Fatigue Driving Detection System Based on Bayes' Theorem

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***Abstract*—In this paper, a multi-feature fatigue decision making method based on Bayesian conditional probability formula is proposed. The captured video is detected by a face detector and then positioned to the eyes and mouth portion. The eye closure degree, the mouth opening degree, and the nodding frequency data are collected, and the driver is judged to be in a fatigue state according to the Bayesian probability formula. If fatigue is detected, an alarm is issued. According to the method, it is possible to accurately detect whether the driver is in a fatigue state, and to help the driver return to the awake state by means of the alarm method, thereby reducing the occurrence of traffic accidents.**

***Index Terms*—Bayesian probability formula, eye chosure degree, mouth opening degree, nodding frequency**

I. Introduction

With the rapid development of the global economy, cars have become the tool of choice for people to travel, and it is especially important to ensure traffic safety. According to statistics, in the major traffic accidents that occur every year on expressways, accidents caused by fatigue driving are more than 40%. The threat posed by fatigue driving to traffic accidents should not be underestimated. In order to reduce the harm caused by fatigue driving, it is of great practical significance to study an efficient and accurate fatigue driving detection system.

Nowadays, the way to measure fatigue is mainly divided into two categories. One is contact measurement: EEG, ECG, and the test is analyzed by the signal of contact with the body. The second method is the non-contact test method, which is currently mainly used in two aspects: (1) human facial expression features. For example, when people are sleepy, the frequency of blinking, slowing of blinking, yawning, nodding, etc. can show some fatigue. (2) in terms of behavior, there are mainly two large channels to obtain, one is the operating characteristics of the steering wheel, and the other is the driving trajectory of the vehicle. From the two detection methods, the physiologically based detection method may be more accurate in terms of accuracy. However, the need to wear a sensor may cause discomfort to the driver and is not easily accepted by people. This disadvantage can be avoided based on a non-contact detection method. But it needs to be high enough in real time and accuracy. This paper proposes a non-contact detection method, which uses Bayesian probability formula to judge whether the driver is in fatigue state according to facial eye, mouth and nodding characteristics.

II. System Design

In this paper, the video is captured by the camera, and the captured video is processed in the following order.

A. Pretreatment

Due to the different collection environments, such as daylight, night, rain, snow, sunny, tunnels, etc., the illumination intensity is different and the performance of the equipment is not good, so there are certain disadvantages such as noise and insufficient contrast. Moreover, the driver's head will certainly oscillate, and the distance from the camera is different, which makes the position of the face in the whole image uncertain, which causes great interference to the effective recognition of the target, resulting in deviation of the target state judgment in the video frame. In order to ensure the consistency of the face size, position and face image quality in the image, the image must be pre-processed.

In this paper, the homomorphic filtering [1]-[3] method is used to preprocess the image to improve the recognition rate of the face image. Homomorphic filtering is a processing method that combines frequency filtering and grayscale transformation. It is a processing technique that uses the image illumination/reflection model as the basis for frequency domain processing, and uses compressed gamma range and enhanced contrast to improve the image. An image can be represented by the product of its illumination component and reflection component, that is, after homomorphic filtering, the result will change the characteristics of image light intensity

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and reflected light intensity. So we can achieve the same effect by reducing the dynamic range of the image and increasing the contrast.

In this paper, Gaussian homomorphic filtering is used for preprocessing, which can effectively modulate the gray level of the image, the detail contour is clearer, and the problem of uneven illumination is improved.

B. Face Recognition and Extraction Features

In this paper, the HOG [4] + linear SVM [5] object detector is trained in advance to perform face detection, and then 68 points are located from the detected face [6], including key positions such as eyes, eyebrows, nose, mouth and facial contour. The 68 feature point models of the face are shown in Fig. 1 below:

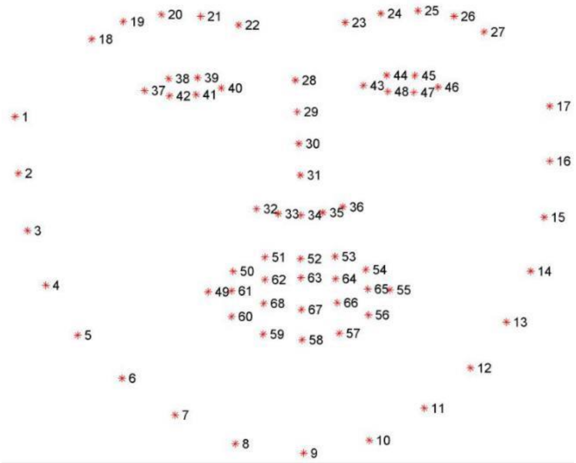

Figure 1. 68 feature point location information of the face.

Human fatigue is a subjective discomfort that is usually not directly observable, and it is difficult to quantitatively analyze it. It can only indirectly reflect the degree of fatigue through certain information. Human fatigue can be manifested through the appearance of the human body, such as limb weakness, bending down, eyes closed and yawning. Most machine vision fatigue tests reflect the degree of fatigue only by the driver's eye closure statistics. When the driver is tired, it is usually accompanied by physiological behaviors such as yawning and nodding, and the characteristics of the mouth and head are also obvious. Therefore, in addition to the eye features including eye closure and blink frequency, the mouth features of the yawn frequency and the head features of the nodding frequency are extracted to enhance the accuracy and robustness of the system. In this paper, the eye extraction (point 37-48) coordinates and the mouth (point 49-68) coordinates are extracted according to the 68 points that are located for feature extraction.

1) Eye features

According to relevant data, abnormal changes in the eye will occur some time before the accident caused by fatigue driving [7], [8]. That is, the blink frequency and the eye closure [9], [10] time change in advance. Therefore, the eye closure and blink frequency are chosen as eye features. The extraction process includes two parts: eye positioning and eye closure. The specific flow chart is shown in Fig. 2:

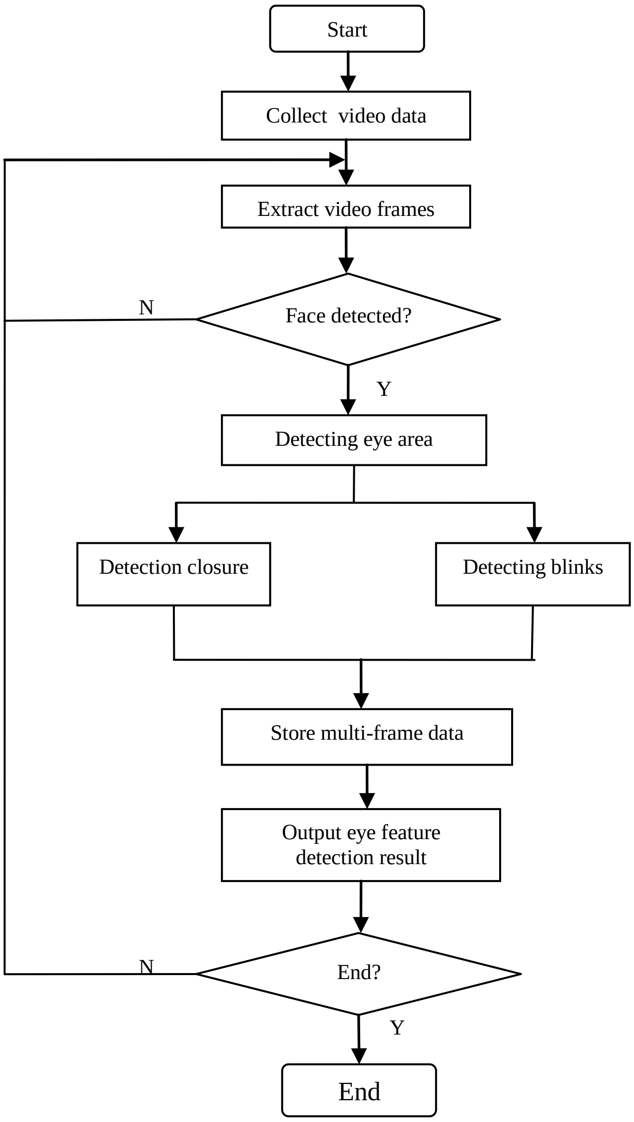

Figure 2. Eye feature extraction flow chart.

a) Eye closure

The study found that after comparing the physiological characteristics of many fatigues, the most closely related to fatigue is the degree of eye closure and strong directivity.

Percentage of Eyelid Closure Over the Pupil Over Time (PERCLOS) is usually used to indicate the degree of closure of the eyes [11]. Practice has proved that when the driver is not fatigued and tired, the eye closure time is greatly different, and the closure time increases with the increase of fatigue severity. The PERCLOS feature counts the percentage of eye closure time per unit time and is one of the most effective features for current driver fatigue testing. This feature is very practical, and most of the non-contact real-time fatigue testing products that have emerged today use this method.

The calculation method of PERCLOS is shown in Fig. 3.

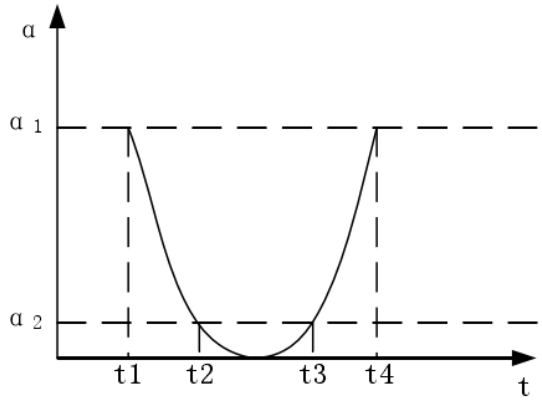

Figure 3. PERCLOS calculation diagram.

The threshold α_2 is a threshold for determining the closure of the eyelid, and when the eyelid aspect ratio is smaller than the threshold α_2, it is determined that the eyelid is in a closed state. The PERCLOS calculation formula in one unit time (T=t4-t1) is shown in (1):

$$P=\frac{t3-t2}{t4-t1} \tag{1}$$

For eye closure, the eye aspect ratio can be used to represent the eyelid height-width ratio calculation as shown in Fig. 4.

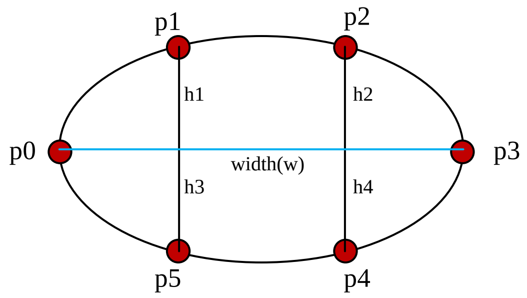

Figure 4. Eye aspect ratio calculation method.

The formula for calculating the aspect ratio of the eyelid is in (2):

$$EAR=\frac{h_1+h_2+h_3+h_4}{2w}. \tag{2}$$

In this paper, the average of the aspect ratios of the two eyes is calculated.

The eye aspect ratio reflects the various transformation features of the driver's eye in time series, as shown in Fig. 5, which plots the eye aspect ratio of the video clip as a function of time. As we can see, the eye aspect ratio is constant (indicating the eye is open), then rapidly drops to zero, then increases again, indicating a blink has taken place. Set a threshold α_2, when the eye aspect ratio is less than α_2, the eye is closed. The threshold for this article is set to 0.3.

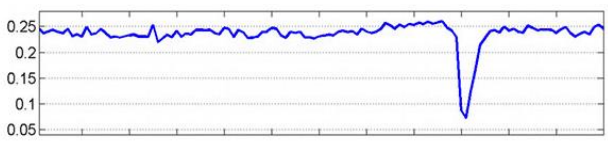

Figure 5. Eye aspect ratio changes over time.

The eye closure ratio can be obtained by counting the number of eye frames closed in the unit time.

b) Eye blink frequency

The blink frequency also plays a role in characterizing fatigue in the detection of fatigue. Blinking refers to a quick eye-closing behavior of the eye. The relevant data shows that the normal person's normal blinking frequency is about 15 times/minute, the completion of a single blink is 200~400 milliseconds, and the blink interval is about 2~6 seconds [12]. The specific time varies according to individual differences. Due to brain fatigue, there is a physiological feature that the duration of blinking becomes longer and the frequency of blinking increases.

The blink frequency is also measured by the aspect ratio of the eye. When the detection aspect ratio is lower than the threshold (i.e., close the eye), continue to detect whether it is higher than the threshold, and if it is higher, a blink will occur. The number of blinks in the statistical unit time is the blink frequency.

2) Mouth feature

In the fatigue test, the mouth also reveals fatigue information, and yawning is one of the fatigue characteristics in the mouth feature. When you are tired, you will yawn continuously and last longer [13]. Yawning is obvious in many features and easy to recognize. The most prominent feature of yawning is that the mouth opens much more than normal. Therefore, the judgment of the state of the mouth cannot only reflect the fatigue state, but also provide a good early warning of the fatigue state.

The mouth area is positioned through the face area 49-68 points, and then the degree of mouth opening is judged to complete the extraction of the mouth feature. Usually there are three states of mouth: closing, speaking and yawning. The most obvious feature of yawning is that the mouth closure is much larger than usual during a period of time. When yawning, the mouth is opened to the maximum. As shown in Fig. 6, the three states of the identified mouth are: closed, speaking, yawning.

Figure 6. Three states of mouth.

Then calculate the opening angle of the mouth(h) according to the coordinates of the mouth. This paper uses MOA to indicate the state of the mouth, i.e. MOA∈{close, speak, yawn}.

Calculate MOA according to points 49-68 (Fig. 7). The formula for calculating the mouth angle is shown in (3):

$$MOA=\frac{\|P63-P61\|^2+\|P67-P61\|^2-\|P67-P63\|^2}{2*\|P63-P61\|*\|P67-P61\|} \tag{3}$$

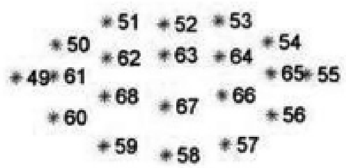

Figure 7. Mouth area coordinates.

After a lot of experimental tests, it was found that the threshold of the mouth in the closed state and the speaking state was 30 °, and the threshold of the speaking state and the yawning state was 60 °. When the mouth is more than 60 ° and lasts for more than 3s, it is yawned once. The equation is in (4):

$$\text{MOA}=\begin{cases}\text{closed} & h <= 30° \\ \text{speaking} & 30° < h <= 60° \\ \text{yawning} & h > 60°\end{cases} \quad (4)$$

3) Nodding fature

When fatigue occurs, the body often has a snoring condition and tends to lower the head. Fatigue is often accompanied by eye-closure [14], [15] when the head is bowed. At the same time, after a period of low-headed nap, there may be a sudden movement of raising head and waking up, which is accompanied by the movement of opening eyes at the same time. In this way, the head reciprocates up and down, that is, the nodding action is completed multiple times.

The state parameter of the driver's head is counted within a period of time, and the state of the eye is combined to determine the degree of fatigue of the driver. When the position of the corner feature point near the bridge of the nose is lower than the half-eye width of the initial state and the eyes are in a drowsy state, the duration is more than 0.5 seconds, the driver's nodding motion is detected.

C. Fatigue Judgment

1) Bayesian formula fusion

In this paper, a multi-feature fatigue decision method based on Bayesian [16] conditional probability formula is proposed, which fuses the characteristic [17]-[19] state of eyes, mouth and nodding to further obtain fatigue state.

The degree of eye closure, blink frequency, yawning, nodding and fatigue are different, so the directivity to fatigue is also different. This paper uses probability model to calculate the degree of fatigue.

Definition 1 Definition 1 $F(t)$ is the degree of fatigue of the driver at time t, $F(t) \in [0\ 1]$, where 0 is the fully awake state and 1 is the full fatigue state.

Definition 2 $P(F_i|x_i)$ characterizes the probability of being in a fatigue state when the fatigue characteristic x_i appears, $P(F_i|x_i) \in [0\ 1]$.

Definition 3 $P(x_i|F)$ represents the probability of fatigue characteristic x_i occurring during fatigue, $P(x_i|F) \in [0\ 1]$.

For the acquisition of the correlation degree $P(F_i|x_i)$, this paper adopts the method based on statistics and learning to carry on the continuity analysis of the collected reasonable samples, and uses the Bayesian formula to obtain the correlation degree, and continuously adjusts and adjusts the $P(F_i|x_i)$ value. It can be obtained by the Bayesian formula in (5):

$$\mathrm{P}(\mathrm{F_i}|\mathrm{x_i})\frac{\mathrm{P(F)*P(x_i|F)}}{\mathrm{P(x_i)}} \quad (5)$$

$P(F)$ represents the probability of fatigue, $P(x_i)$ represents the probability of occurrence of fatigue characteristic x_i, and $P(x_i|F)$ represents the probability of fatigue characteristic x_i occurring during fatigue, $P(F_i|x_i)$ represents the probability of fatigue when the fatigue characteristic x_i occurs. The fatigue correlation result of the fatigue characteristic x_i can be obtained by correlating the statistics and calculating the above parameters. Table I shows the correlation between multi-features and fatigue state, which is consistent with prior knowledge. Eye closure degree EAR has higher correlation with fatigue, blink frequency BF is second, and yawn MOA has medium correlation with fatigue and lowest nodding frequency NF.

TABLE I. CORRELATION BETWEEN MULTIPLE FEATURES AND FATIGUE STATE

$\mathbf{x_i}$	$\mathbf{P(F_i|x_i)}$
EAR	0.862
BF	0.706
MOA	0.605
NF	0.500

After setting the degree of association $P(F_i|x_i)$ corresponding to the single feature x_i, the fatigue degree $F_i(t)$ of the single feature, that is, $F_i(t) = P(F_i|x_i)$, can be obtained, as shown in Table II.

TABLE II. DEGREE OF FATIGUE OF A SINGLE FEATURE

$\mathbf{x_i}$	$\mathbf{P(F_i|x_i)}$	$\mathbf{F_i(t)}$
EAR	0.862	0.862
BF	0.706	0.706
MOA	0.605	0.605
NF	0.500	0.500

The degree of fatigue in the appearance of a single feature is relatively easy to obtain. When multiple features appear, it often indicates an increase in fatigue. In order to characterize the fatigue degree more accurately and reduce the limitation of fatigue judgment based on single feature, the multi-feature fatigue degree $F(t)$ is obtained from Bayesian formula by fusing multi-feature.

With n events A1, A2, A3, ... An independent of each other, we can get in (6), (7):

$$P(A1 \cap A2 \cap A3 \cap ... \cap An) = P(A1)P(A2)P(A3)...P(An) \quad (6)$$

$$P(A1 \cup A2 \cup A3 \cup ... \cup An) = 1 - P(\overline{A1})P(\overline{A2})P(\overline{A3})...P(\overline{An}) \quad (7)$$

The premise of fatigue state decision in this paper is that the effects of eye closure, blink frequency, mouth characteristics and nodding frequency on fatigue are independent of each other. Therefore, by introducing mutually independent preconditions, the calculation of multi-feature fatigue can be replaced by a formula. The correlation results between the multiple features and the fatigue state as shown in Table III were obtained.

$$F(t) = P(x1 \cup x2 \cup x3 \cup ... \cup xi) \\ = 1 - P(\overline{x1})P(\overline{x2})P(\overline{x3})...P(\overline{xi}) \quad (8)$$

TABLE III. FATIGUE OF MULTIPLE FEATURES

x_i	$F_i(t)$	F(t)
EAR	0.862	0.9900
BF	0.706	
MOA	0.605	
NF	0.500	

From the data of 0.9900 in Table III, it can be seen that when four kinds of fatigue characteristics occur simultaneously, the degree of fatigue *F*(*t*) is approximately equal to 1, i.e. complete fatigue, which accords with cognition. In addition, the introduction of mouth and nodding features not only increases the system reliability, but also improves the system's ability to predict fatigue.

2) Fatigue judgment

In this paper, the time window T = 30s is used to slide the continuous video data. The sliding interval is 1 second. The values of EAR, BF, MOA and NF in the time window are calculated and compared with the thresholds. If the values exceed the thresholds, the driver is in a fatigue state during the time period. Then the Bayesian formula is used to solve the fatigue probability. If the fatigue probability exceeds 0.8500, the driver is judged to be in a fatigue state at this time, and an alarm is given.

3) Test results

Awake state test results is shown in Fig. 8:

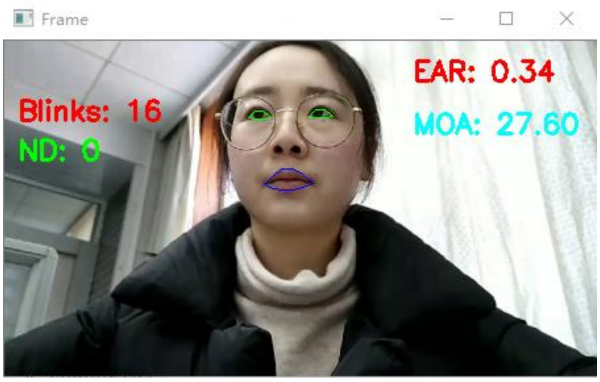

Figure 8. Awake state.

The probablity of fatigue is:

$$F(t) = 0.138*0.294*0.495*0.500 = 0.0100$$

0.0100<0.8500. The driver is not in a state of fatigue.

If fatigue is detected, an alarm is started. In the figure, DROWSINESS ALERT is used instead of the alarm. The fatigue state test results are shown in Fig. 9, Fig. 10, and Fig. 11:

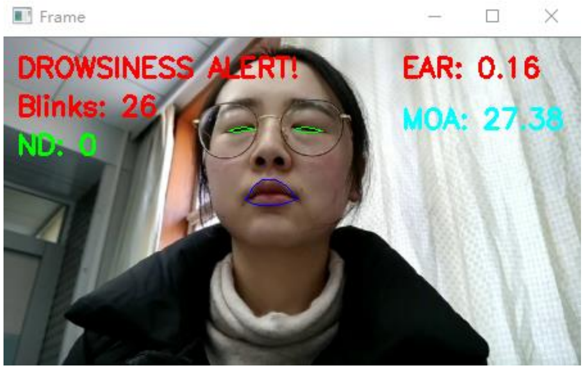

Figure 9. Eye closure.

We can see from Fig. 9 that both the eye closure and the blink frequency exceed the threshold. The mouth opening and nodding frequency did not exceed the threshold. The probability of fatigue is:

$$F(t) = 1\text{-}0.138*0.294*0.605*0.500 = 0.9877$$

0.9877>0.8500. Therefore, at this time, the driver is in a state of fatigue and the alarm is alarmed.

Figure 10. Yawning and eye closure

In Fig. 10, the eye closure, blank frequency and mouth opening exceed the threshold. Nodding frequency did not exceed the threshold. The probability of fatigue is:

$$F(t) = 1\text{-}0.138*0.294*0.495*0.500 = 0.9899$$

0.9899>0.8500. Therefore, at this time, the driver is in a state of fatigue and the alarm is alarmed.

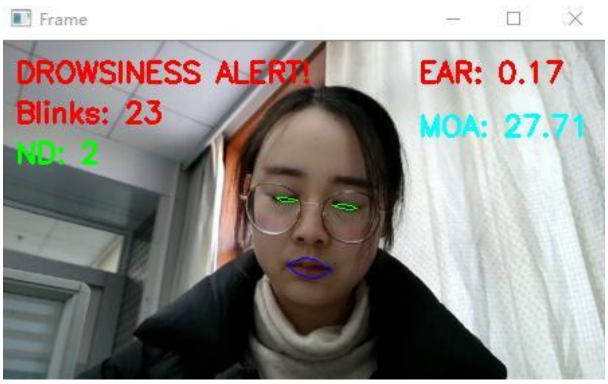

Figure 11. Noding and eye closure.

In Fig. 11, the eye closure, blank frequency and nodding frequency exceed the threshold. The mouth opening did not. The probability of fatigue is:

$$F(t) = 1\text{-}0.138*0.294*0.605*0.500 = 0.9877$$

0.9877>0.8500. The driver is in a state of fatigue and the alarm is alarmed.

III. Conclusion

In this paper, a non-contact fatigue driving detection method [20] is adopted. The captured video is firstly passed through a face detector to extract the features of the eyes, mouth and nodding. According to Bayes' theorem, the driver is judged to be in a fatigue state. If fatigue occurs, an alarm is issued. The design can detect the fatigue state of the driver, provide an alarm, help the driver to return to the awake state, and has good real-time performance to avoid traffic accidents.

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