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DEVELOPMENT OF DROWSINESS DETECTION SYSTEM

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Abstract: The development of technologies for preventing drowsiness at the wheel is a major challenge in the field of accident avoidance systems. Preventing drowsiness during driving requires a method for accurately detecting a decline in driver alertness and a method for alerting and refreshing the driver. As a detection method, the authors have developed a system that uses image processing technology to analyze images of the driver's face taken with a video camera. Diminished alertness is detected on the basis of the degree to which the driver's eyes are open or closed. This detection system provides a noncontact technique for judging various levels of driver alertness and facilitates early detection of a decline in alertness during driving.

1. Introduction

The growing number of traffic accident fatalities in Japan in recent years has become a problem of serious concern to society. Based on the results of accident analysis, the authors are engaged in research and development work on active safety systems that are intended to reduce the number of accidents causing death or injury. The key to driving safety and the prevention of accidents before they happen lies with the driver. For this reason, eliminating situations in which the driver is insecure is essential to accident prevention.

Accidents due to drowsiness at the wheel have a high fatality rate because of the marked decline in the driver's abilities of perception, recognition and vehicle control when sleepy. The prevention of such accidents is a major focus of effort in the field of active safety research.

Preventing accidents caused by drowsiness requires a technique for detecting sleepiness in a driver and a technique for arousing the driver from that sleepy condition. This paper describes a system that uses an image processing technique to recognize the open or closed state of the driver's eyes as a way of detecting drowsiness at the wheel. The results of various investigations are presented to show the effectiveness of this system in detecting a state of reduced alertness in the driver.

2. Drowsiness-Related Accidents

Drowsiness can be caused by various factors such as fatigue, lack of sleep and the use of medication. In addition, another factor that can be considered is the monotony of driving on expressways or in congested traffic.

The continued construction of highways and improvement of vehicle performance have made it possible for drivers to enjoy pleasant, comfortable motoring. On the other hand, drivers are more apt to operate their vehicles under monotonous driving conditions. This observation is proved by the findings of various surveys, which indicate that approximately 70% of the respondents said they have experienced drowsiness while driving.

Table 1 Techniques for Detecting Drowsiness

Detection Techniques		Description	Detection Accuracy	Practicality	Extendibility
Sensing of Human Physiological Phenomena	Physiological Signals	Detection by Changes in Brain Waves, Blinking, Heart Rate, Pulse Rate, Skin Electric Potential, etc.	◎	×	△
	Physical Reactions	Detection by Changes in Inclination Driver's Head, Sagging posture, Frequency at Which Eyes Close, Gripping force on Steering Wheel, etc.	◎	○	◎
Sensing of Driving Operation		Detection by Changes in Driving Operations (Steering, Accelerator, Braking, Shift Lever , etc.)	○	◎	×
Sensing of Vehicle Behavior		Detection by Changes in Vehicle Behavior (Speed, Lateral G, Yaw Rate, Lateral Position, etc.)	○	◎	×
Response of Driver		Detection by Periodic Request for Response	△	×	◎
Traveling Conditions		Detection by Measurement of Traveling Time and Conditions (Daytime or Nighttime, Speed, etc.)	×	○	◎

◎ : Very Good   ○ : Good   △ : Average   × : Poor

An examination of the situations when drowsiness occurred shows that approximately two-thirds of the instances were on expressways. The vehicle speed at the time drowsiness occurred was over 80 km/h in about 60% of the instances and over 60 km/h in nearly 80%. These large percentages are due in part to the high incidence of drowsiness while driving on expressways. In view of these vehicle speeds, it is clear that sleepiness at the wheel is likely to result in a serious accident.

The time frame in which drowsiness most often occurs is from late at night to early morning, followed by the early afternoon hours. During these time frames, drowsiness occurs most often after less than one hour of continuous driving. This result indicates that drowsiness is not necessarily caused by long hours of continuous driving.

Among those who experienced drowsiness, over half also indicated that they felt anxious about falling asleep while driving.

In many instances, drivers are not conscious of becoming drowsy while driving. A consideration of the psychology of drivers suggests that a slight feeling of sleepiness is not regarded as a sufficient reason for stopping to rest. As a result, it is not unusual for drivers to subsequently fall asleep while continuing to drive. An active safety system that could effectively prevent drowsiness at the wheel would contribute to a large reduction in fatal and injury-causing accidents.

3. Techniques for Detecting Drowsiness in Drivers

The process of falling asleep at the wheel can be characterized by a gradual decline in alertness from a normal state due to monotonous driving conditions or other environmental factors; this diminished alertness leads to a state of fuzzy consciousness followed by the onset of sleep. The critical issue that a drowsiness detection system must address is the question of how to accurately and early detect drowsiness at the initial stage.

Possible techniques for detecting drowsiness in drivers can be broadly divided into five major categories, as shown in Table 1.

Among these different methods, the best detection accuracy is achieved with techniques that are based on physiological phenomena, which can be accomplished in two ways.

One approach would be to measure changes in physiological signals, such as brain waves, eye blinking, heart rate, pulse rate or skin electric potential, as a means of detecting a drowsy state. While this approach is suitable for making accurate and quantitative judgments of alertness levels, it would be annoying to drivers because the sensing electrodes would have to be attached directly to the body. Thus, it would be difficult to use a system based on this approach under real-world driving conditions. It also has the disadvantage of being ill-suited to measurement over a long period of time owing to the large effect of perspiration on the sensors.

The other approach in this category focuses on physical changes, such as the inclination of the driver's head, sagging posture, decline in gripping force on steering wheel or the open/closed state of the eyes. Ways of measuring these physical changes are classified as being either the contact type or the noncontact type. The former type involves the detection of movement by direct means, such as by using a hat or eye glasses or attaching sensors to the driver's body. The latter type makes use of optical sensors or video cameras to detect changes.

Detection methods that are superior in terms of practicality are ones that sense driving operation or vehicle behavior that is distinctly characteristic of a sleepy driver. The vehicle control systems that might be monitored for sensing driving operation include the steering wheel, accelerator, brake pedal or transmission shift lever. The vehicle behavior detected might be the vehicle speed, lateral acceleration, yaw rate or lateral displacement. Since these techniques allow noncontact detection of drowsiness, they do not give the driver any feeling of discomfort. On the negative side, they are subject to numerous limitations depending on the vehicle type and driving conditions. It would also be necessary to devise a different detection logic for each type of vehicle. Still another problem with this approach is that detection would not be possible at low speed.

This research focused on an investigation of a system for detecting changes in the degree of openness of the driver's eyes, which has a high correlation with drowsiness. In Table 1, this approach falls under the category of detection of physical changes in physiological phenomena. This particular method was selected because a practical drowsiness detection system would have to assure a high level of detection accuracy equivalent to that of methods based on physiological signals and an early detection at the initial stage. Moreover, the system should be able to detect drowsiness in the driver by means of a noncontact technique.

4. Drowsiness Detection by Image Recognition

4.1 Detection method

An investigation of the human eyes under a condition of reduced alertness indicated that the eyes are narrower than in a wide-awake state and that there are times when the eyes actually close. Fig.1 presents experimental results showing the alertness level and the number of times the driver's eyes closed for two or more seconds while driving on a test course. Good correlation is seen between the two sets of data. This result indicated that a reduced level of alertness could be detected with good accuracy by monitoring changes in the degree of openness of the driver's eyes.

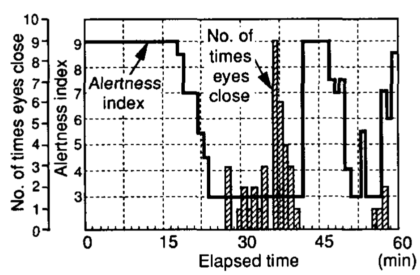

Fig.1 Number of times eyes close and alertness level

4.2 System configuration

The configuration of the drowsiness detection system is shown in Fig.2.

A small CCD camera positioned in front of the driver takes images of the driver's face. The facial image data are converted to binary image data by one frame and sent to the frame memory of the image processor. The frame memory stores each image in a 512x432 pixel format, with eight bits of memory capacity used for each pixel.

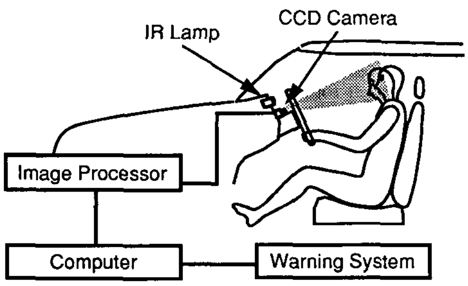

Fig.2 System configuration

A personal computer connected to the image processor controls the image processing procedure and judges the processed results.

An infrared lamp is provided in the instrument panel to facilitate the recording of facial images during nighttime driving.

4.3 Basic algorithm

4.3.1 Flowchart of major functions

A flowchart of the major functions of the drowsiness detection system is shown in Fig.3.

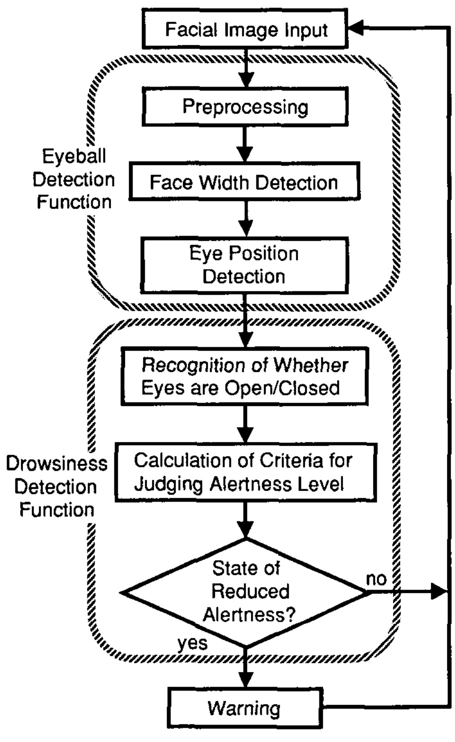

Fig.3 Flowchart of Major Functions

The functions of the system can be broadly divided into an eyeball detection function, comprising the first half of the processing routine, and a drowsiness detection function, comprising the second half.

4.3.2 Eyeball detection function

A brief explanation is given here of the eyeball detection procedure.

After inputting a facial image, preprocessing is first performed to binarize the image and remove noise, which makes it possible for the image to be accepted by the image processor.

The maximum width of the face is then detected so that the right and left edges of the face can be identified. After that, the vertical position of each eye is detected independently within an area defined by the center line of the face width and lines running through the outermost points of the face. On that basis, the area in which each eye is present is determined.

Once the areas of eye presence have been defined, they can be updated by tracking the movement of the eyes. The degree of eye openness is output simultaneously with the establishment or updating of the areas of eye presence. That value is used in judging whether the eyes are open or closed and also in judging whether the eyes have been detected correctly or not. If the system judges that the eyes have not been detected correctly, the routine returns to the detection of the entire face.

The following explains the eyeball detection procedure in the order of the processing operations.

(1) Preprocessing

The preprocessing operations include the binarization of a facial image to increase the processing speed and conserve memory capacity, and noise removal.

The image processor developed for this drowsiness detection system performs the expansion and contraction operations on the white pixels, and processing for noise removal is performed on the small black pixels of the facial image.

After the binarization, the noise removal procedure involves a expansion processing method combined with the use of a median filter. These preprocessing operations are sufficient to support detection of the vertical positions of the eyes.

However, following identification of the eye positions, the size of the eyes must be converted back to the original image format at the time the degree of eye openness is output. To facilitate that, data contraction is performed in the latter stage of preprocessing.

(2) Face width detection

The maximum width of the driver's face must be detected in order to determine the lateral positions of the areas in which the eyes are present.

Face width is detected by judging the continuity of white pixels and the pattern of change in pixel number. On that basis, the outer edges of the face are recognized and determined, as indicated in Fig.4.

(3) Detection of vertical eye positions

Each vertical eye position is detected independently within an area demarcated by the center line of the face, which is found from the face width, and straight lines running through the right and left outer edges of the face. In a binary image, the eyes become collections of black pixels along with the eyebrows, nostrils, mouth and other facial features.

These collections of black pixels are recognized on the basis of a labeling operation, and the position of each eye is extracted by judging the area of each label along with its aspect ratio and relative coordinate positions in the facial image.

Through this process of detecting each vertical eye position, the central coordinates of each eye are recognized. The coordinates serve as references for defining the areas of eye presence, as indicated in Fig.4.

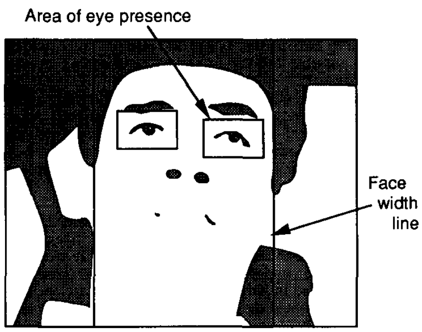

Fig.4 Image of face and objects of detection

(4) Eyeball tracking

A function for tracking the positions of the eyeballs is an important capability for achieving high-speed processing because it eliminates the need to process every frame in order to detect each eye position from the entire facial image. This function consists of a subroutine for updating the areas of eye presence and a subroutine for recognizing when tracking becomes impossible.

The basic concept of eyeball tracking is to update the area of eye presence, in which an eye search is made in the following frame, according to the central coordinates of the eye in the previous frame.

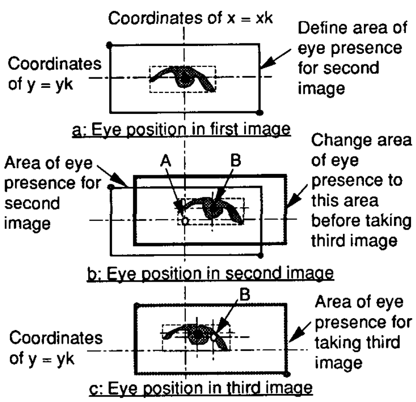

Fig.5 Tracking of eye position

The following is an explanation of the specific processing procedure.

The updating process involves defining an area of eye presence on the basis of the coordinates (xk, yk) at the point of intersection of center lines running through the Feret's diameter of the detected eye (Fig.5-a). The area thus defined becomes the area of eye presence in which the system searches for the eyeball in the image data of the next frame.

Owing to movement of the driver's head or other reasons, the center point (point B) of the eye detected in this area in the next frame changes relative to the center point (point A) of this area of eye presence (Fig.5-b). In relation to this change in eye position, the area of eye presence is updated in reference to the center point (point B) of the eye detected in this frame, and then the facial image data of the next frame are input. Similar to the previous step, the system then searches for the eyeball in the updated area of eye presence (Fig.5-c).

This process of using information on eye position to define the eye position for obtaining the next facial image data makes it possible to track the position of the eyeball. As is clear from this description, the size of the area of eye presence can be defined so as to correspond to these eye position changes.

If the eyes are tracked correctly, their degree of openness will always vary within a certain specified range for each individual driver, as illustrated in Fig.6. Consequently, if the value found by the system falls outside that range, it judges that the eyes are not being tracked correctly. The process of detecting the position of each eye from the entire facial image is then executed once more.

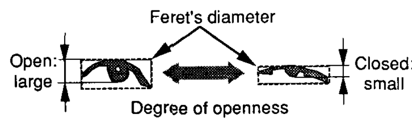

Fig.6 Degree of eye openness.

4.3.3 Drowsiness detection function

(1) Judgment of whether eyes are open/closed

A window is defined on the basis of the Feret's diameter of the eyes. The maximum number of black pixels along the vertical axis of the window indicates the degree of eye openness and is used as the basis for judging whether the eyes are open or closed (Fig.6).

(2) Criterion for judging eye open/closed state, and learning function

A threshold value is established for each driver for judging whether the person's eyes are open or closed. That criterion is based on the degree of eye openness observed for the individual when the eyes are open and closed.

The system also learns the size of each person's eyes in order to cope with variation in eye sizes due to individual differences or to differences in the distance between the camera and the driver's face at the time facial images are taken.

(3) Method of judging alertness level

As the level of alertness drops, rapid blinking gives way to the appearance of long intervals when the eyes are closed, which provides a basis for detecting drowsiness.

A specific method which we have devised for judging the level of alertness, is to count the number of times the eyes close within a specified interval.

As shown in Fig.7, the method of counting the number of times the eyes close begins with the second consecutive closure. This is done to avoid including instances of eye closure due to blinking. In the figure, the numbers in the middle of the interval for judging the alertness level indicate the eye closure count. In this example, the system judged that the eyes closed four times. The specified interval for judging the alertness level with this system has been set at one minute.

This interval for judging the alertness level varies according to the processing speed determined from the ability of the image processor.

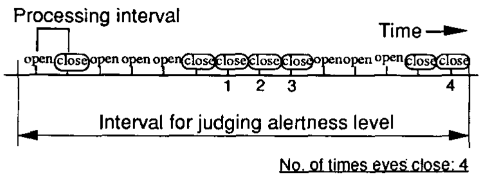

Fig.7 Method of totaling no. of times eyes close

Criteria for judging the alertness level on the basis of the eye closure count have been determined according to the results of driving tests in which drowsiness at the wheel was investigated.

5. Drowsiness Detection Performance

5.1 Alertness index

An alertness index has been devised for making quantitative judgments of a driver's state of drowsiness. This index is based on the assignment of points to brain waves, blinking and facial expression, which are known to vary according to a person's level of alertness. The point total provides a quantitative measure for judging the alertness level. The specific procedure for rating these three elements is outlined in Fig.8.

Rank	Brain waves	Blinking	Facial expression
3	No α2 waves	Continuous rapid blinking	Rigid face muscles
2	Clusters of small amplitude α2 waves	Appearance of slow blinking	Drooping of upper eyelids
1	Continuous appearance of large-amplitude α2 waves	Eyes close for long intervals	Eyes half-closed

Fig.8 Evaluation criteria for brain waves, blinking and facial expression

As a person's level of alertness drops, a large number of α2 waves appear and their amplitude becomes larger. Points are thus assigned according to the number and amplitude of the α2 waves detected.

Blinking is rated by evaluating the measured waveforms for the upper and lower electric potential of the eyes. In a normal state of alertness, blinking appears as sharp spikes in the waveform. As the level of alertness drops, the spikes appear more frequently and subsequently lose their shape to become a gentle waveform when a person becomes drowsy. Eventually, the waveform shows trapezoidal shapes indicating that the eyes close for long intervals.

In terms of facial expression, a drowsy-looking appearance can be determined from the slackness of the face muscles and the drooping of the upper eyelids.

Each of the three elements is rated in this way using a three-point scale and the points are totaled to indicate the alertness level, which ranges from a wide-awake state (9 points) to a fuzzy state just prior to falling asleep (3 points).

The correlation between the alertness level, based on the alertness index, and the eye closure count was found from the driving test data. When the correlation was determined, states of alertness were divided into three levels: a wide-awake state (an alertness index of 9.0-8.0), a slight decline in alertness accompanied by a little drowsiness (7.5-6.5) and a large decline in alertness, a state ill-suited for continued driving (6.0-3.0).

5.2 Evaluation of detection performance

The drowsiness detection performance of the system was evaluated in laboratory tests and actual driving tests. In these tests, the subjects were asked to perform a simple task or to drive under monotonous conditions in order to induce drowsiness.

5.2.1 Laboratory tests

Fig.9 shows the laboratory test setup used to simulate a condition of driving while drowsy.

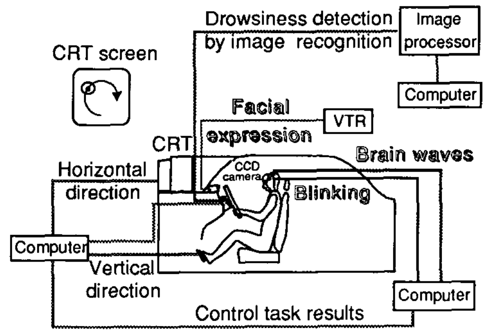

Fig.9 Schematic diagram of test setup

A CRT monitor was positioned in front of the driver's seat of a trimmed body, the interior of which was darkened by covering the windows.

A subject sat in the driver's seat and performed a simple task while watching the CRT screen. The task involved using a ring to pursue a target point that moved at a constant speed in a circular pattern on the screen. The subject moved the ring laterally by turning the steering wheel and vertically by operating the accelerator.

Because of the monotonous simplicity of this task, it soon made the subject drowsy. The subject's alertness level was judged by the methods explained earlier for detecting drowsiness from physiological signals. The performance of the drowsiness detection system was evaluated on the basis of the degree of correlation between the alertness level provided by the system and the alertness level obtained from the physiological signals.

5.2.2 Driving tests using an actual vehicle

The subjects were asked to drive at a constant speed on a circuit around the periphery of a test course, and this monotonous driving served to induce a natural state of drowsiness.

Similar to the laboratory tests, a data recorder was used to record the subject's brain waves and eye electric potential in order to facilitate judgment of the alertness level on the basis of physiological signals. A CCD camera was installed on the steering column in the same position as in the laboratory tests. The camera recorded the facial image data used to facilitate drowsiness detection by means of image recognition. This image data was also used to facilitate judgment of the alertness level on the basis of facial expression of physiological signals.

Just as in the laboratory tests, drowsiness detection performance was evaluated by comparing the degree of correlation between the alertness level indicated by image recognition and that based on the physiological signals.

5.3 Evaluation results

Laboratory tests and driving tests were conducted several times with multiple subjects and comparisons were made of the alertness index scores found from the physiological signals and the alertness levels obtained by image recognition. An example of the results obtained is given in Fig.10.

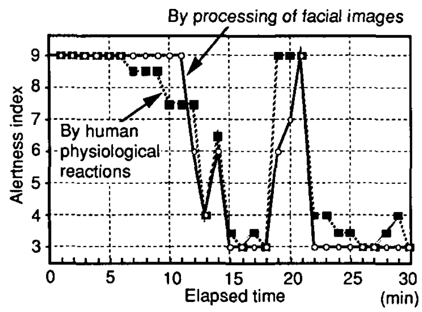

Fig.10 Evaluation of drowsiness detection

It is seen that the method of detecting alertness on the basis of image recognition accurately traced the changes that occurred in the alertness level with elapsed time.

Table 2 Correlation coefficients

Subject	No. of trials	Correlation coefficient (individual)	Correlation coefficient (average)
A	4	0.79	0.77
B	3	0.74	
C	3	0.83	
D	3	0.73	
E	4	0.78	

Using the method of counting the number of eye closures, alertness levels were determined for 17 facial image records obtained in laboratory tests involving five subjects.The results were then subjected to a correlation analysis and the correlation coefficients obtained are given in Table 2. These data also indicate that an exceptionally high level of detection performance was obtained with the system in these multiple tests involving a number of subjects.

The foregoing results thus confirmed that the drowsiness detection system based on image recognition can provide detection performance close to that of techniques using physiological signals, even though it is a noncontact method. This indicates that the system is capable of early detecting the initial stage of drowsiness .

Various factors can be considered as possible causes of a decline in the degree of correlation. One factor might be subjective variation on the part of the test engineers in judging intermediate levels of alertness from the physiological signal data. Another factor might be discrepancies between the timing for changes in alertness levels and the time when alertness judgments are made. In order to obtain better correlation with alertness levels based on physiological signals, further studies are needed, including possible alternation of the criteria for judging the alertness level.

6. Conclusion

The results of tests conducted under a drowsy state in the laboratory and on a test course with an actual vehicle have made the following points clear.

(1) Image recognition achieves highly accurate and reliable detection of drowsiness.

(2) Image recognition offers a noncontact approach to detecting drowsiness without annoyance and interference.

(3) A drowsiness detection system developed around the principle of image recognition judges the driver's alertness level on the basis of a continuous time history and provides early detection of reduced alertness at initial stage.

There are a number of issues that remain to be addressed in the drowsiness detection system. These include improvement of its adaptability to changes in ambient brightness, assurance of reliability and attainment of a more compact system design.

7. References

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(2) M.Kaneda et al., "Development of a Drowsiness Warning System", The 14th International Conference on Enhanced Safety of Vehicles, Munich, 1994, 94-S3-O-08