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Development of a drowsiness warning system based on the fuzzy logic images analysis

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Abstract

In the present study, a vehicle driver drowsiness warning system using image processing technique with fuzzy logic inference is developed and investigated. The principle of the proposed system is based on facial images analysis for warning the driver of drowsiness or inattention to prevent traffic accidents. The facial images of driver are taken by a CCD camera which is installed on the dashboard in front of the driver. A fuzzy logic algorithm and an inference are proposed to determine the level of fatigue by measuring the blinding duration and its frequency, and warn the driver accordingly. The experimental works are carried to evaluate the effect of the proposed system for drowsiness warning under various operation conditions. The experimental results indicated that the proposed expert system is effective for increasing safe in drive. The detail of image processing technique and the characteristic also is present in this paper.

Keywords: Drowsiness warning system; Vehicle safety; Image processing; Fuzzy logic inference

1. Introduction

Due to the increase in the amount of automobile in recent years, problems created by accidents have become more complex as well. Traditional transportation system is no longer sufficient. In recent years, the intelligent vehicle system has emerged and became a popular topic among transportation researchers. However, the research of safety in vehicle is an important subset of intelligent vehicle system research. Meantime, active warning system is one of the designs on active safety system. The safety warning systems, mostly active warning systems for preventing traffic accidents have been attracting much public attention. Many techniques have been developed for detecting fatigue of drivers. For example, a system used the interval of steering adjustment to estimate the driver's drowsiness for lane keeping was proposed (Fukuda, Akutsu, & Aoki, 1995). However, some other physical information of driver is also used in fatigue warning systems such as detection of driver bodily functions: the tilt of driver's head, brain waves and pulse. Detection of driver's operations: vehicle wheel, gas pedal and vehicle speed. However, in the fatigue detection systems developed to date, drowsiness warning system using image processing has become most widely used because it provides a remote detection (Perez, Palma, Holzmann, & Pena, 2001; Sugiyama et al., 1996; Ueno, Kaneda, & Tasukino, 1994). Owing to the progress of digital signal processing technology, real time image processing is beginning to be achieved breakthroughs in the field of many practical applications.

Typically, after long hours of driving or in absent of alert mental state, the eyelids of driver will become heavy due to fatigue. The attention of driver starts to lose focus, and that creates risks for accidents. These are typical reactions of fatigue, which is very dangerous. Usually many exhausted drivers are not aware that they are in falling asleep. In fact, many such drivers can fall asleep any time during their driving. In an image fatigue detection, correct and real time decision is important. In past research (Nakano, Mizuno, Yamamoto, Kimura, & Tokunaga, 1994; Seki, Shimotani, & Nishida, 1998) most of warning

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system detect the blinding duration then make a warning when duration is long. In this study, a fuzzy logic determined algorithm is proposed to determine the level of fatigue by measuring both of the blinding duration and blinding frequency then warn the driver accordingly.

2. Principle of drowsiness warning system

Owing to the great improvement on microprocessor in recent years, a large, two-dimensional image can be easily process by a computer. The image analysis techniques have been greatly accepted and applied. In the proposed design, a without interference drowsiness warning system for driver is sketched as Fig. 1. A charge coupled device (CCD) camera is installed on the dashboard for taking consecutive facial images of the driver in the format of windows bitmap (BMP). It then uses program which is written in C++ code to calculate the positions of the eyes and the eyelid closure duration based on the images taken. Finally, a fuzzy logic is used to determine the driver's alertness. Fig. 2 shows the main interface of system. The system is capable of taking multiple, consecutive images and analyze them. Fig. 3 shows the flow chart of the entire process analyzing whether a warning should be signaled.

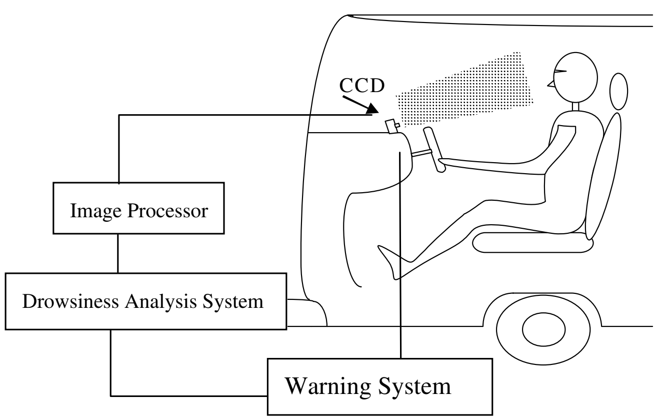

Fig. 1. Sketch of drowsiness warning system for driver.

3. Image processing technique of drowsiness system

3.1. Facial detection

An image which taken inside a vehicle includes the driver as well as other items as shown in Fig. 4. Hence, the proposed system applies a facial detection technique to single out the driver's face from the rest of the image (Valle & Dugelay, 2001). Typically, CCD takes images within the RGB model (Red, Green and Blue). However, the RGB model includes brightness in addition to the colors. When it comes to human's eyes, different brightness for the same color means different color. When analyzing a human face, RGB model is very sensitive in image brightness. Therefore, to remove the brightness from the images is necessary. To accomplish this, the images are converted from RGB to HIS color model, where H stands for hue, S stands for saturation, and I stands for intensity of image.

The characteristics of skin among different human races are similar. The only major difference between a people with a lighter complexion versus one who has a darker complexion is in the different lighting conditions. Hue and saturation will determine the facial skin in an image. Eqs. (1) and (2) can be used to determine the skin tone.

$$0.23 \leqslant \text{Saturation} \leqslant 0.63, \quad 10^\circ \leqslant \text{Hue} \leqslant 50^\circ \tag{1}$$

The formula to convert RGB to HSV is as followed:

$$\begin{aligned}
\theta &= \cos^{-1}\left\{\frac{[(R-G)+(R-B)]/2}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}\\
H &= \begin{cases}\theta & B \leqslant G\\ 360-\theta & B > G\end{cases}\\
S &= 1-\frac{3\cdot \mathrm{Min}(R,G,B)}{R+G+B}\\
I &= (R+G+B)/3
\end{aligned} \tag{2}$$

After to determine the skin tone, we then use vertical and horizontal projection. Projection basically uses every pixel

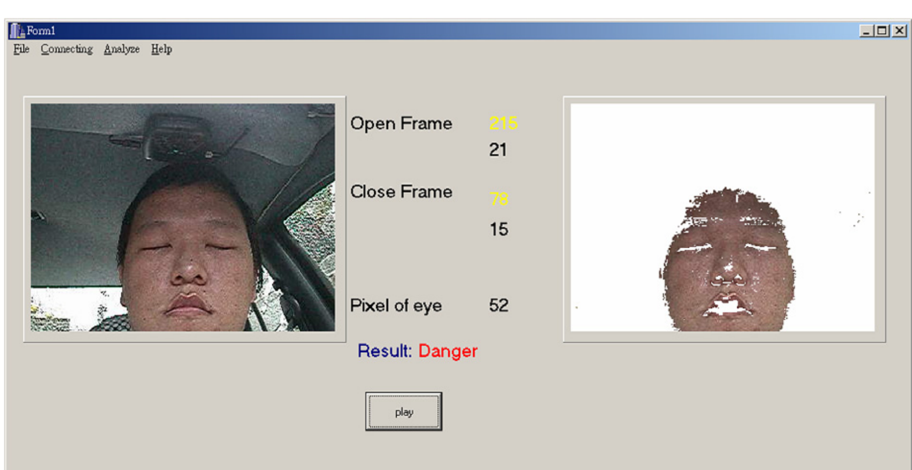

Fig. 2. Main interface of proposed system.

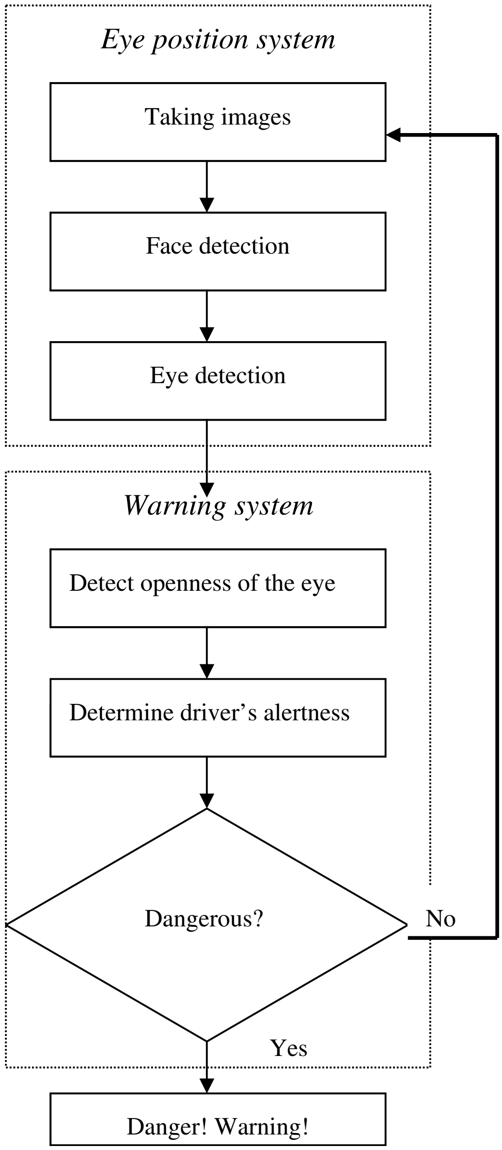

Fig. 3. Flowchart of proposed drowsiness warning system.

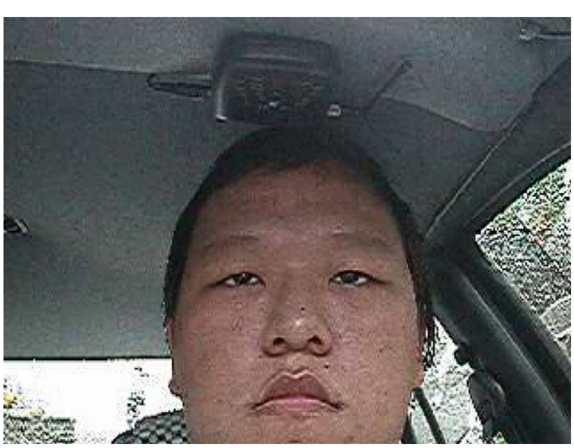

Fig. 4. An image taken by CCD in vehicle.

in the skin to progress vertically and horizontally until it reaches a specific threshold value. When projection is done,

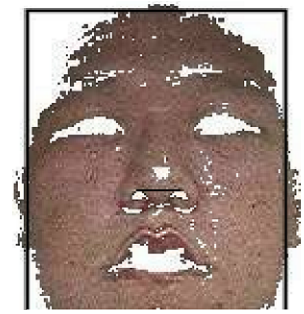

Fig. 5. Facial skin region after facial detection.

the driver's face area can be determined as shown in Fig. 5. The area with the most of dense projection is the center of the face.

3.2. Eye position detection

Since the center of every person's face is around the nose area and that blinking of the eyes usually happen concurrently, we can then assume that the right eye will be positioned at the upper left-hand side of the center of the face is showed as Fig. 6. Therefore, calculation will be based on only one eye. By taking these assumptions, the search for the eye will be limited to the area between 70° and 90°. This limited area will make the search more efficient and converting this particular area to grayscale will speed up the search even more.

Normally, a grayscale image can be divided with colors in the image into 256 values. Besides having 0 as black and 255 as white, there are 254 different shades of gray in the middle. Since a color image is three times the size of a grayscale image, we decided to use the following grayscale formula to facilitate the calculations:

$$\text{Grayscale value } (Y) = 0.299R + 0.587G + 0.114B \tag{3}$$

The eye is in a 20×15 matrix within the eye region. Therefore, we used a 20×20 mask to begin search. The four corners of search area are smaller than the threshold value but the center area is larger than the threshold value. From such search, we can determine the smallest matrix for the eye.

Fig. 6. Eye region before eye detection.

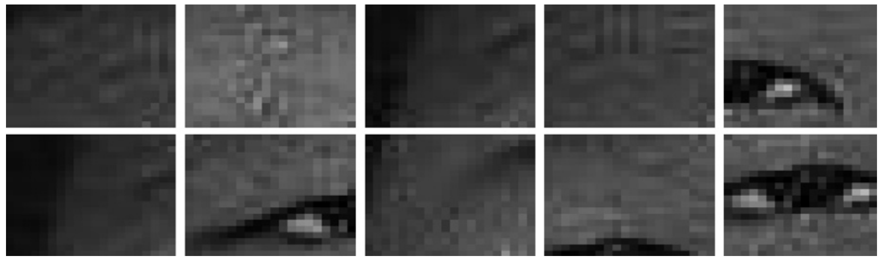

Fig. 7. Searching the eye region.

Fig. 7 shows the search results. Only the lower right-hand side image fits the criteria.

3.3. Detecting the openness of eyes

In this section, the concept of threshold is used to detect the openness of the driver's eyes. Thresholding is the operation of setting a pixel to black if the value is below a given threshold. On the other hand, a pixel is set to white if the value is above the threshold. From this process, we can generate a black-and-white image. In the following formula, n is the thresholding value.

$$n = \sum_{i=1}^{t} g(x, y) \tag{4}$$

where g is the image, t is the number of pixels, $g(x, y)$ is pixel coordinates and (x, y) is pixel's grayscale.

$$\text{If } (x, y) > n, \text{ then } (x, y) = 255$$
$$\text{If } (x, y) < n, \text{ then } (x, y) = 0$$

This study requires the calculation of the eyelid closure duration. After obtaining the thresholding value based on tests, set the skin pixel to white and the pupil to black. Based on the number of black pixels in an image, we are able to determine whether the eye is open or closed as illustrated in Fig. 8.

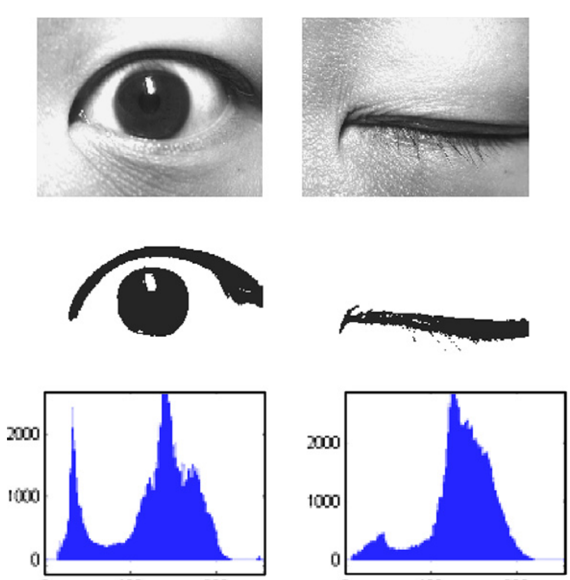

Fig. 8. Thresholding the eye area.

4. Method of drowsiness level estimation

4.1. Principle of fuzzy logic

The concept of fuzzy set is a class with unsharp boundaries. It provides a basis for a qualitative approach to the analysis of complex systems in which linguistic rather than numerical variables are employed to describe system behavior and performance. In this way, a much better understanding of how to deal with uncertainty may be achieved, and better models of human reasoning may be constructed. The concept of fuzzy logic has gained wide acceptance in recent years and have found numerous applications in expert systems and artificial intelligence applications (Lin, Kung, & Lin, 1997; Wei, Yong, Xuanqin, & Yan, 2001). Fatigue is a type of fuzzy bodily state. It cannot be quantified objectively. Thus, we use computers to apply the fuzzy logic and determine the level of fatigueness. The variable used by the drowsiness detection system encompasses the blinking time and the eyelid closure duration. The risk factor is calculated based on rule-table decision and defuzzification as shown in Fig. 9.

4.2. Establishing the grade of membership

To establish the grade of membership, we enter the eye blinking frequency and eyelid closure duration as input variables. The physical state is the output variable. The eye blinking frequency and eyelid closure duration as input variables:

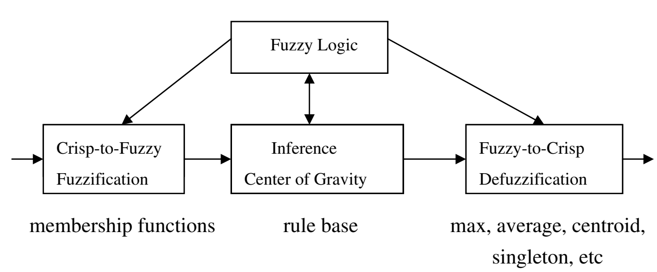

Fig. 9. The process of the fuzzy logic.

$$\begin{aligned}
&\text{Short eye blinking frequency} = \text{Triangular }(0,0,4)\\
&\text{Medium eye blinking frequency} = \text{Triangular }(3,8,13)\\
&\text{Long eye blinking frequency} = \text{Triangular }(8,25,25)\\
&\text{Short eyelid closure duration} = \text{Triangular }(0,0,5)\\
&\text{Medium eyelid closure duration} = \text{Triangular }(4,10,20)\\
&\text{Long eyelid closure duration} = \text{Triangular }(8,30,30)
\end{aligned} \tag{5}$$

The physical state as the output:

$$\begin{aligned}
&\text{Safe} = \text{Triangular }(0,0,4)\\
&\text{Caution} = \text{Triangular }(3,5,9)\\
&\text{Danger} = \text{Triangular }(8,10,10)
\end{aligned} \tag{6}$$

Fig. 10 illustrates the membership function of the input and output variables, Fig. 10a is the input variable, eye blinking frequency, membership function. Fig. 10b is the input variable, eyelid closure duration, membership function, and Fig. 10c is the output variable, physical state, membership function.

4.3. Establishing the fuzzy scale

Normally, the duration of eye blinks is between 3 and 4 s, with blinks that last 0.25–0.3 s for a normal vehicle driver. The variable is changed according to the driver's physical conditions. For example, when the driver is tired, his eyes will involuntarily extend the eyelid closure duration to protect the eyes. Based on the preliminary experiments, typical blink duration is 0.3 s (approximate 9–10 closed-eye images). When the driver is alert, his eye blinking frequency is lower (fewer closed-eye images) and his eyelid closure duration will be slower (more open-eye images). However, when the driver is exhausted, his eye blinking frequency is higher (more closed-eye images) and his eyelid closure duration will be faster (fewer open-eye images). Therefore, based on eye blinking frequency and eyelid closure duration, nine-rule base of the fuzzy logic is defined as follow.

Rule 1: IF eye blinking frequency is **short** AND eyelid closure duration is **slow** THEN **safe**

Rule 2: If eye blinking frequency is **short** AND eyelid closure duration is **medium** THEN **safe**

Rule 3: IF eye blinking frequency is **short** AND eyelid closure duration is fast THEN **caution**

Rule 4: IF eye blinking frequency is **short** AND eyelid closure duration is slow THEN **caution**

Rule 5: IF eye blinking frequency is **medium** AND eyelid closure duration is **medium** THEN **caution**

Rule 6: IF eye blinking frequency is **medium** AND eyelid closure duration is **fast** THEN **danger**

Rule 7: IF eye blinking frequency is **medium** AND eyelid closure duration is **slow** THEN **danger**

Rule 8: IF eye blinking frequency is **short** AND eyelid closure duration is **medium** THEN **danger**

Rule 9: IF eye blinking frequency is **long** AND eyelid closure duration is **fast** THEN **danger**

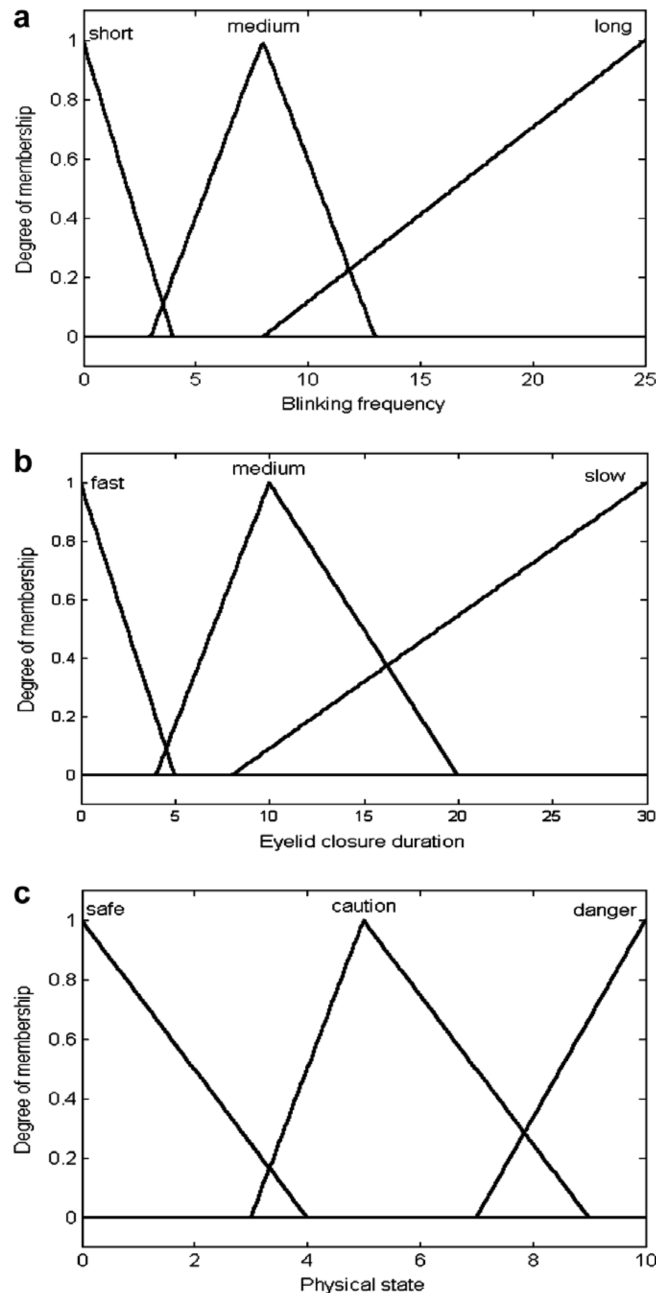

Fig. 10. Membership function of the input and output variables. (a) The input variable, eye blinking frequency, membership function; (b) the input variable, eyelid closure duration, membership function; (c) the output variable, physical state, membership function.

4.4. Fuzzification

Fuzzification is related to the impreciseness of human languages. It is a process of converting measurable values into subjective judgements. The inputs of proposed system are the eye blinking frequencies and eyelid closure duration. These two variables are converted into "short eye blinking frequency", "medium eye blinking frequency", "long eye blinking frequency", "slow eyelid closure duration", "medium eyelid duration", and "fast eyelid closure duration" based on the images taken and analyzed by the CCD images.

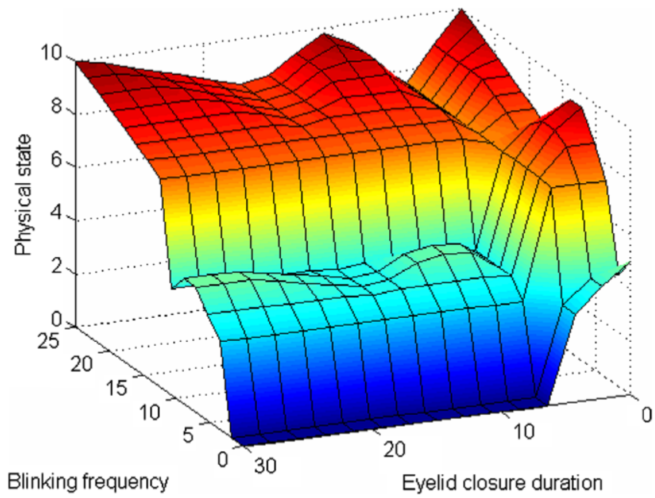

Fig. 11. Fuzzy control surface.

4.5. Defuzzification

Defuzzification is the result of the fuzzy logic. Its primary goal is to convert the fuzzy value (an average) to a single number, a crisp value. There are many ways can be used to achieve defuzzification, and the method of center of gravity is the most common technique. The center of gravity in an inferred area is calculated using the following formula:

$$CG = \frac{\sum_{i=1}^{k} yi \times Bi}{\sum_{i=1}^{k} Bi} \tag{7}$$

OUTPUT = sum (representative value × confidence)/sum (confidences)

Finally, following fuzzy logic's Eq. (5) to Eq. (7), the output of the fuzzy logic can be obtained. This output value will determine whether the driver is exhausted. The end result, the fuzzy control surface, is shown in Fig. 11.

5. Conclusion

A vehicle driver drowsiness warning system using fuzzy logic image processing is proposed in this study. The study proves the feasibility of apply image processing technique to safety of vehicle. In the system, besides judging the driver's level of fatigue, it also allows the head of driver moving within an acceptable region. However, one important issue that is not addressed in this paper, the lack of lighting during sunset may cause errors when the images are read. Also, it may be too dark at night for the system to properly detect the driver's eyes. Nevertheless, the fuzzy logic based system is more accurate than the older ones which only capture the amount of time that the driver's eyes are closed. In other words, the fuzzy logic system is better at determining the driver's physical conditions. The future work will be focused on the development of more robust system for other conditions such as in lack of light. Infrared light could be a solution can be used for taking the images and thus lower the possible errors caused of the lack of or change of the lighting.

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