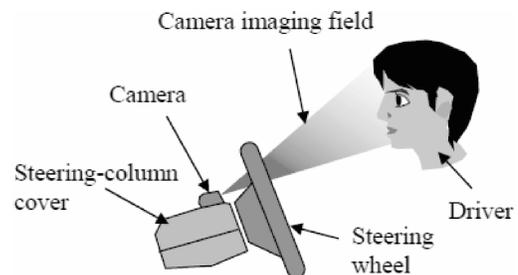


Figure 12. Facial direction detection camera

Application to Forward Collision Avoidance System

Application to the warnings in a forward collision avoidance system was studied based on the facial angle characteristics described above for the case when the driver's attention is not in the forward direction. The study considered detecting the facial angle by a camera monitoring the driver (Ohue et al., 2006; see Figure 12), and setting an early warning timing (Figures 13 and 14) when the vehicle approaches a forward hazard during an extended period of driver inattention to that direction (Hattori et al., 2006). The logic for early warning was set using the reaction time to warning (Figure 6) and the relationship between fixation time and facial angle (Figure 11).

CONCLUSIONS

Eye movements and facial direction were examined when the fixation point moves horizontally. It was found that fixation point movement accompanied by changes in facial direction increases when the fixation point range is exceeded in urban driving. As a result, it was confirmed that facial direction could be used to help estimate driver inattention to forward objects. Facial angles when the driver's attention is in the forward direction and not in the forward direction were analyzed during driving on a straight road. It was found that the driver is more likely to be inattentive to the forward direction when the facial angle exceeds 15°. Brake pedal reaction times to warnings of inattention to forward objects are slower when the driver's attention is not in the forward direction. Setting the warning timing earlier, therefore, could be an effective safety measure. As a result, an application of these results to the warning

timing of a forward collision avoidance system was studied.

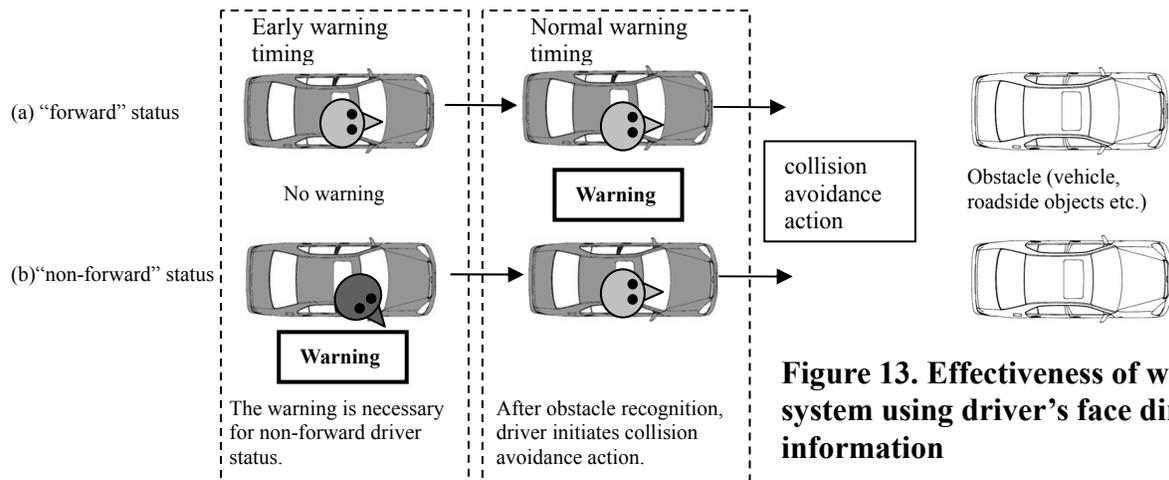


Figure 13. Effectiveness of warning system using driver's face direction information

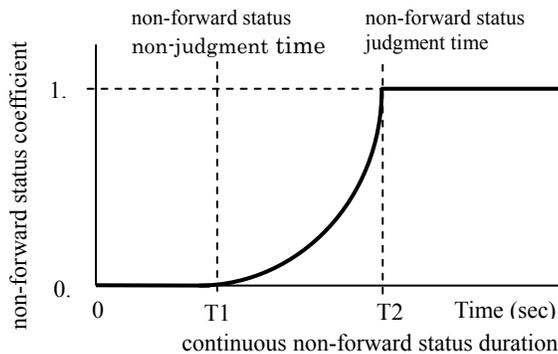


Figure 14. Driver's face direction non-forward status judgment function

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