Fatigue Driving Detection with Modified Ada-Boost and Fuzzy Algorithm

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Abstract: Facial features is the most important and obvious characteristics for the fatigue driving detection. This paper uses the modified Ada-Boost algorithm to detect face and to locate eyes and mouth precisely. The adaptive threshold is used to extract the characteristics of the eyes and mouth status. At last, fuzzy algorithm is used to judge the fatigue status which combined with PERCLOS rules. Experiments show that the proposed method has stronger robustness, faster speed, more accurate precision and meet the real-time demand.

Key Words: Feature expression, Ada-Boost algorithm, Fuzzy

1 INTRODUCTION

With the development of economy and technology, the car ownership is rapidly increased, as well as the traffic accidents are highly occurred. According to incomplete statistics, the casualties of traffic accidents caused by driver fatigue are 560 thousand, and the direct economic losses are tens of billions. Therefore, fatigue driving real-time online detection, real-time monitoring the driver's status have great significance for safe driving.

The detection of fatigue driving has four classes approaches: (1) physiological signals detection; (2) driver's behavior detection; (3) vehicle real-time status information detection; (4) driver's physiology response characteristics detection[1]. Among them, the best method is based on facial features detection which belongs to driver's physiology response characteristics approach possessing highly accuracy and real time computing results.

Facial features detection has been investigated for many years and several approaches have been proposed to achieve accuracy recognition. Yuan Wei Qi[2] proposed the statistical method to estimate the maximum open value, where the fatigue threshold was obtained by PERCLOS method combined with the experiments; Li Ying[3] combined Fisher, Grayscale templates, Hough transformations to detect eye status and constructed a combination detection algorithm. Unlike the former, Ma Ying[4] put forward the method of the improved "three Five Eyes" method to locate and detect facial features. Khan[5] proposed a vision-based fatigue driving real-time detection algorithm, which realized eye real-time monitoring and classification driver fatigue detection by correlation function classifier and automatically generated online template.

Overall, the most widely used method is the PERCLOS approach[6], but this method also has some limitations, just rely on single data to determine the results, and the results in some cases can't be timely and accurate real-time effective judgments.

In view of the above problems, the paper improves the detection algorithm and proposes a new algorithm, which not only relies on the eye as a basis for judging fatigue, but also uses mouth judgment for facial features detection. On this basis, the Ada-Boost algorithm[7-9] and the fuzzy algorithm[10] are combined to identify fatigue driving. The eye and mouth positioning are performed for face detection by the Ada-Boost algorithm. The fuzzy method is used to judge the eye and mouth, and the membership function is designed to accurately and effectively identify the fatigue status.

2 FEATURE EXTRACTION AND DISCRIMINANT

2.1 Identify faces with Ada-Boost algorithm

The Ada-Boost algorithm is an iterative algorithm. The core idea of it is to train different weak classifiers for the same training set, and then combine the trained weak classifiers to form a stronger final classifier. Then, the weight of these classifiers becomes larger and reduces their numbers to make them more specific. Finally, we can get the result of the classification. The Ada-Boost algorithm based on the Haar feature are listed as follows:

Definen samples to be entered $(x_1,y_1),\ldots,(x_n,y_n)$, where x_i is the input i-th sample, and y_i represents the attribute value of the corresponding element. The number of positive and negative samples are a, b, $\mathrm{n}=\mathrm{a}+\mathrm{b}$.

The weight of the initial training sample x_i is D (i): $\mathrm{i}=1,\ldots,\mathrm{n}$; If the number of positive and negative samples are the same, then, we have

$$D_{1(i)}=\frac{1}{n}. \tag{1}$$

If the number is different, define the proportion of positive samples are:

$$D_{1(i)}=\frac{1}{n_+}\ , \tag{2}$$

and negative samples are:

$$D_{1(i)}=\frac{1}{n_-}\ . \tag{3}$$

Then, the error is expressed as:

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$$\varepsilon_t = \sum_{i=1}^{m} D_t||y_{i\neq h_{t(Xi)}}|| \quad (4)$$

After a training session, if the samples are divided correctly, it does not calculated into the error inside; otherwise, it will be included in the error.

The error rate can be yields:

$$\alpha_1 = \frac{1}{2}\ln\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right), \quad (5)$$

then the proportion of the wrong sample becomes:

$$D_{1(i)} \times \left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) . \quad (6)$$

After T cycles, the final strong classifier can be obtained as:

$$H_{(X)} = sign\left(\sum_{t=1}^{T} \alpha_t h(x)\right). \quad (7)$$

The two important parts of the training algorithm are the selection of Haar features and the calculation of eigenvalues.

The image is modeled by the gray histogram which with horizontal projection and vertical projection. Then, the threshold of the image is obtained according to the result of the above methods. In this paper, multiple thresholds are selected, thus different facial detail features are obtained, which can get more accurate fatigue driving detection results than single threshold.

2.2 Positioning eyes and mouth

The positioning of the eyes and mouth are the most important steps for fatigue driving detection. Since eyes position with a wealth of edge characteristics, firstly, image marginalization is detected; then, the position is located by Ada-Boost algorithm. The classifier training of eyes and mouth are the same as the face classifier, but the face features are replaced with eyes features and mouth features. According to a number of the same size of the eyes, mouth pictures and non-eyes, non-mouth pictures which are positive and negative samples, the position of the eye and mouth are trained with the Ada-Boost algorithm and the results are pinpoint obtained.

2.3 Positioning area binarization

Image binarization process can produce a better segmentation results. In order to extract the desired features more accurately, the binarized image is corroded and swollen to remove the effects of the eyelids and other regions on the fatigue discrimination. Thus, a valid binary image of the eye and mouth can be obtained.

2.4 Eye feature extraction and analysis

In this paper, PERCLOS value is selected for the method of the eye fatigue determining. The PERCLOS value can be defined as the percentage of eyes closure time per unit time. The length of the eyes closure time is closely related to the driver's fatigue. Experiments show that the PERCLOS value of P80 (the eye close more than 80% of the time percentage of unit time) are that the driver fatigue has the best correlation. So that it is inspired to use the ratio of the number of eyes to the total number of pictures in the unit time as the desired PERCLOS value. The measurement principle of PERCLOS value illustrates in Figure 1.

T1 is the time that the eye closes to 80%, T2 is the time taken to close the eye from 80% to 20%, T3 is the time that the eye closes to 20%, and T4 is the time that the eye opens from 20% to 80%. The f is the percentage of the time that eyes close in a specific time. For the measurement method of P80, we take $f > 0.15$, which means the driver in a status of fatigue. The PERCLOS value can be calculated as:

$$f = \frac{t_3 - t_2}{t_4 - t_1} x100\% . \quad (8)$$

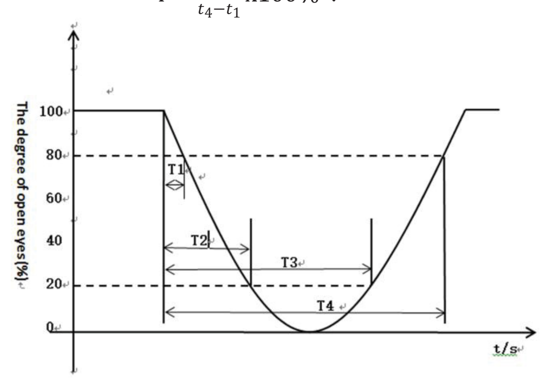

Fig 1. Measuring principle of PERCLOS

2.5 Mouth feature extraction and analysis

When people are in a status of fatigue, the number of yawns will increase significantly. Thus the standard of fatigue can be judged by the percentage of the total opening time of the mouth in the unit time. Lateral length and longitudinal height in normal human mouth and yawning situation are different, it is possible to detect the mouth status by the aspect ratio of the mouth. In this paper, a rectangular box is used to position the mouth. Define the leftmost coordinate of the mouth as X_{min} ,the rightmost coordinate as X_{max} , the top coordinate as Y_{max} ,the lowest coordinate as Y_{min} . Then, the length and width of the mouth can be expressed as:

$$L = X_{max} - X_{min} \quad (9)$$

$$V = Y_{max} - Y_{min} \quad (10)$$

The vertical and horizontal ratio of the mouth can be obtained

$$Z = \frac{V}{L} \quad (11)$$

When the mouth closed, Z = 20%, when it is fully opened, Z = 50%. Therefore, the mouth in a half status is Z $\geqslant$ 35%.

Mouth in the closed, half open, all opened are separately defined as a,b,c , the number of half of the mouth in all open pictures is defined m, and the pictures number is M, When the pictures are passed into the camera, if the mouth is closed, then $a = a + 1$; if the bit half, then $b = b + 1$; if full open, then $c = c + 1$. Finally, we have

$$K = \frac{m}{M} = \frac{b+c}{M} \quad (12)$$

3 FUZZY DESIGN

3.1 Principle of fuzzy identification

Because of the random overlap of feature in the process of target conversion, the single identification mode is difficult to meet the requirements and even misidentification. In this paper, fuzzy method is used to discriminate the multiple features to obtain more accurate results.

The fuzzy identification can be divided into the following three steps:

(1) Select the characteristics of the identified object: Information acquisition;

(2) construct the membership function of fuzzy model;

(3) identify the features with the maximum membership principle.

Assume the face has k characteristics, the q efficient features is selected to extract. These q features are correspond to q membership degrees: $\mu 1, \mu 2, \cdots \mu q$. Then, we have:

$$F = \sum_{i=1}^{q} a_i \mu_i \tag{13}$$

where a_i, $i = 1,2,\ldots,q$ are weight coefficients.

Define the fuzzy set $U = \{x1, x2, \cdots, xn\}$. The human status is divided into three types as three fuzzy subsets $Ai \in F(U)$ $(i = 1, 2, 3)$ on U by clustering. A1 is in the normal state; A2 is the critical state; A3 is the fatigue state. This paper extracts two main indicators to describe the status of each standard person $\underset{\sim}{A}i$ $(i = 1, 2)$:

(1) η1: PERCLOS method is used where η1 = Total closed eyes time/total time;

(2) η2: The ratio of the mouth longitudinal length to the transverse length.

3.2 Process

Table 1 Index of feature detection

Status	Feature detection (indicator)	
	η 1	η 2
Normal A1	$\overline{x_{11}}$	$\overline{x_{12}}$
Critical A2	$\overline{x_{21}}$	$\overline{x_{22}}$
Fatigue A3	$\overline{x_{31}}$	$\overline{x_{32}}$

For each standard face status A_i, the two indicators are also fuzzy set $\underset{\sim}{A}i = (\underset{\sim}{A}i1, \underset{\sim}{A}i2$ $(i = 1, 2, 3))$ (See Table 1). A variety of standard face status are tested through a large number of tests, where $\eta 1\left(\underset{\sim}{A}i1\right)$, $\eta 2\left(\underset{\sim}{A}i2\right)$ are normal fuzzy sets. The corresponding membership function can be defined as:

$$\underset{\sim}{A_{ij}}(x_j) = \begin{cases} 0, & |\, x_j\text{-}\overline{x}_j\,| > 2s_j \\ 1 - \left(\frac{x_j-\overline{x}_j}{2S_j}\right)^2, & |\, x_j\text{-}\overline{x}_j\,| \le 2s_j \end{cases} \tag{14}$$

where the $\overline{x}_j$ is the mean value; $2s_j$ is the standard deviation $(i = 1, 2, 3; j = 1, 2)$:

$$A_i(x) = \frac{1}{2}\sum_{j=1}^{2} \underset{\sim}{A_{ij}}(x_j) \tag{15}$$

Different two indexes have different influence on the identification of three kinds of Status. That is, the weight of two indicators are different. Let the weight is w_j $(j = 1, 2)$, we have:

$$A_i(x) = \frac{1}{2}\sum_{j=1}^{2} w_j \underset{\sim}{A_{ij}}(x_j) \tag{16}$$

3.3 Maximum Membership degree

Set $\underset{\sim}{A}1, \underset{\sim}{A}2, \underset{\sim}{A}3, \ldots\ldots \underset{\sim}{A}q$ are q standard Model. Among them $\underset{\sim}{A}i = \left(\underset{\sim}{A_{i1}}, \underset{\sim}{A_{i2}}, \ldots \underset{\sim}{A_{ik}}\right)$, $x^\circ = (x_1^\circ, x_2^\circ, \ldots, x_k^\circ)$ are normal vector. If presence of $i \in \{1, 2, \ldots, q\}$ makes $\underset{\sim}{A_i}(x^\circ) = \max\{\underset{\sim}{A}1(x^\circ), \underset{\sim}{A}2(x^\circ), \ldots, \underset{\sim}{A}q(x^\circ)\}$ hold, that $x^\circ = (x_1^\circ, x_2^\circ, \ldots, x_k^\circ)$ is relatively subordinate to $\underset{\sim}{A}i$.

4 EXPERIMENT RESULTS

The goal of Ada-Boost algorithm is to locate the eyes and mouth accurately. A strong classifier is obtained by the modified Ada-Boost algorithm and the final position is obtained. Figure 2 and 3 show the results of the modified Ada-Boost results.

The classifier is obtained after training by the modified Ada-Boost algorithm in figure 2. The training error is illustrated and that shows it nearly to zero at 6 second.

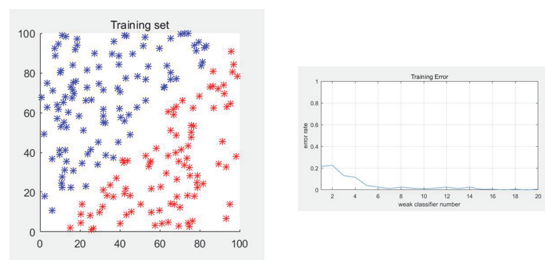

Fig 2. Training results of Ada-Boost model

Figure 3 is the test results after training, it is clearly shown that the classifier can be well done by modified Ada-Boost algorithm.

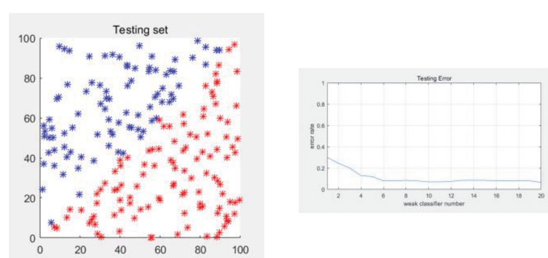

Fig 3. Testing results of Ada-Boost model

The camera captured face images is preprocessed and the Ada-Boost algorithm is used for positioning. Then, to select the mouth and eyes pictures transformed into binary maps by the threshold, afterwards, calculate the PERCLOS value of the eyes and the Z value of the mouth. Finally, the fuzzy algorithm is applied to determine the fatigue value and obtain the results.

The following figures are the examples of identification. In Figure 4, (1) is the acquired image, (2) is the result of the grayscale processing image, (3) is the result of face position, (4) is the result of the positioning of the eyes and the mouth, and (5) is the final binarized image. Finally, the result is fatigue by the fuzzy recognition. Figure 5 is non-fatigue identification figures.

(1) (2) (3) (4) (5)

Fig 4. Fatigue identification figures

(1) (2) (3) (4) (5)

Fig 5. Non-fatigue identification figures

By using the simulated images, the results of the two features detected in three states (mean + variance) are shown in table 2, When the weight coefficient w = {0.6,0.4}, it has more accuracy.

Table2 Index of feature detection

Status	Feature detection (indicator)	
	$\eta 1$	$\eta 2$
Normal A1	**0.0715±0.0005**	**0.93±0.0066**
Critical A2	**0.1215±0.0005**	**0.465±0.0024**
Fatigue A3	**0.1468±0.0002**	**0.28±0.0085**

5 CONCLUSION

In this paper, we studied the method of image detection of fatigue driving. Since single judgment of PERCLOS algorithm has limit, a modified Ada-Boost algorithm was proposed with multiple elements to identify the fatigue driving. The fuzzy method was applied to combine the eigenvalues of the eyes and the mouth for judging whether the fatigue was comprehensive or not. The combination of the two features was more reliable than judging the fatigue by using one feature alone. Experiments and simulations demonstrated the effectiveness of the proposed approaches.

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