# ADAPTABILITY TO AMBIENT LIGHT CHANGES FOR DROWSY DRIVING DETECTION USING IMAGE PROCESSING

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## ABSTRACT

A drowsy driving warning system has been developed that uses image processing technology to calculate the blink rate of the driver's eyes. One issue that had to be addressed in developing this system was to ensure sufficient adaptability to ambient light changes in the passenger compartment during driving. The aim of the present work was to develop an image processing algorithm capable of coping with such ambient light changes. The results of drowsy driving detection tests conducted with an actual vehicle have confirmed the effectiveness of the detection algorithm.

## INTRODUCTION

There are various methods that can be used to detect drowsy driving. These detection methods can be broadly divided into two categories. One category makes use of information about the driver such as psychological signals; the other category uses information about the vehicle such as the operation of vehicle control systems or vehicle motions. Typical examples of physiological signals include brain waves, eye electric potential, heart rate and skin electric potential. Driving operations such as the movement of the steering wheel or the operation of the accelerator or brake pedal can be sensed, and characteristics for identifying drowsy driving can be detected. Detectable vehicle motions stemming from drowsy driving include the vehicle speed, lateral acceleration, yaw rate and lateral displacement, among others.

Measurement of physiological signals provides a rather accurate means of detecting drowsy driving, but it is necessary to attach sensors directly to the driver's body. Methods based on the use of vehicle information offer the advantage of noncontact detection, but they are subject to severe limitations depending on the characteristics of the vehicle or the driving environment.

Taking these issues into account, it was decided to use image processing technology to detect drowsy driving. The reason for this choice is that it offers the advantages of not causing the driver any discomfort or annoyance and of providing high detection accuracy.

## OVERVIEW OF DROWSY DRIVING DETECTION AND TECHNICAL ISSUES

The drowsy driving detection system consists of a CCD camera that takes images of the driver's face and a controller that detects drowsy driving by determining the eye positions from the driver's facial image and judging the open or closed state of the eyes.

This type of drowsiness detection system based on the use of image processing technology must be able to accommodate individual driver differences as well as the use of glasses. Likewise, it must also be able to adapt reliably to changes in the ambient light in the passenger compartment between day and night and depending on the weather, the height of the sun and other factors. When light is uniformly distributed over the driver's face, facial images have distinct gray scale values, making it relatively easy to detect the eye positions and to judge whether the driver's eyes are open or closed. However, when a portion of the driver's face is exposed to direct sunlight, the contrast between the eyeballs and the surrounding skin is weaker both on the side bathed in sunlight and on the side in the shadow. This reduced contrast makes it difficult to detect the eyes simply on the basis of gray scale information extracted from the facial image. In this case, because sunlight is not reflected evenly, it is not possible to process the entire facial image uniformly either with absolute gray scale values or with relative values such as the average gray scale value of the entire image.

The aim of this research was to devise an algorithm for resolving this issue and to confirm that a system incorporating the algorithm would be able to detect drowsiness reliably under varying ambient light conditions.

## DETECTION ALGORITHM

The flowchart in Figure 1 shows the main sequence of operations performed by the drowsy driving detection system. This system consists of two main functions. One is a function for detecting the eyeball positions from the overall facial image data. The other is a function for detecting drowsy driving by monitoring and confirming changes in the open or closed state of the eyes.

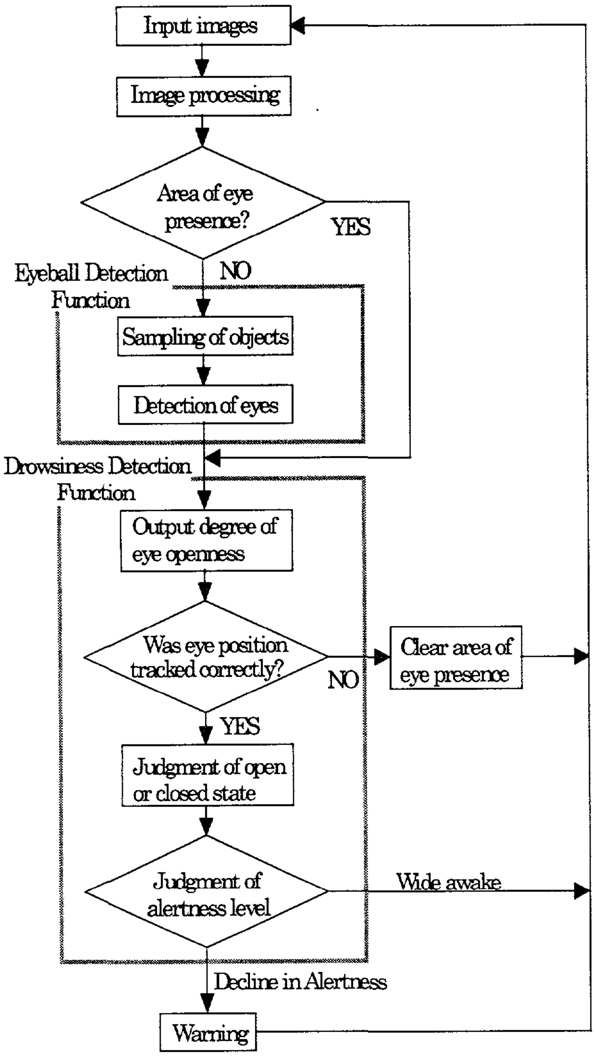



**Figure 1. Flowchart.**

### Eye Position Detection

The details of the process for detecting the positions of the driver's eyes are explained here in reference to Figure 2. The image of the driver's face photographed with the CCD camera is initially stored in an image memory. Gray scale values in the vertical direction are then read out from the image data, as indicated in Figure 2-(a). The changes in the gray scale values along line Xa in Figure 2-(a) are shown in Figure 2-(b). Feature points are then extracted along each line from these changes in the gray scale values. The feature extraction method is explained in reference to Figure 2-(b). Changes in gray scale values to darker features representing the eyebrows, eyes and other parts of the face are indicated by the downward projections in the graph. Accordingly, these features can be detected as the points denoted as p1 to p5 in the differential value graph where the values change from negative to positive.

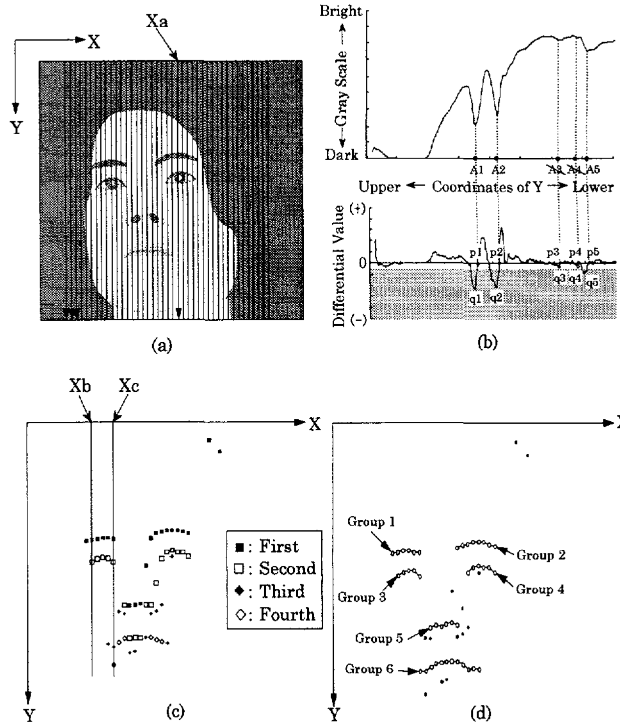



**Figure 2. Method of Detecting Eye Positions.**

However, the dark portions along any arbitrarily chosen vertical line also include shaded areas due to uneven facial contours, in addition to an eye or an eyebrow. Consequently, the degree of change in the gray scale values toward the darker feature points of interest is judged on the basis of the level of the negative differential values, in order to remove shadows and other unwanted noise. A specific example is explained here in reference to Figure 2-(b). It is seen that there are five points, denoted as p1 to p5, where the differential values change from positive to negative. On the other hand, the minimum differential values (q1 to q5), indicating the degree of change in the gray scale values toward those points, do not reach the specified level (i.e., do not enter the gray shaded area) at q3 and q4, so p3 and p4 are removed. As a result, the three points A1, A2 and A5 are obtained as the feature points of line Xa. The feature points extracted in this manner along each vertical line are shown in Figure 2-(c). Two points have been extracted along line Xb and four points have been extracted along line Xc. The feature points are then grouped as shown in Figure 2-(d) according to the degree of vertical contiguity with the feature points of each adjacent line. When this grouping operation is performed, attention is focused only on those groups having a length longer than a certain specified value. This is because it is known that the eyes can be recognized as features having a long horizontal length. Simultaneously, the central coordinate values, length and other characteristics of each group are stored in memory as reference values of each group's data. The positions of the eyes are detected by using these reference values to select data corresponding to the eyes. An example of the feature points extracted in this manner is shown in Figure 3.

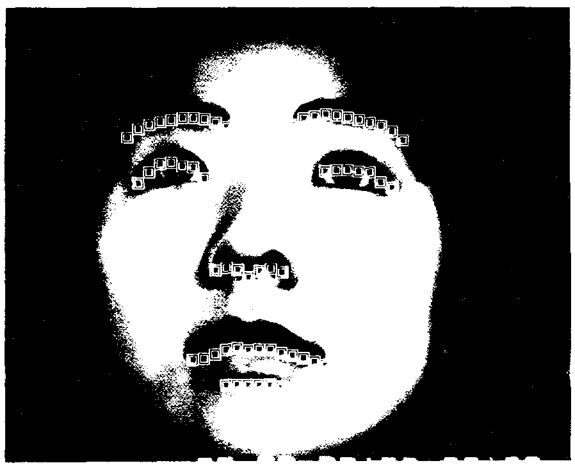


**Figure 3. Example of Processed Image.**

**Detection of Open/Closed State of the Eyes**

An outline is given here of the process for judging the degree to which the driver's eyes are open or closed. This process consists of the following four steps.

(1) Based on the eye positions detected in reference to each group's data, small rectangles are defined as the areas where the eyes are present. The feature points in each rectangle are extracted by the same process as that explained in section 3.1.

(2) A gray scale range is set by using the minimum differential values that represent the level of change in gray levels toward the feature points.

(3) The number of continuous pixels in the vertical direction judged to be the dark portion of the eyes is used to calculate the degree of eye openness (Figure 4).

(4) Judgement of whether the eyes are open or closed is based on the calculated degree of eye openness.

Following this judgment, the areas in which the eyes are present are set based on the central coordinates of the eye group data, and the process then proceeds to input the next facial image. This procedure makes it unnecessary to detect the eye positions each time once they have been identified, because eye data will also be included in the areas of eye presence in the next facial image, so long as there is no large movement of the driver's face. The degree of eye openness used to detect the open/closed state of the eyes changes only in a limited range for a specific driver. Consequently, if a value exceeding that range is calculated, it can be judged that the eye positions have not been detected correctly. When such a judgment is made, the areas set for eye presence are cleared, and the process returns again to the step of detecting the positions of the eyes from the entire facial image.

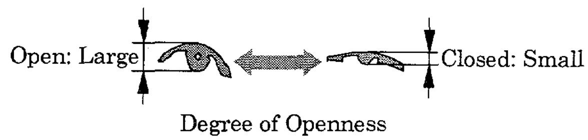



**Figure 4. Method of Judging Open or Closed State.**

**Method of Adapting to Ambient Light Changes**

The method explained above for detecting the eye positions and open/closed state of the eyes uses relative gray scale values as the condition for extracting the feature points along each line. Therefore, it can extract the feature points according to each place in the facial image even if the ambient light balance over the entire face is poor. A specific example of the method of adapting to ambient light changes is shown in Figure 5.

The vertical lines Xa and Xb indicate the portion of the face exposed to direct sunlight and the portion in the resulting shadow, respectively. Even in this case, the points where the gray scale values become partially darker can be reliably extracted by processing each line, as shown in Figure 6. An example of the extracted feature points is given in Figure 7.

An infrared lamp is used as an auxiliary light source to compensate for the insufficient amount of ambient light at night or when driving through a tunnel. This makes it possible to detect the eye positions and the open/closed state of the eyes just as is done during the daytime. An example of the feature points extracted at night with the use of the infrared lamp is shown in Figure 8.

**Accommodation of Glasses**

A separate issue that had to be considered for

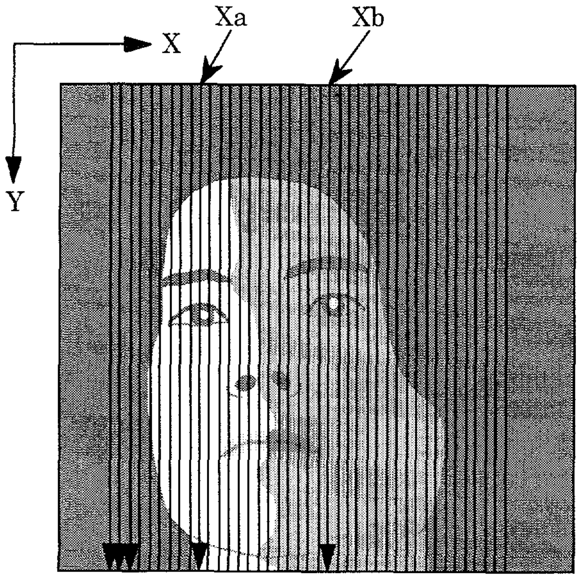
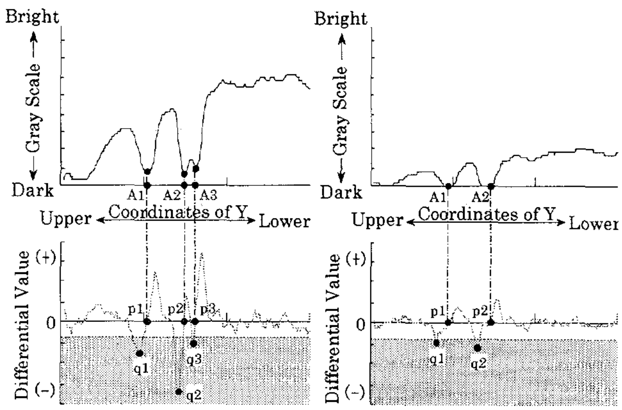



**Figure 5. Variation in Ambient Light on a Facial Image.**




(a)Sampled Points along Line Xa (b)Sampled Points along Line Xb

**Figure 6. Method of Adapting to Changes in Ambient Light.**

drivers who wear transparent lens glasses was the fact that the frames would become noise that would add another possible feature candidate in the process of detecting the eye positions. The decline in contrast between the eyes and the surrounding skin due to the reflection from the lenses of the glasses, on the other hand, can be treated in the same way as changes in the ambient light in the passenger compartment. Accordingly, the procedure explained in section 3.3 is fully sufficient in this regard. An example of the feature points extracted for a driver who was wearing glasses is given in Figure 9. One method of resolving this separate issue of how to select the eyes from among feature points that include many noise candidates is to recognize the shape of the lower

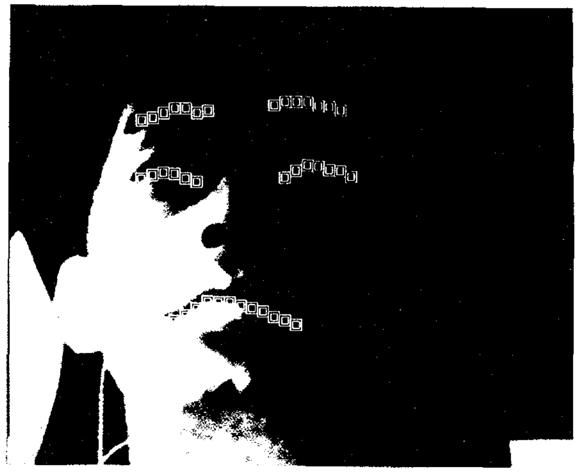


**Figure 7. Example of Processed Image Daytime: Lighted & Shaded.**

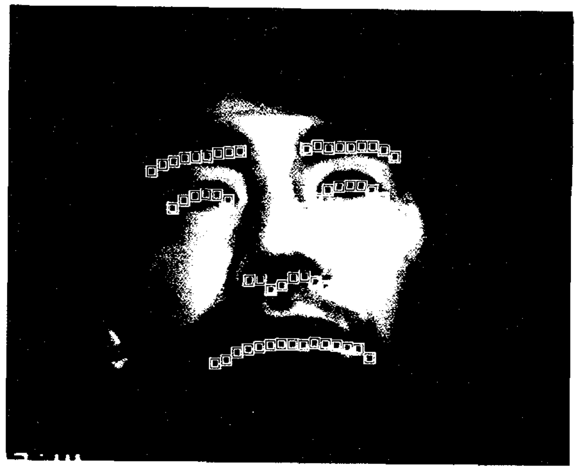


**Figure 8. Example of Processed Image Nighttime: with an Infrared Lamp.**

**Figure 9. Example of Processed Image Wearing Glasses.**

portion of the frames as a feature candidate with a downward projection. Accordingly, the proposed system can detect the eye positions and the open/closed state of the eyes even in the case of drivers who are wearing glasses with transparent lenses coated with an antireflection treatment.

## EVALUATION TESTS

### Test Method

The drowsiness detection performance of the system was evaluated in laboratory tests and driving tests. In the former tests, drowsiness was induced in the subjects by having them perform a simple tracking task and in the latter tests by having them drive under monotonous conditions.

The configuration of the experimental drowsiness detection system is shown in Figure 10. It consisted of a camera for photographing images of the driver's face, a controller for detecting a drowsy driving condition by determining the eye positions from the facial images and judging the open/closed state of the eyes, and a warning buzzer for alerting the driver when the controller detected drowsy driving. An infrared lamp was installed as a nighttime light which did not interfere with driving operations.

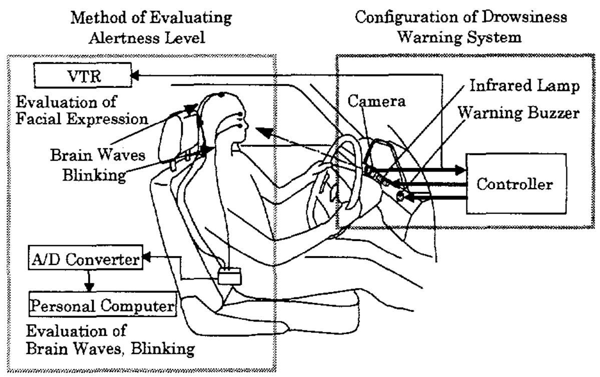



**Figure 10. Configuration of Experimental System.**

<u>Laboratory Tests</u> - Tests were conducted using a trimmed body with the windows covered to darken the interior. The subjects operated the steering wheel and the accelerator pedal to perform a simple tracking task on a CRT screen which was installed in front of the driver's seat. This experiment was conducted with the infrared lamp in a completely dark room so as to create conditions simulating nighttime driving.

<u>Driving Tests</u> - The subjects were asked to drive at a constant speed on a course around the periphery of the proving ground. This monotonous driving condition induced a natural state of drowsiness.

### Quantification of Alertness Index

The performance of the system in detecting drowsy driving was evaluated on the basis of an alertness index, shown as the left-hand scale in Figure 11. This index was used to judge a subject's alertness level quantitatively, based on the total of the evaluation scores assigned to brain waves (α2), eye electric potential and facial expression, which are known to vary according to a person's level of alertness. A state of reduced alertness was defined as an alertness index value of 6.0 or lower. (1)

### Test Results

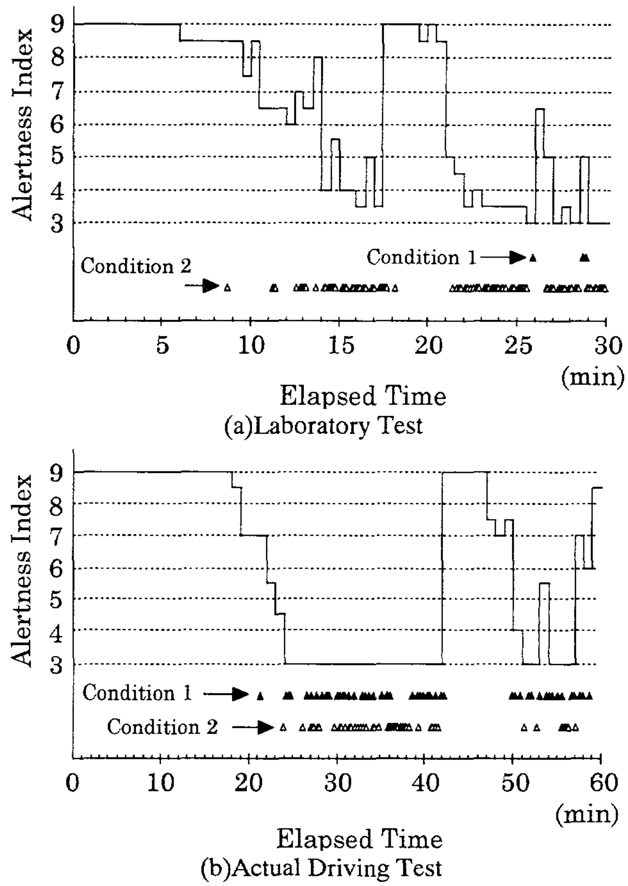



**Figure 11. Evaluation of Drowsiness Detection Performance.**

The rate at which the eyes blink changes as a driver becomes drowsy at the wheel. Blinking declines from a rapid rate characteristic of a wide-awake condition to a slow rate as the level of alertness drops. In these tests, drowsiness detection performance was evaluated on the basis of two conditions that focused on the duration of eye closure. Condition 1 was defined as a case where the cumulative eye closure time at a somewhat slow blink rate (0.2 sec. or greater) exceeded a specified value within a given interval of 30 sec. Condition 2 was defined as a case where the eyes closed for a rather long interval of 1.5 sec. or more. The detection performance of the system was evaluated using the above-mentioned alertness index as the criterion. Examples of the detection results obtained in each type of test are shown in Figure 11.

Although drowsiness warnings were not issued to the subjects when conditions 1 and 2 were detected in the tests, the results suggest that reduced states of alertness corresponding to these two defined conditions were accurately detected in both types of tests. While condition 2 frequently appeared in both the laboratory and driving tests, it should be noted that condition 1 did not occur very frequently in the laboratory tests. It is thought that the reason for this can be attributed to the difference in the tasks required of the subjects in the two types of tests. In the laboratory tests, since the subjects were only given a simple task involving the operation of the steering wheel and the accelerator pedal, they may have felt secure in closing their eyes for longer intervals. Compared with that situation, in the driving tests they could not safely allow themselves to become sleepy while operating an actual vehicle. Accordingly, it can be concluded that a long eye closure interval is not likely to occur at the onset of drowsiness during real-world driving.

## CONCLUSION

An algorithm for detecting drowsy driving was developed and its adaptability to ambient light changes was confirmed.

Test results verified the effectiveness of this algorithm for detecting drowsy driving on the basis of long eye closure and a slow blink rate as the detection conditions.

It was confirmed that the detection algorithm is also effective for drivers who wear glasses, although the problem of having to select the eyes from among many feature candidates remains an issue to be addressed for this type of driver.

One issue that must still be resolved is to devise a more accurate procedure for detecting the eye positions by taking into account individual driver differences. Nonetheless, the results of the present work indicate that the practicality of this drowsy driving detection system has been improved.

## REFERENCES

(1) M. Kaneda, H. Iizuka, H. Ueno, M. Hiramatsu, M. Taguchi and M. Tsukino, "Development of a Drowsiness Warning System," the 14th International Technical Conference on ESV, May, 1994, Munich.