Efficient Train Driver Drowsiness Detection on Machine Vision Algorithms

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Abstract

In order to give a warning to the drowsy driver, this paper proposes a new Fatigue Driving Detection Algorithm. AdaBoost algorithm is applied to fast detect and track human faces, and the algorithm is implemented in FPGA; differential template-based multi-algorithms are used to localize human eyes and recognize eye states; PERCLOS algorithm is adopted to analyze and determine whether a person is fatigue. Test is implemented based on DM368 add FPGA platform ,and confirms that the algorithm used in the paper can quickly and accurately locate the face and the human eye, and determine the status of the driver's fatigue. Experimental results show that the algorithm has high recognition accuracy and robust performance under real train driving environment, even in head rotation, eye movements and wearing glasses was the case.

Keywords: PRECLOS, template matching, Face detection, Eye Localization, Eye States Recognition

1. Introduction

The As the development of the transportation system and the increase of vehicle owners, traffic accidents happen more frequently recently. Thus more emphasis should be put on the preventive measures. 210812 traffic accidents happened on 2011 and 62387 people are killed in China [1]. Of all the reasons of traffic accidents, factors related to drivers themselves occupy a higher percentage. 20% of UK road accidents caused by fatigue [2], and the figure is closer to 40% in Australia [3]. Research on Driver Fatigue Detection System, which aims to ensure the safety of operations and reduce traffic accidents caused by artificial factors related to drivers, has been a research focus in the area of transportation safety abroad and at home. Drivers' behaviors such as visual delay, false determination on the environment and inappropriate handling of emergencies just before the accidents have close connection with the breakdown. Visual delay and mishandling of emergencies are common faults for high-speed train drivers, heavy rail freight locomotive drivers and car drivers. According to related materials, if the latent dangers could be warned to drivers several seconds before they become out of control, 90 percent of the traffic accidents could be avoided [2-3]. Actually, visual delay is the appearance of fatigue, so we should improve the early warning system for fatigue driving. In this way, a large number of traffic accidents will be reduced. It's important to realize the real-time monitoring of drivers and vehicles condition and send out warnings when abnormal cases happen.

Previous research on driver drowsiness detection has focused on medical science, people considered the fatigue driving from an aspect of medical science with the help of medical electroencephalograph (EEG), electrocardiograph (ECG) and electromyography (EMG) to detect a driver's EEG waveform, ECG waveform and EMG wave-form [4-8]. In spite of the accuracy of medical methodology, it's complicated and need certain environment which made it hard to generalize. The method we'll discuss in this paper, fatigue driving based on image processing, is deemed as the most potential one. The research "An Evaluation on Various Vision-based Fatigue Driving Detection Methods" which was conducted in 1998 compared four methods and nine parameters fatigue driving results, and PRECLOS especially P80 detection method shows it's superiority [4-5], figure 1.

In order to avoid or reduce the traffic accidents, warnings to a fatigue driver should be accurate and prompt, thus made it impossible for a single algorithm and hard-ware to realize

this function. In this paper, we use a distributed algorithm system combining the pipeline structure of its hardware implementation. The main topics contained are: In order to avoid or reduce the traffic accidents, warnings to a fatigue driver should be accurate and prompt, thus made it impossible for a single algorithm and hard-ware to realize this function. In this paper, we use a distributed algorithm system combining the pipeline structure of its hardware implementation. The main topics contained are:

Analyzed and improved the AdaBoost algorithm which is used to fast localize human faces and track the movements on a Field-Programmable Gate Array (FPGA) chip.

Eyes localization, tracking and eyes state recognition are realized by using DSP. Eyes localization, tracking and eyes state recognition require immediate and accurate processing. Single recognition, tracking and location methods are not so useful any more, we need to merge different algorithms. The strong floating point arithmetic capacity of DSP satisfies our requirements. This part of research is crucial for the entire fatigue driving detection system. Performed fatigue recognition analysis algorithm in Micro Controller Unit (MCU).
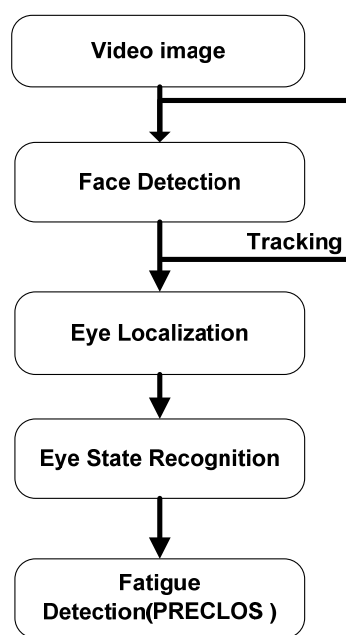

Figure 1. Driver fatigue detection process

2. Face Detection
2.1. Algorithm of Face Detection

Algorithms for face detection face many challenges; for example, facial expression, illumination condition and vibration. There are several mainstream methods for face detection, artificial neural network method, template matching method, skin color detection method, motion detection method and AdaBoost face detection algorithm. Therein, skin color detection method is useful when it comes to multi-face detection and tracking. Systems based on color can recognize human faces from different visual angles, but this method adapts to color image and cannot be used in night mode [9-10]. Template matching method mainly recognizes human faces by the geometrical relationship within face structure. As for illumination and pose variation and covered partial human faces, this method shows its drawbacks. AdaBoost algorithm is adaptable to light variation, anti-shake and can localize human faces with all-weather conditions [10-11].

2.2. Implementation of Modified AdaBoost Algorithm

Figure 2 is the detection process of AdaBoost algorithm, Viola and Jones [12-13] came up with the cascade of the Haar classifiers, which enhances the computational speed without

sacrifices its detection rate. In this paper, we modified Viola and Jones algorithm according to the characteristics of FPGA. First, we used 16 classifiers as parallel computing tool. We changed the training mode for Haar classifier, each stage has 16 integer multiple of the number of classifiers. Also, the output passing rate of Bayesian training algorithm is modified to insure the overall detection rate and false alarm rate remain un-changed after modified the number of classifiers. The eventually trained Haar classifier contains 40 stages, 2192 classifiers and 4680 features. The trained results have been verified on CMU frontal face image library and achieved a very good recognition rate.
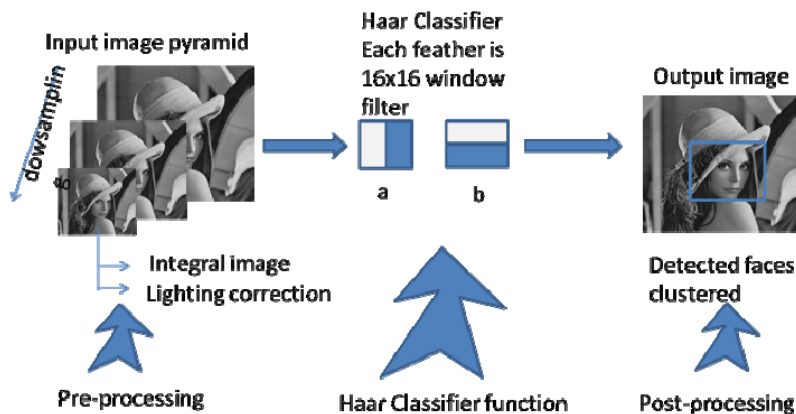

Figure 2. Face detectin flow based on the Haar classifiers

2.3. Implementation on FPGA

This paper takes the advantages of parallel processing and pipelining computing of FPGA to design. The characteristics of this design are as below:

Only the region of the picture through all of the stages is considered as human face region, and each stage contains 16 integer multiple of the number of classifiers, figure 3. In this paper, we designed to simultaneously process the computing of 16 classifiers, and could obtain a speed 16 times faster than the traditional computing process.

Because each stage declines regions that don't contain face area, declined regions cannot enter the next stage [11-13], Figure 3. The pass rate of the first stage in this design is 20%, while traditional pass rate is 50%. Because most of the computation is centralized on the first stage, as long as image region is blocked by the first stage, then there is no need to initialize parameters for the second stage. Thus time wasted on initialization will be cut off.

A classifier unit is designed using pipeline structure, Figure 4. It uses five stage pipelines, includes processes such as read from memory, Haar feature computation, threshold determination. A classifier unit contains two or three Haar feature computation. In this paper, we adopted three feature computations which are compatible to two Haar feature computations. 16 identical classifiers are built in the FPGA. We can convert them to different stages by initializing them with different parameters.

3. Face Eye Localization and Eye State Recognition

In this paper, we concentrate on train drivers. After obtaining a large number of drivers' eyes pictures, we formed a general eye pattern for train drivers. Therefore, after detection human faces, sensitive eye areas are obtained through general eye pattern, then time difference method is applied to video image sequence and obtain eye difference image [14] [15]. Adding N eye difference images deduce frame differential accumulation figure, and then the eye position.
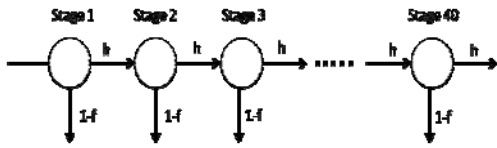
Figure 3. Cascade of the Haar classifiers, where hit rate is h40 and false alarm rate is f40
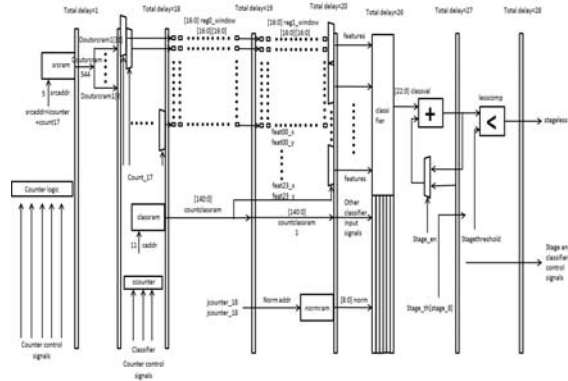

Figure 4. Pipelined design of face detection accelerator in FPGA

We use PRECLOS as the criteria for fatigue judging. PRECLOS is recognized as the most effective vision-based fatigue evaluation method [15-17]. It's also the standard measurement of fatigue driving recommended by the U.S. Highway Traffic Safety Administration. PRECLOS is the time ratio of eye slowly close in a certain period of time rather than rapid eye blinking. Person whose eyelids are closed at least 80% time within one minute is defined as sleeping [4] [18-19]. Eye state recognition should be conducted as soon as eye localization finishes.Eye position, open eye pattern and closed eye pattern of a detected person are obtained by frame differential accumulation figure [15-16]. Then use closed and open eye pattern to determine whether this person is fatigue or not[7]. Above is the template matching algorithm, where Pm,n (i,j) denotes the pixel value of eye coordinates i, j. T(i,j) denotes the pixel value of pattern coordinates i, j. S(m,n) denotes the correlation value between detected eye image and pattern image, 0≤S(m,n)≤1.Threshold   th is set. If S(m,n)≥th , detected eye image and pattern image are considered match each other..

$$s(m,n) = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} P^{m,n}(i,j) \bullet T(i,j)}{\sum_{i=1}^{I}\sum_{j=1}^{J} \left[P^{m,n}(i,j) \right]^2} \tag{1}$$

Modified histogram equalization algorithm introduced by Jiang Duan and Guo Ping Qiu [11] is used to eliminate light effect. This algorithm uses floating-point numbers to represent the gray value of a RGB image.

$$P_r\left(r_r\right) = n_k \big/ n \tag{2}$$

Where 0≤r_k≤1, k=0,1,2…L-1 n_k denotes the number of certain gray value in an image, and n denotes the total number of pixels, L is the gray value.
It's convincible that the image contains the most information when its histogram distributed evenly. The histogram conceived in this paper is:

$$H\left[k\right] = P_r\left[Lu\left(i,j\right)\right] = K \tag{3}$$

Project the gray values to dynamic [0, 255] gray levels:

$$Lu\left(i,j\right) = 0.299 \times R\left(i,j\right) + 0.587 \times G\left(i,j\right) + 0.114 \times B\left(i,j\right) \tag{4}$$

where $R(i,j), G(i,j)$, $B(i,j)$ denote the red, green, blue pixel values of eye coordinates i, j separately. Find an a_0 and make it satisfies:

$$\sum_{k=0}^{a_0} H[k] = \sum_{k=a_0}^{255} H[k] \tag{5}$$

Then divide gray level into [0, c_0] and [c_0, 255].

$$c_0 = (255+0)/2 + b(a_0 - (255+0)/2 \tag{6}$$

where b is the control parameter. Find a_1 from [0, c_0] and make it satisfies:

$$\sum_{k=0}^{a_1} H[k] = \sum_{k=a_1}^{c_0} H[k] \tag{7}$$

Gray level is divided into 256 values, and we can obtain the new histogram by adjusting each gray value. Then we performed image rotation and resizing through the use of CORDIC and bilinear interpolation algorithms in FPGA [12], Figure 5.
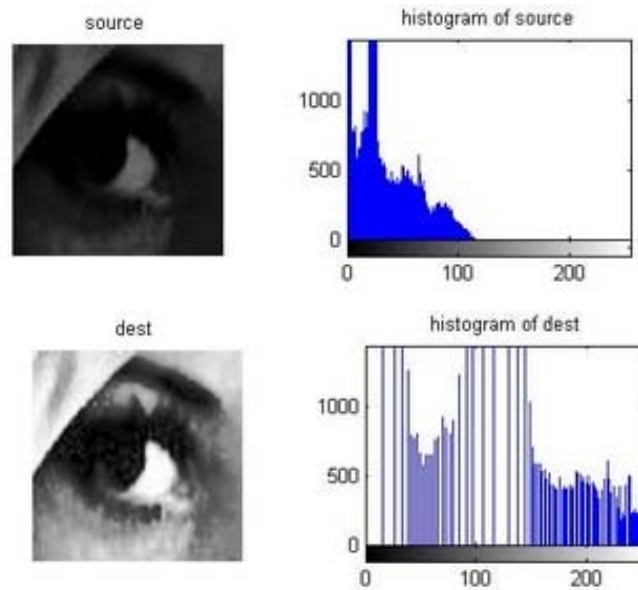

Figure 5. Histogram and the processed image

4. Experimental Result

The theory suggests that different environments lead to different mechanisms of the movements. The driver's eye movements and mechanism is different from the usual in the vehicle running form, due to the highly concentration.

Analysis of the driver's eye movement law has been done in this research in order to make the simulation experiment with higher accuracy. In the process of observation, the driver's eye movements seem as a regular random motion, but in fact it is associated with the driving environment, road conditions, and unexpected situations closely. Most of the time the driver's eye movements are aimed to the lights in front of the monitor, as well as part of the nonlinear mutations movement of the instrumentation in the actual driving environment.

Through the analysis of experimental data, we can sum up the driver's eye movement with some regularity and characteristics. The driver's attention data map is an eye movement

data distribution and driver's gaze point map, precisely made by the position of the region as well as the attention of the moving direction of eye movements in the driving process, Figure 6.

We developed HD camera in the laboratory to verify the accuracy and real-time of this algorithm. We use Ti DM368 and FPGA combine to create a unique HD Camera solution. This system, Figure 7, contains FPGA as the necessary parts to enable the Face detection. The video compression, decompression, streaming and storage use Ti DaVinci™ solutions, Figure 7.
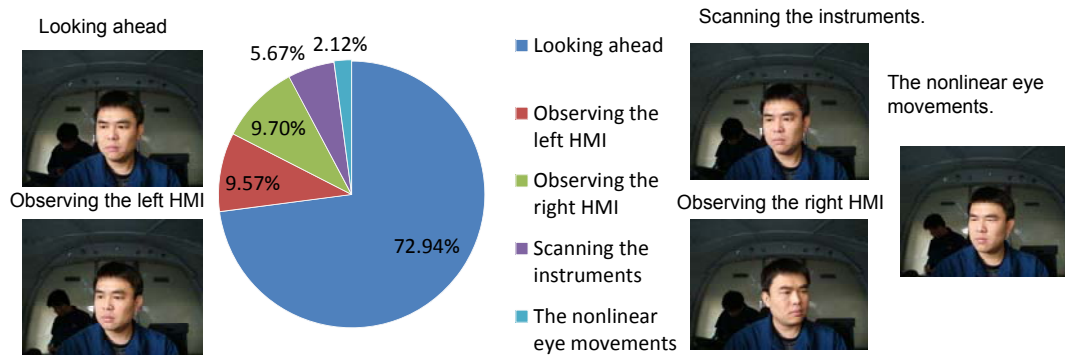

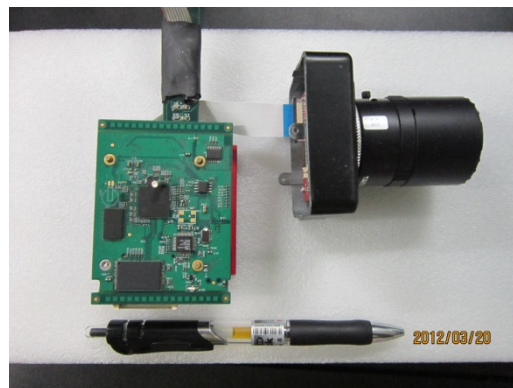Figure 6. Train driver's eye movement

Figure 7. Developed camera hardware

In order to quiz the actual effect of the algorithm, two experiments were carried in this research. Experiment one is a simulation testing experiment. In this situation there are 20 volunteers who have been divided into two groups. The first group is set in a school laboratory environment and the second one is in the office environment. Both of them have the same condition with a camera in front of the volunteers who have to simulate the driver's eye movement. The results are showed in table 1 and table 2. Experiment two is a real train environmental testing experiment that means the experiments carried out on a real moving train and the data were acquired from the train drivers, figure 8. The results are showed in table 3.

The analysis of the experimental results shows that: firstly, the algorithm has a highly adaptability to different lighting conditions and background environment. And it can achieve a high recognition rate both in the laboratory environment and the real train driving condition. Secondly, As a result of the effective combination of hardware acceleration and algorithm, the average rate of the detection and identification is close to 30 frame / second, compared with the condition with no hardware acceleration, the real-time detection has been greatly improved. Thirdly, it has a high recognition rate of the human faces in this algorithm. In addition, this algorithm also improves the face recognition accuracy of different genders and ages, to solve

the problem of the low identification caused by the wrinkles and other facial features in the past. Finally, the analysis with the identification data of the human eyes show that it has a good recognition rate when the driver observing the left HMI (Human Machine Interface) and right HMI, looking ahead and scanning the instruments. Although the recognition rate need to be improved during the situation of the nonlinear eye movements.

Table 1. Test in laboratory environment and office environment

Recognition rate	Test in laboratory environment	Test in office environment
Video frames	225325	223870
Unsuccessful identification frame	190777	193733
Successful identification frame	34548	30137
Correct rate	84.6%	86.5%

Table 2. Recognition test in real train driving environment

Recognition rate	Looking ahead	Observing the left HMI	Observing the right HMI	Scanning the instruments	The nonlinear eye movements
Video frames	27201	3567	3619	2115	789
Unsuccessful identification frame	3808	777	917	971	607
Successful identification frame	23393	2790	2702	1144	182
Correct rate	86.0%	78.2%	74.6%	54.0%	23.0%

Table 3. Recognition test

Recognition rate	Test in the laboratory environment	Test in the train environment
Video frames	449195	37291
Unsuccessful identification frame	64684	7080
Successful identification frame	384510	30211
Correct rate	85.6%	81.0%

5. Conclusion

In this paper, AdaBoost algorithm is used to fast detect and track human faces; differential template-based multi-algorithms are used to localize human eyes and recognize eye states; PERCLOS algorithm is used to determine whether a person is fatigue.

We use modified AdaBoost algorithm, and CORDIC algorithm as a hardware accelerator so that face detection is processed effectively without losing its detection rate.

From the experimental results of eye localization and state recognition, we verified our fatigue driving detection system. It can localize human eyes accurately, eliminate the effect from lights and improve the system behaviors.

Based on the test in lab environment and real train driving environment, the results show that the using of the hardware-accelerated method made a great enhance of the real-time detection and identification of detection. It also made the average speed to nearly 30 frames per second. And the algorithm gave a high recognition accuracy and good robust performance even if the head rotations, eye movements and wearing glasses.

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