The Research on Fatigue Driving Detection Algorithm

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***Abstract*—Researches on Driver Fatigue Detection System, which aims to ensure the safety of operations and to reduce traffic accidents caused by artificial factors, has been the major research subject in transportation safety. There is an enormous advantage in the method obtaining the driver's image by camera, We propose efficient tracking and detecting algorithm and with an appearance model based on haar-like features, finding out the accuracy and robustness of tracking of eyes movements and the conflict between real-time tracing and accuracy of fatigue detection algorithms systems. First, PERCLOS algorithm is adopted to analyze and determine whether a person is fatigue. Second, AdaBoost algorithm is applied to fast detect and the algorithm is implemented in FPGA. Third, We propose a compressed sample tracking algorithm, which compress samples of image using the sparse measurement matrix and train the classification online. The algorithms runs in real-time and is implemented based on ARM add FPGA platform. Experimental results show that the algorithm has high recognition accuracy and robust performance under real train driving environment, in the case of nonlinear tracking of the human eye, illumination change, multi-scale variations, the driver head movement and pose variation.**

***Index Terms*—PRECLOS, Face Detection, AdaBoost, Compressed sample tracking**

I. Introduction

As the development of the transportation system and the increase of vehicle owners, traffic accidents caused by artificial factors, has been the major research subject in transportation safety. Fatigue driving (or driving while sleepy) is a main contribution to road crashes, in 1999-2000[1]. Up to 20% of all traffic accidents are believed to be due to driver fatigue, In Europe. In the U.S.A, falling asleep while driving cause at least 100,000 crashes annually; 40,000 lead to nonfatal injuries, over 1500 result in fatal injuries, at the year of 2002[2]. As many as 28% polled U.S. drivers admit to nodding off at the wheel at least once in 2009. Of all the reasons of traffic accidents, factors related to drivers themselves occupy a higher percentage. 20% of UK road accidents caused by fatigue[3], and the figure is closer to 40% in Australia[4]. Drivers' behaviors such as visual delay, false determination on the environment and inappropriate handling of emergencies just before the accidents have close connection [3]. 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 [5][6]. 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[7][8][9][10]. 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 compared four methods and nine parameters fatigue driving results, and PRECLOS especially P80 detection method shows it's superiority[11][12].

In order to avoid or reduce the traffic accidents, warnings driver the algorithms 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

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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).

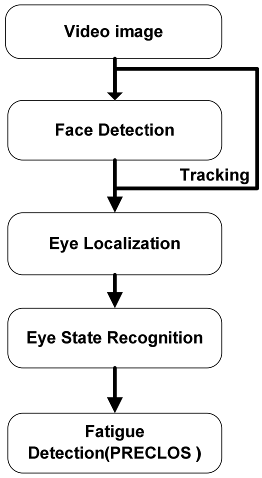

Figure 1. Driver fatigue detection process

II. Detection Algorithm

A. Fatigue Detection Indicators

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.

We use PRECLOS as the criteria for fatigue judging. PRECLOS is recognized as the most effective vision-based fatigue evaluation method[4][15][16][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.

$$PRECLOS = \frac{Time\ of\ eyelids\ closed}{Total\ time}. \quad (1)$$

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.

B. Algorithm Based on Pattern Recognition

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 illumination change, and can localize human faces with all-weather conditions [10][11].

To figure axis labels, use words rather than symbols. Do not label axes only with units. Do not label axes with a ratio of quantities and units. Figure labels should be legible, about 9-point type.

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C. Implementation of Modified AdaBoost Algorithm

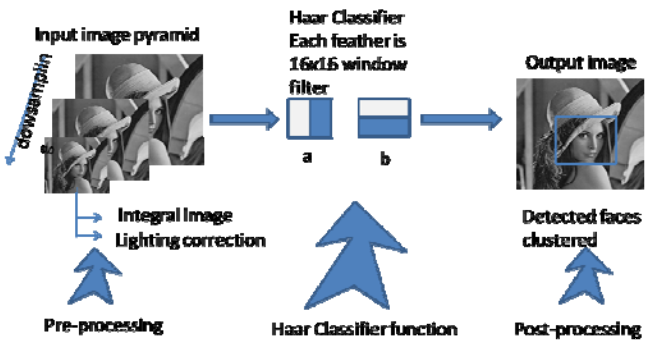

Figure 2. Face detection algorithm based on the Haar classifiers

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-like 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.

D. 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,

Fig. 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][12][13], Fig. 3. The pass rate of the first stage in this design is 20%, while traditional pass rate is 50%.

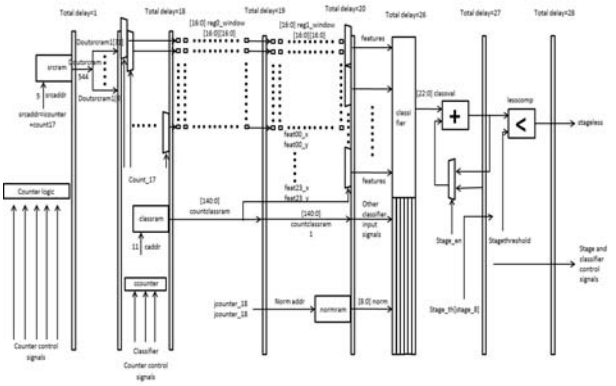

Figure 3. Pipelined design of face detection accelerator in FPGA

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, Fig. 3. It uses five stage pipelines, includes processes such as read from memory, Haar-like feature computation, threshold determination. A classifier unit contains two or three Haar-like feature computation. In this paper, we adopted three feature computations which are compatible to two Haar-like feature computations. 16 identical classifiers are built in the FPGA. We can convert them to different stages by initializing them with different parameters.

III. Online Tracking Algorithm

Recently Offline detection and tracking algorithm has been used where an object is model. Many offline tracking algorithm achieve a high recognition rate and robustness,. Despite much demonstrated success of these Offline detection algorithms, several problems remain to be solved. these algorithm for changes in morphology Eye tracking is still a challenging problem, caused by illumination, head movement and shelter, people attitude change. In response to these problems, the rise of online detection model attracting much attention, and online detection use detection - tracking - updated algorithm mode. The algorithm can effectively detection of the human eye, and the real-time tracking to update the template of the human eye, to adapt appearance changes, can effectively overcome illumination change, head movement and other issues. Online tracking algorithms can be generally categorized as either generative or discriminative [24][25]. The typical generation tracking algorithm is to make sure that the target object shape model of the target object, and then use to search the entire image area, to predict the next frame target image area. Grabner et al. [23] propose an online boosting algorithm to select features for tracking. Despite much demonstrated success of these online tracking algorithms, Black et al [24] subspace offline learning object tracking key points. Literature [27] proposed the use of the incremental subspace morphological model to adapt to the changes of the tracking object shape. Break through as image compression perception theory, the use of sparse matrix tracking objects morphological modeling complex templates and track the target for sparse linear combination to achieve the simplified templates computing purposes [28]. Several problems remain to be solved. First, the computational complexity of this tracker is rather high, thereby limiting its applications in real-time scenarios, Second, the online learning algorithm requires the interception of a large number of samples from the continuous video training. Due to the fewer number of samples in the initial state of the video stream, so most algorithms are often assumed in the video stream of the initial target morphology did not change a lot, but in practice, it is easy to lead due to tracking error; Third, these algorithm do not use the background information, and the camera background do not changes in the driving environment, so use this information is likely to improve tracking stability and accuracy.

A. Compressed Sensing

Resent year, Compressed Sensing theory providing the possibility of online data calculated optimization. In this paper, we propose a Compressed Sensing tracking algorithm to reduce the dimensions and characteristics of the original sample data, A very sparse measurement matrix is adopted to efficiently extract the image data.

Johnson-Lindenstrauss pointed out in the literature[30], any $\varepsilon \in (0,1/2)$, $x_1,\dots x_N \in \mathbb{R}^m$ there is a Lipschitz function f: $\mathbb{R}^m \to \mathbb{R}^n$, $n{=}O\left(\varepsilon^{-2}\log k\right)$ such that:

$$\begin{aligned}&\forall i,j \quad \left(1\text{-}\varepsilon\right)\|x_i\text{-}x_j\|_2 \le \|f(x_i)\text{-}f(x_j)\|_2\\&\le \left(1+\varepsilon\right)\|x_i\text{-}x_j\|_2.\end{aligned} \quad (2)$$

The theory proved a random high-dimensional space $\mathbb{R}^m$ can be projected onto a low-dimensional $\mathbb{R}^n$, where n << m , the information basically is not lost, and the distance between the two points of the spatial signal error ε is very small, so we can restore the high probability of the signal. Consider an simple image matrix $x \in \mathbb{R}^m$, the definition of a random matrix $R \in \mathbb{R}^{n\times m}$ allows the projector to the space in which mathematical expression:

$$y{=}\mathrm{R}x\,. \quad (3)$$

$\sum k$ is a collection of sparse vector :

$$\sum k{:=}\{x \in \mathbb{R}^m{:}\|x\|_0 \le k\}\,. \quad (4)$$

$\|x\|_0$ is the number of non-zero elements of space. Definition of f: $\mathbb{R}^m \to \mathbb{R}^n$, the inverse transform f^{-1}: $\mathbb{R}^n \to \mathbb{R}^m$, Baraniuk [31] proved that meet Johnson-Lindenstrauss inference meet the same random matrix theory of compressed sensing RIP (Restricted Isometry Property) assumes that the encoding matrix meet order the sparse matrix RIP , and RIP constant then for any $x \in \sum k$, have

$$f^{-1}(Rx)=x\,. \qquad (5)$$

The theorem shows that the image space to meet sparse matrix satisfies RIP, we can restore sparse vector matrix via RIP. High-dimensional image into low-dimensional compression problem becomes how to determine RIP matrix and image space sparse.

B. RIP Matrix

CandeS and Tao proved [24] that the independent and identically distributed random Gaussian matrix to meet RIP conditions of observation matrix $R \in \mathbb{R}^{n\times m}$, where $r_{ij} \in N(0,1)$ .but the normal random Gaussian matrix calculation amount and the amount of data storage is still a huge.

$$r_{ij=}\sqrt{s}\times\begin{cases}1,\Pr\text{obability }\dfrac{1}{2s}\\ 0,\Pr\text{obability }1\text{-}\dfrac{1}{s}\\ \text{-}1,\Pr\text{obability }\dfrac{1}{2s}\end{cases}. \qquad (6)$$

Literature [25] proved that this type matrix is very sparse matrix and satisfies the Johnson-Lindenstrauss lemma. This type matrix with s = 2 or 3, is very easy to implement, and requires only a uniform random number generator. When s = 3, r is zero with probability $2/3$, then $2/3$ the matrix multiplication calculation can reduce.

C. Image Space Sparse

Simple image signal is not n sparse naturally, but in the -ory, all the signals in a transform domain can be approxi mated sparse that the image can be decomposed into its w here space is finite or infinite linear combination of the ba -sis functions.

If the length of vector $x=\left[x_1,x_2,x_3\ldots x_N\right]$ is N, can be expressed by a linear combination $\psi^T=\left[\psi^1,\psi^2\ldots\psi^M\right]$

$$x=\psi\alpha\,. \qquad (7)$$

$$y=Rx=R\psi\alpha=D\alpha\,. \qquad (8)$$

Every column in D (dictionary) is a prototype signal (atom). The vector α is generated randomly with few (say L for now) non-zeros at random locations and with random values. The image sparsity problem is to select a reasonable base of sparse, making the number as little as possible.

$$\min_{\underline{\alpha}}\ \left\|\underline{\alpha}\right\|_0^0\ \ s.t.\ \left\|\mathbf{D}\underline{\alpha}-\underline{y}\right\|_2^2\le\varepsilon^2\,. \qquad (9)$$

The MP is one of the greedy algorithms that finds one atom at a time[26].

Step 1: find the one atom that best matches the signal.

Next steps: given the previously found atoms, find the next one to best fit the residual.

The algorithm stops when the error $\left\|\mathbf{D}\underline{\alpha}-\underline{y}\right\|_2$ is below the destination threshold.

The Orthogonal MP (OMP) is an improved version that re-evaluates the coefficients by Least-Squares after each round.

D. Classifier Construction and Update

In this paper PN lerning algorithm [34] is used to impr ove the performance of the detection module (Haar-like Feature Detection) through the online processing of the video sequence. For each frame of the video, and algorith m simple false detection of assessing detection module in the current frame, and in order to update the target model, so that to avoid similar mistakes from happening again in the future video frame processing.

PN learning lies in the two types of "experts (experts)": P-experts to check the detection module misclassification positive samples (foreground object) data; N-experts to c heck which detection module misclassified as negative sa mples (background) data; need to be reminded that the P-experts or N-experts will have a certain deviation. So, wit h these there is a deviation of the data to update the detect ion module (target model). After the study, Literature [3 4] found that despite the presence of errors, under certain conditions, the error is allowed, and the performance of th e detection module will therefore be improved.

For each sample $z \in \mathbb{R}^m$, its low-dimensional representation is $v=(v_1,\ldots,v_n)^T \in \mathbb{R}^n$ with n<<m We assume all elements in v are independently distributed. Diaconis and Freedman [23] showed that the random projections of high dimensional random vectors are almost always Gaussian.

If Image target may exist in all regions assigned with t he label, The regions belongs to the foreground or backgr ound, The label here only either foreground or backgroun d. The main steps of our algorithm are summarized:

Step 1: Prepare a small number of training sample set and a large number of the test sample collection.

Next steps: using of training samples to train an initial classifier. Meanwhile, the training samples (a priori) constraints make the appropriate adjustments.

Next steps: assigne with the label in the test sample by the classifier, and find the classifier gives tags with the constraint conditions contradict those samples;

Next steps: samples of the above-mentioned contradictory are re-assigned with the label, then added them in training samples to re-train the classifier;

Iterative process until meet certain constraints

V. EXPERIMENTAL RESUL

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, Fig. 5.

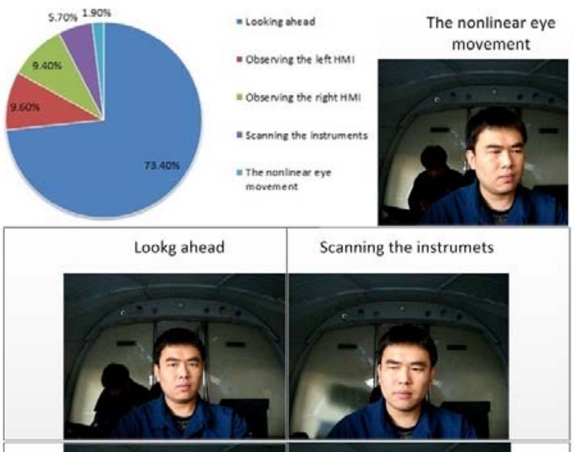

Figure 5. Train driver's eye movement

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, Fig.3, contains FPGA as the necessary parts to enable the Face detection. The video compression, decompression, streaming and storage use Ti DaVinci™ solutions, Fig. 6.

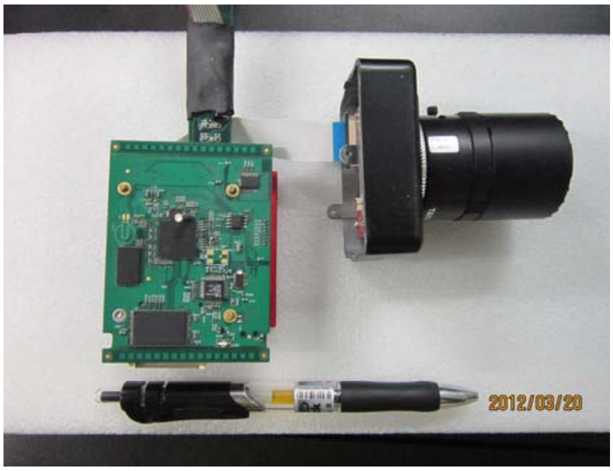

Figure 6. Developed camera hardware

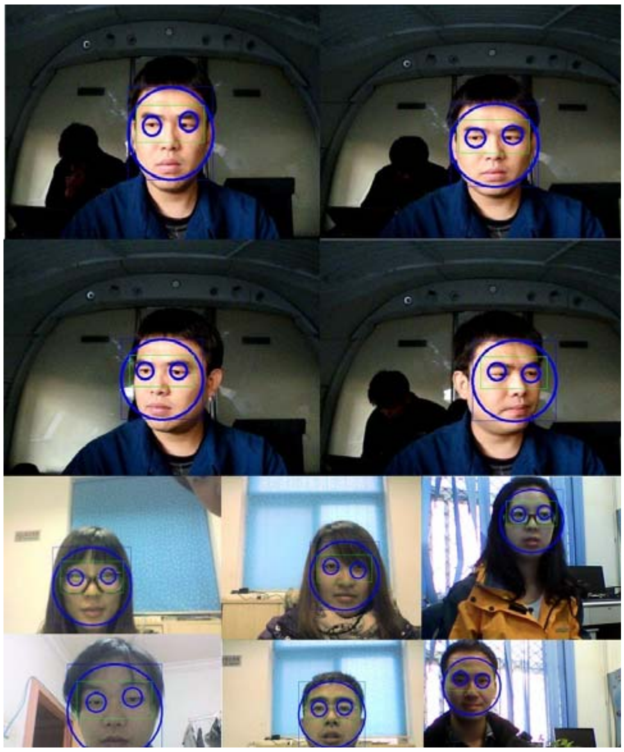

Figure7. Recognition test

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 Tab. 1 and Tab 3. 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, Fig. 7. The results are showed in Tab 2.

Figure8. Recognition test in the case of the, multi-scale variations, the driver head movement and pose variation.

TABLE I.
RECOGNITION TEST

Laboratory environment and office environment test		
Recognition rate	Test in 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%

TABLE II.
RECOGNITION TEST IN LABORATORY ENVIRONMENT AND OFFICE ENVIRONMENT

Laboratory environment and office environment test		
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 III.
RECOGNITION TEST

Laboratory environment and office environment test					
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%

The analysis of the experimental results shows that: firstly, the algorithm has a highly adaptability to different illumination 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 and the right HMI, looking ahead and scanning the instruments. Although the recognition rate need to be improved during the situation of the nonlinear eye movements.

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 propose online compressed tracking algorithm and modified PN classifier construction, in the case of nonlinear tracking of the human eye, illumination change, multi-scale variations, the driver head movement and posture variation.

V. CONCLUSION

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 algorithms runs in real-time and is implemented based on ARM add FPGA platform. Experimental results show that the algorithm has high recognition accuracy and robust performance under real train driving environment, in the case of nonlinear tracking of the human eye, illumination change, multi-scale variations, the driver head movement and pose variation.

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