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Intelligent Video-Based Drowsy Driver Detection System under Various Illuminations and Embedded Software Implementation

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***Abstract* - An intelligent video-based drowsy driver detection system, which is unaffected by various illuminations, is developed in this study. Even if a driver wears glasses, the proposed system detects the drowsy conditions effectively. By a near-infrared-ray (NIR) camera, the proposed system is divided into two cascaded computational procedures: the driver eyes detection and the drowsy driver detection. The average open/closed eyes detection rates without/with glasses are 94% and 78%, respectively, and the accuracy of the drowsy status detection is up to 91%. By implementing on the FPGA-based embedded platform, the processing speed with the 640x480 format video is up to 16 frames per second (fps) after software optimizations.**

I. INTRODUCTION

For the past few years, accidents caused by fatigue driving have occurred frequently. Therefore, many researchers and experts have paid great efforts in this issue [1-3]. Some useful techniques for detecting driver drowsiness can be generally separated into three main categories [1]: the first category is based on driver's current state, which is relating to the eye and eyelid movements, closed eyes period, and physiological state changes. The second category is based on the vehicle's behavior, e.g. the driving speed. The third category is based on combination of the driver's current state and driver performance [1]. Regarding the fatigue detection issue, the driver's drowsy status can be evaluated through the closed eyes and head gesture conditions [2-3] by using facial image processing. In this work, by the NIR-based facial image processing, firstly the accurate eye position is recognized, and then the driver drowsy condition without/with glasses can be detected effectively. Finally, the fatigue alert is generated to warn the driver properly.

II. THE PROPOSED SYSTEM

The proposed system is split into two cascaded computational procedures: (1) the driver eyes detection and (2) the drowsy driver detection, which are detailed as follows:

2.1 Driver Eyes Detection

To overcome various illumination conditions, the NIR camera is applied to capture the driver's facial images. Only gray-scale images are processed without using color information, and the proposed system operates effectively in day and night. The proposed driver eyes detection scheme includes five functions, which comprise the pre-processing, face detection, face boundary detection, eye-glasses bridge detection, and eyes detection. Fig. 1 illustrates the processing flow of the driver eyes detection.

For the pre-processing, the gray-scale images are filtered by Sobel filters, and then processed by erosion and dilation. For the face detection, we use two-stage facial region detection scheme by Haar-like features [4] from coarse to fine. At the Level-1 stage, the possible driver's facial region is detected through a simple black-and-white Haar-like facial feature. The possible facial searching range is narrowed after the Level-2 process, and more precise facial region is recognized by a smaller Haar-like feature (Fig. 1). The integral images are applied to speed-up the Haar-like features searching. Based on the results of the facial region detection, the facial size and the eyes search region are achieved through the centralization and symmetry of facial features by using the facial boundary detection. Next, the eye detection scheme for eyes location is separated into two processing flows to judge whether the driver wears glasses or not.

For the eye-glasses bridge detection, the number of edges in the bridge region with wearing glasses will be more than that without wearing glasses. For the eyes detection with glasses, we use the horizontal projection, and calculate the average to find the axis of symmetry. Because the shape of the glasses frame is mostly circular or rectangular, we can find the horizontal and vertical symmetry axes of the left and right frames respectively, and the center of the intersection is obtained by two symmetrical axes. Then the center of the intersection will be the possible locations of eyes. For the eyes detection without glasses, the inverted triangle eyes filter with local gradient patterns [5] is used to find the correct eyes location in the possible eyes region (Fig. 1).

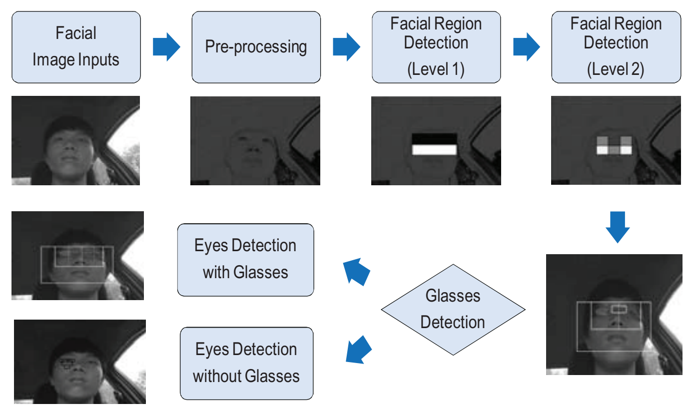

Fig. 1 Flow of the proposed driver eyes detection

2.2 Drowsy Driver Detection

Based on the eyes detection, the region-of-interesting (ROI) of eyes location can be extracted for the successive process. The following drowsy driver detection includes five functions, which include the edge filtering in ROI, binarization, iris location, open/closed eyes detection, and drowsy detection. Fig. 2 illustrates the processing flow of the proposed drowsy driver detection. For the edge filtering, the derivative of the Gaussian filer is used to convolute in the ROI region, and the edge information is obtained. To reduce the computational complexity, the 2-D convolution scheme is replaced with two 1-D convolutions. Next, the edge map is processed by the histogram statistics, and the mean edge values will be the threshold for binarization. For the iris location, the circle Hough transform [6] is applied for iris detections. For each point belonging to the edge of the iris, it is possible to identify the iris center. Thus, a three-dimensional cone accumulator is used to accumulate these edge points. If the edge points belong to the iris, the circles centered on these edge points will be overlapped to create the intersection at the center of the target circle, and the center and radius of the iris can be found by the location which has the maximum intersection. Based on the location and radius of the iris, we can do the open/closed eyes detection. The closed eyes measurement index can be obtained by calculating the difference of sum of the gray-scale pixels between the inner and outer donut-shape regions. When the difference is smaller than a threshold, the closed eyes state will be detected.

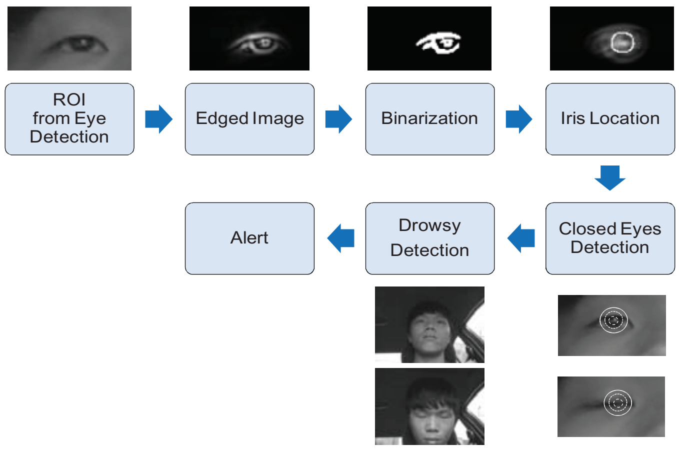

Fig. 2 Flow of the proposed drowsy driver detection

Fatigue measurement is an important issue, and the characteristic of fatigue measurement reveals a practical problem for road safety [1]. Based on the closed eyes measurement index, the drowsy driver condition can be detected by evaluating the time period of closed eyes. When the closed eyes time period exceeds a pre-defined threshold (e.g. 30 frames in Fig. 3), the alert for drowsy detections will be generated to warn the driver.

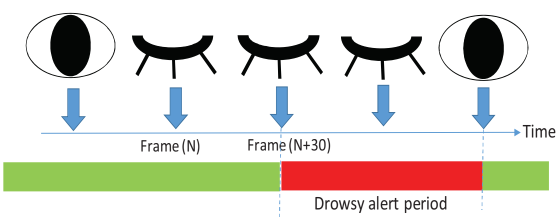

Fig. 3 Fatigue measurement scheme

III. EXPERIMENTAL RESULTS

In our experiments, the average processing frame rates are up to 45 fps in a PC at a 3.4GHz operational frequency. The average detection rate of eye locations is 98.06%, which depends on eight driver test sequences including four non-glasses and four glasses cases. Fig. 4 demonstrates eight test video sequences for our experiments. For example, Fig 4(a) "DNN" shows a day, normal, and non-glasses condition, and Fig. 4(h) "NGS" shows a night, drowsy, and wearing glasses condition. Table 1 shows the closed eyes detection rates without and with glasses. In Table 1, the average open/closed eyes detection rates without/with glasses are 94% and 78%, respectively. Compared with the non-glasses cases, the average closed eyes detection rate with glasses is reduced due to the strong lens reflex of glasses. By the scheme in Fig. 3, the drowsy driver detection rate will be up to 91%.

Fig. 4 Test sequences with/without glasses

Table 1 Open/closed eyes detection rate without/with glasses

	Without Glasses					With Glasses				
Test Video	Day Normal (DNN)	Night Normal (NNN)	Day Drowsy (DNS)	Night Drowsy (NNS)	Avg. Detect Rate	Day Normal (DGN)	Night Normal (NGN)	Day Drowsy (DGS)	Night Drowsy (NGS)	Avg. Detect Rate
Closed Eyes Detect Rate	96%	94%	96%	90%	94%	78%	83%	67%	82%	78%

IV. EMBEDDED SYSTEM IMPLEMENTATION

The embedded platform with a processor-based FPGA chip [7] is chosen to implement the proposed system. The FPGA chip contains two high-performance floating-point RISC-based processors, which have Dhrystone performance 2.50 DMIPS/MHz per core and operate a maximum operational frequency of 800MHz. The Linux-based embedded operational system is applied for boosting the platform. To reduce the complexity of the proposed algorithm, some complex operations, such as Logarithmic, exponential, square root, and trigonometric functions are replaced with the look-up-table based fast designs by memories. By using fast algorithms and software optimizations, the processing speed can operate up to 16 fps.

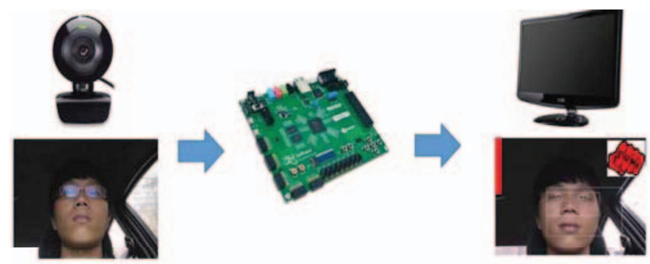

Fig. 5 Embedded software implementation

V. CONCLUSION

The proposed video-based drowsy detection system is unaffected by various light conditions, even if a driver wears glasses. The average open/closed eyes detection rates without/with glasses are 94% and 78%, respectively, and the drowsy detection accuracy is up to 91%. By the embedded software realization, the processing speed with the 640x480 video can operate up to 16 fps on the FPGA-based embedded platform.

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