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Design and Implementation of a Fatigue Detection System Based on Dlib for Driver Facial Features

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Abstract. There are currently three commonly used methods for detecting fatigue driving, namely physiological feature based detection, vehicle driving information based detection, and driver behavior feature based detection. The first two methods have issues such as invasiveness to drivers and low detection accuracy, which makes them unable to be put into large-scale use under actual production conditions. This article adopts a driver fatigue detection method based on Dlib, using the 68 person face feature point model database contained in the Dlib database for facial localization. The driver is judged whether they are tired driving by the three fatigue features of blinking, yawning, and nodding. The three features are standardized, and the number of blinking, nodding, and yawning is counted using coordinate points to determine whether they are tired. The recognition success rate is about 95%, More than 90% reach the application level.

Keywords: Fatigue characteristics, Dlib, face recognition, raspberry Pi

1. Introduction

With the continuous development of the automotive industry and the rapid development of China's economy, the development speed of freight transportation systems based on these two modes is also accelerating. It is a common practice in the industry for truck drivers to stay up 24 hours in the car to avoid traffic congestion. According to the National Bureau of Statistics of China, fatigue driving accounts for 20% to 30% of car accidents, and 50% of people have experienced fatigue driving. Especially on highways, among the serious traffic accidents that have occurred in recent years, drivers' fatigue driving accounts for over 40%. Fatigue driving refers to a decrease in responsiveness caused by a lack of sufficient sleep or prolonged driving [1-2].

For fatigue driving, if a timely warning can be given before an accident occurs, it will greatly reduce the occurrence of accidents. If a driver issues a warning one second before a fatigue accident, the probability of accidents caused by driving fatigue will be reduced by 90%. Therefore, it is necessary to effectively reduce the incidence of traffic accidents, provide fatigue warnings for drivers, and take corresponding preventive measures in a timely manner. There are currently multiple methods: 1) Road warning system, which is a computer-controlled infrared monitoring system installed on highways, that alerts the driver when the vehicle swings on the centerline or shoulder of the road. 2) The drowsiness detection system uses a combination of Doppler radar and

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signal processing technology to obtain information that reflects the driver's psychological emotions, eye position and status, blink frequency, and duration to detect fatigue driving [3-4]. 3) A device for measuring the position of a head. It is designed for the driver's seat, and each sensor can output the driver's head position from this sensor. By real-time tracking the position of the driver's head and determining whether the driver is napping based on changes in head position. 4) Steering wheel monitoring system. A sensor system suitable for abnormal movement of the steering wheel in various types of cars. The sensor system will not alarm when the steering wheel is in normal motion, but will issue a warning when it is abnormal. The above is a measurement based on physiological signals, which require wire connections in multiple parts of the driver's body and a large number of sensors, even wearable sensors, to measure the driver's physiological signals. This can hinder driving and is not conducive to safe driving [5].

This article designs a driver fatigue detection system based on Dlib, which includes a set of C++ open source machine learning algorithms and is a machine learning software for solving complex practical problems. Dlib has now been widely used in industry and academia, such as robots, embedded devices, mobile phones, and large-scale high-performance computing environments. Dlib is open source and free, and choosing the Dlib model can effectively reduce costs and make implementation simple.

The contributions of this article are summarized as follows:

1) Targeted selection of datasets for fatigue systems.

2) Design a framework for driver fatigue detection system.

3) The system was tested and analyzed.

The remaining parts of the paper are organized as follows: in the second section, the dataset is selected, in the third section, the system framework is designed, with a focus on the design of the blink detection module, yawn detection module, and nodding detection module. In the fourth section, the system is tested and analyzed, and in the fifth section, the full text is summarized.

2. Data preparation

2.1 Facial dataset

Face dataset adopts shape_predictor_68_face_landmarks.dat dataset is a dat model library for detecting 68 key points in human faces. Using this model library, it is easy to perform face detection and perform simple applications. Extracting facial feature points is to surround each part with 68 points, draw 68 points on the face, and indicate their serial numbers. The change in distance between these points can be used to determine the changes in the face, such as whether to blink or not. The 68 feature point calibration function implemented is shown in Figure 1.

2.2 Drowsiness dataset

The drowsiness detection dataset uses the driver drowsiness video dataset collected by the Computer Vision Laboratory of National Tsinghua University. The entire dataset (including training, evaluation, and testing datasets) includes records of 36 participants from different races in various simulated driving scenarios (including normal driving, yawning, slow blinking, and nodding). The training dataset includes 18 subjects from 5 different scenarios (day, night, showing up, wearing sunglasses, and glasses). The sequence of each object, including yawning, blinking, and nodding, is recorded for approximately one minute each. The evaluation and testing dataset contains 90 driving videos.

Figure 1. 68 facial feature points

3. System Design

3.1 System architecture

The driver fatigue detection system based on Dlib mainly consists of an image acquisition module, a fatigue processing module, and a voice module. By using a camera, it can detect information such as the driver's position, pupil direction, opening and closing degree, blinking frequency, and pupil narrowing. Based on this information, the driver's focus is judged in real-time, whether the driver is tired is judged, and corresponding safety voice warnings are provided. The overall architecture is shown in Figure 2.

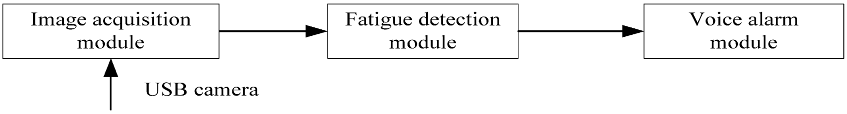

Figure 2. Overall architecture

3.2 Image acquisition module

The driver's facial images were collected through the camera, and the Dlib model was used to process the images, dividing the three fatigue features into coordinates. Due to the lack of a camera in Raspberry Pi, an additional camera needs to be connected. The image processing flowchart is shown in Figure 3.

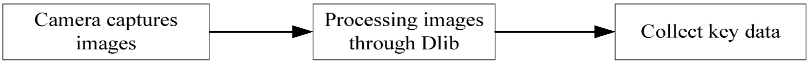

Figure 3. Image processing flowchart

3.3 Fatigue detection module

Fatigue detection is divided into three features, namely the mouth, eyes, and head. These three parts can be detected separately or combined to improve accuracy. The flowchart is shown in Figure 4.

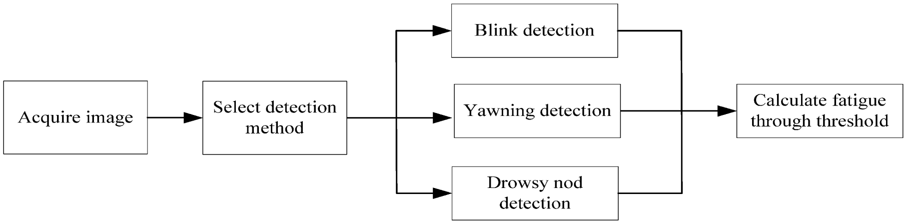

Figure 4. Fatigue detection flowchart

The characteristics of fatigue include blinking, yawning, nodding, and using a computer camera for simulation training before transplanting it to Raspberry Pi for practice.

3.3.1 Blink detection

1) Calculate eye aspect ratio
The formula for calculating the eye aspect ratio (EAR) is shown in formula (1).

$$EAR = \frac{\|P2 - P6\| + \|P3 - P5\|}{2\|P1 - P4\|} \tag{1}$$

When a person's eyes are open, EAR will fluctuate with a certain value, while when the eyes are closed, EAR will sharply decrease to almost zero. Therefore, when EAR is below the set threshold, the eyes are closed [6]. The eye reference point is shown in Figure 5.

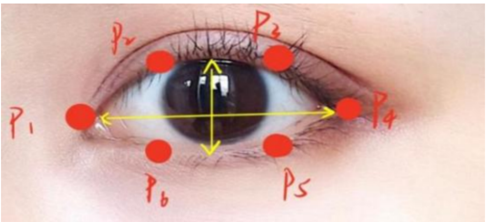

Figure 5. Eye reference point

2) Calculate the number of blinks per unit time
When the eyes are closed, the opening and closing degree of the eyes changes from large to small, while when the eyes are opened, the opposite is from small to large. Normal eye closure and eye opening are not features of fatigue detection. During fatigue, drivers may frequently open and close their eyes for a period of time, or enter a sleep state with their eyes closed. Therefore, the features that need to be detected are the number of alternating times of opening and closing eyes per unit time and the longest time of closing eyes. Dividing time into frames can avoid detection omissions, and determining whether a person's driving state is fatigue driving by setting thresholds for the number of times and duration of eye closure per unit time. Looking at the facial feature points in Figure 6, you can determine the coordinates of the left and right eyes.

Figure 6. Facial feature points

The formula for left and right eye opening and closing is shown in formula (2):

$$EyeOpenness = normalize\left(\frac{p_{42} \bullet y + p_{41} \bullet y - p_{38} \bullet y - p_{39} \bullet y}{p_{40} \bullet x - p_{37} \bullet x}\right) \tag{2}$$

In the formula, p is the feature point, x is the horizontal coordinate, and y is the vertical coordinate. If the absolute difference between the aspect ratio of the two eyes in the current frame and the previous frame exceeds 0.2, it is considered fatigue.

3.3.2 Yawning detection

The opening and closing of a person's mouth are different, so the mouth can be used as one of the feature points for detecting fatigue. However, the difficulty of detection lies in the fact that the mouth is open when speaking and yawning. It is difficult to distinguish whether a driver is fatigued by simply judging whether the mouth is open or closed [7]. How to accurately determine whether the driver is speaking, exhaling, or feeling tired and drowsy has become a challenge for mouth features. After experiments, it was found that the mouth can be divided into two aspects: internal and external contours, as shown in Figures 7-1 and 7-2.

Figure 7-1. Outer contour

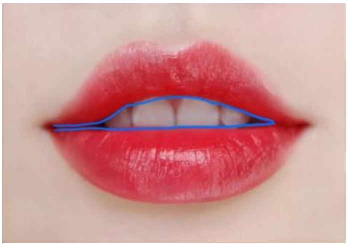

Figure 7-2. Internal contour

The opening and closing of the mouth can be distinguished by the external contour. It can be seen that the opening amplitude of yawning is different from that of regular mouth opening speech, and the internal contour of yawning changes even more, as shown in Figure 7..Setting two variables for the mouth, one to detect the opening and closing of the mouth, and the other to detect the opening and closing amplitude of the mouth, can solve the problem of yawning detection by combining the two.

We can calculate the opening amplitude of the inner and outer contours of the mouth using the mouth feature coordinate values obtained from the Dlib library. The mouth coordinate division is shown in Figure 8.

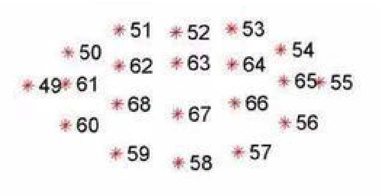

Figure 8. Mouth reference point

It is usually impossible for a person to yawn in an instant, and it will go through a brewing process. Therefore, the detection time for yawning can be calculated by frames. The screen can be divided into frames, and the time required for yawning is usually three to four frames per unit. Within this unit of time, detecting yawning may be fatigue driving, so continue to detect, if yawning is detected for several consecutive units of time, it is considered fatigue. The calculation formulas for the amplitude of internal and external tension are formulas (3) and (4), where P is the coordinate of the feature point.

$$mouth1 = \frac{\|P51 - P59\| + \|P53 - P57\|}{2\|P55 - P49\|} \tag{3}$$

$$mouth2 = \frac{\|P62 - P68\| + \|P64 - P66\|}{2\|P55 - P49\|} \tag{4}$$

3.3.3 Drowsy nod detection

The state of head posture should also be considered as one of the indicators of driver fatigue. The determination of head posture is based on the real-time rotation angle of the head posture. The three parameters for head rotation are Yaw, Pitch, and Roll. When drivers are fatigued while driving, their heads will clearly tilt as if they are swinging their heads and bodies left, right, or back and forth. From the head posture shown when people doze off, it is rare for their heads to sway left and right, mainly nodding up and down and tilting left and right. The threshold limit for setting the parameter is 0.3. Within 10 seconds per unit time, when the throwing angle is greater than or equal to 20 degrees or the proportion of the up and down nodding angle is greater than or equal to 20 degrees exceeds 0.3, the driver is judged to be dozing off and a rest warning is issued. The head rotation is shown in Figure 9.

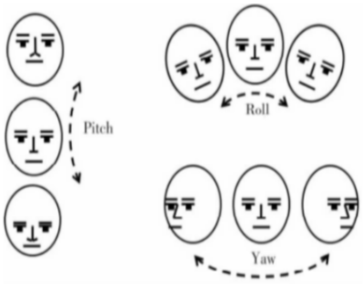

Figure 9. Head rotation angle

This article uses the Head Pose Estimation algorithm, which mainly involves detecting 2D facial key points, matching them with 3D facial models, solving the conversion relationship between 3D points and corresponding 2D points, and solving the Euler angle based on the rotation matrix. We use OpenCV to solve the function solvePnp()

of the PnP problem, calculate the rotation matrix, and then calculate the Euler angle according to formula (5).

$$R = \begin{pmatrix} r_{00} & r_{01} & r_{02} \\ r_{10} & r_{11} & r_{12} \\ r_{20} & r_{21} & r_{22} \end{pmatrix} = \begin{pmatrix} \cos\phi\cos\gamma & -\cos\phi\sin\gamma & \sin\phi \\ \cos\varphi\sin\gamma + \sin\varphi\sin\phi\cos\gamma & \cos\varphi\cos\gamma + \sin\varphi\sin\phi\sin\gamma & -\sin\varphi\sin\phi \\ \sin\varphi\sin\gamma - \cos\varphi\sin\phi\cos\gamma & \sin\varphi\cos\gamma + \cos\varphi\sin\phi\sin\gamma & \cos\varphi\sin\phi \end{pmatrix} \quad (5)$$

In formula (5), R is the Euler matrix, r is the angle between the new coordinate and the x, y, and z axes of the old coordinate.

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$$\varphi = \operatorname{atan}(-r_{12}, r_{22}),\ \phi = \operatorname{atan}(r_{02}, \sqrt{r_{12}^2 + r_{22}^2}),\ \gamma = \operatorname{atan}(r_{01}, r_{00})$$

3.4 Voice alarm module

The voice broadcasting module is implemented using Raspberry Pi, and porting the program to Raspberry Pi can issue a warning message.The voice broadcast module also includes a screen that displays the detection results of the driver's three feature points, which can be reflected in real-time on the Raspberry Pi, selecting the feature points you want to detect, equivalent to a small computer.

4. System testing

This article conducts simulation testing on a driver fatigue detection system based on Dlib. Hardware environment: The PC CPU uses AMD Ryzen™ 53600X, six core 12 threads, frequency 3.8GHz, total DDR4 memory 32GB. Software environment: Use Windows 10 Professional Edition, version number 20H2, use the Pycharm development environment, and configure the Dlib library. This article tested 1400 images and tested their accuracy for features such as blinking, yawning, and nodding. The test results are shown in Table 1, and the accuracy rate of the test results is about 92%, with over 90% reaching the application level.

Table 1. Test result

Test type	Total number of images (Number)	Number of detected objects (Number)	Detection accuracy (%)
Blink	600	556	92.67
Yawn	379	348	91.82
Drowsy nod	421	389	92.40

5. Conclusions

This paper first analyzes the research background of fatigue driving detection, points out the shortcomings of detection methods based on physiological features and vehicle driving information, and analyzes the advantages of detection methods based on driver behavior characteristics. A driver fatigue detection system based on Dlib is designed. Firstly, the dataset was selected and the system framework was designed, focusing on the blink detection module, yawn detection module, and nodding detection module. Simulation testing was conducted on the system, and the accuracy rate reached about

92%, which can reach the application level.The next step will be to apply the system in practice and continue to improve recognition accuracy.

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