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DRIVER HEAD LEANING DETECTING SYSTEM

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Abstract. *The paper proposes a safe driving system to detect driver head leaning. In the system, the LED light sources are sited on the back cushion behind the driver's head, the CMOS sensor is placed above and in front of the driver to acquire frames, and the detecting algorithm is developed to analyze the acquired frame. Any driver head leaning will lead to LED changes in the acquired frame. By analyzing these changes, the detecting algorithm can recognize driver head leaning correctly. The system is robust to violent illumination variation outside the vehicle. After performing MATLAB simulation on the video acquired from vehicle video recorder, the results indicate all the leaning behaviors are warned exactly and the actions the driver watches the rear-view mirror are judged to be normal.*

Keywords: Safe driving system, Driver head leaning, LED light source, CMOS sensor, Detecting algorithm, Illumination variation

1. **Introduction.** When a driver is exhausted or absent-minded, his perception ability to surroundings, handling ability to the car, and decision ability to traffic situation all diminish. It will easily lead to serious traffic accidents and loss of life and property. Hence, the development of safe driving system to monitor whether a driver is exhausted or absent-minded is very important. Actually different brands of car corporations and research centers devote themselves to developing this kind of system over the past decade [1-14].

Many approaches [1-14] for safe driving have been proposed. They can be classified into four categories. 1) The first category [2-5] is based on the driver's physiological signals. 2) The second category [2,3,6-9] focuses on the state of the driver's head or face such as head movement, eye closure, and pupillary variation. 3) The third category [2,3,10-12] is based on the vehicle's behavior such as vehicle lateral position in the lane and distance with the front car. 4) The fourth category [2,3,13,14] combines the above categories.

In the first category, it is necessary to attach sensors to the driver to measure the physiological signal. The attachment will interfere with the driver and hence limit its practical application. On the contrary, to monitor the state of the driver's head or face in the second category, it just needs non-contact sensors instead of contact ones. Well-developed image processing techniques make the category to be a promising approach. However, how to overcome the violent illumination variation outside the vehicle is a big challenge in image processing. Some techniques shine infrared rays on the driver's eyes, use the infrared sensor to acquire the frame with bright pupil, and analyze pupil area change to judge whether the driver is tired. The eyes can faithfully reflect whether the driver is tired. However, this kind of system has three major disadvantages. 1) Shining infrared rays on the driver's eyes continuously may be harmful to the driver's eyes. 2) If the driver wears glasses, the light reflection from glasses will produce bright area which will be confused with the bright pupil. 3) The bright pupil effect is obvious in the nighttime, but it is unobvious in the daytime. Hence, the development of practical monitoring system safe to the driver's eyes, robust to violent illumination variation, and not being affected by glasses is an important topic in the category. In the third category, many products such as Mobileye lane departure warning and forward collision warning systems [12] have been released. The fourth category combines the above approaches to strengthen the driving safety. Lee and Chung [13] measure the driver fatigue by the facial image and physiological signal of the driver.

In the paper, we propose a new system which analyzes the area change of LED light behind the driver's head to determine whether abnormal head departure occurs. The system will preserve the advantages of the second category and improves its disadvantages.

2. **Driver Head Leaning Detecting System.** To detect whether the driver's head leans, the driver head leaning detecting system (DHLDS) is proposed. The schematic diagram of DHLDS is shown in Figure 1. In the system, the LED light sources are sited on the back cushion behind the driver's head, the CMOS sensor is placed above and in front of the driver to acquire frames including the region around the driver's head, and the head leaning detecting algorithm (HLDA) is developed to analyze the acquired frame. Any driver head leaning will lead to the LED changes in the acquired frame. By analyzing these changes, the developed algorithm can detect whether the driver's head leans.

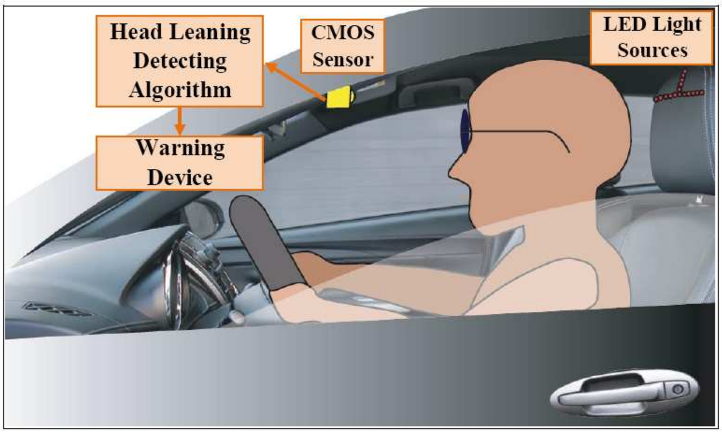

FIGURE 1. Driver head leaning detecting system

In DHLDS, the head leaning detecting algorithm (HLDA) shown in Figure 2 is proposed to monitor the changes of the LED region. To quantitatively describe HLDA, the following notations are adopted and defined:

f_i: the acquired ith frame of size 540×960,

f_H_i and f_V_i: horizontal and vertical regions of interest (ROIs) of size 17×170 and 50×16 in f_i respectively,

$f\_H_i^R(p, q)$, $f\_H_i^G(p, q)$, and $f\_H_i^B(p, q)$: red, green, and blue components of f_H_i (p, q), $1 \leq p \leq 17$, $1 \leq q \leq 170$,

$f\_V_i^R(p,q)$, $f\_V_i^G(p,q)$, and $f\_V_i^B(p,q)$: red, green, and blue components of $f\_V_i(p,q)$, $1 \leq p \leq 50$, $1 \leq q \leq 16$,

f_HS_i and f_VS_i: binarization results from segmenting f_H_i and f_V_i,

$area\_HS_i$ and $area\_VS_i$: foreground areas of f_HS_i and f_VS_i,

$ccog\_HS_i$: column coordinate of center of gravity (COG) of f_HS_i,

$warning_i$: indicator whether to issue a warning signal to the driver at frame f_i.

Based on the defined notations, HLDA is proposed and described as follows.

Step 1: Acquire the new frame f_i, $i = 1, 2, 3, \ldots$.

Step 2: Partition f_i to obtain f_H_i and f_V_i.

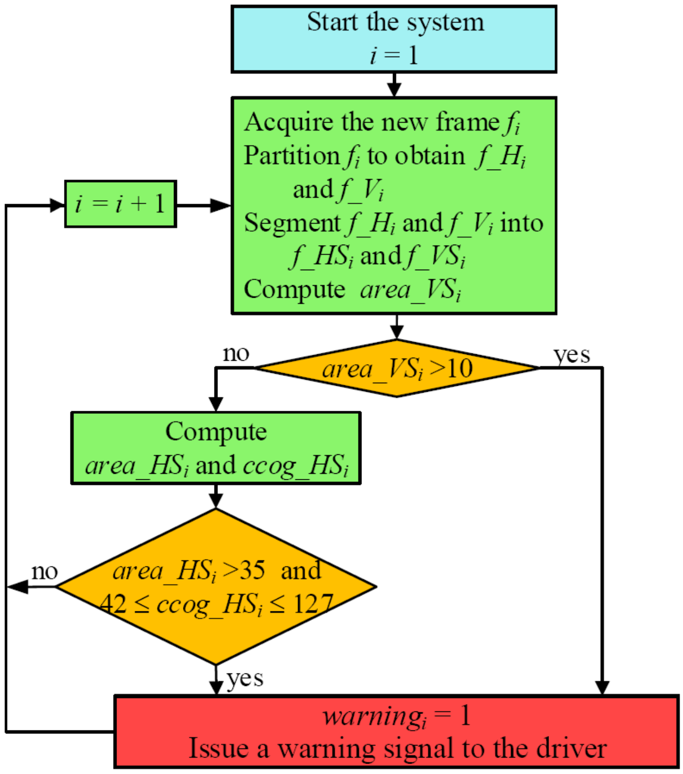

FIGURE 2. The head leaning detecting algorithm in DHLDS

After acquiring f_i, partition f_i to obtain f_H_i and f_V_i. The two ROIs are defined as follows:

$$f\_H_i = \{f_i(p, q)|352 \leq p \leq 368, 401 \leq q \leq 570\}, \quad (1)$$

$$f\_V_i = \{f_i(r, s)|303 \leq r \leq 352, 478 \leq s \leq 493\}. \quad (2)$$

Step 3: Segment f_H_i and f_V_i into f_HS_i and f_VS_i.

According to the color features of f_H_i and f_V_i, segment f_H_i and f_V_i by the following criteria:

$$f\_HS_i(p, q) = \begin{cases} 1, & \text{if } \left|f\_H_i^R(p, q) - f\_H_i^G(p, q)\right| < 25 \\ & \text{and } f\_H_i^B(p, q) > 200, \\ 0, & \text{otherwise,} \end{cases} \quad (3)$$

$$f\_VS_i(r, s) = \begin{cases} 1, & \text{if } \left|f\_V_i^R(r, s) - f\_V_i^G(r, s)\right| < 25 \\ & \text{and } f\_V_i^B(r, s) > 200, \\ 0, & \text{otherwise,} \end{cases} \quad (4)$$

where $1 \leq p \leq 17$, $1 \leq q \leq 170$, $1 \leq r \leq 50$, and $1 \leq s \leq 16$.

Step 4: Compute $area\_VS_i$.

After segmenting f_V_i into f_VS_i, compute the foreground area by the following method:

$$area\_VS_i = \sum_{r=1}^{50} \sum_{s=1}^{16} f\_VS_i(r, s). \quad (5)$$

Step 5: Determine whether the driver's head leans.

Inspect Criterion I:

$$\text{Criterion I:} \quad area\_VS_i > 10. \quad (6)$$

If it is true, set $warning_i$ to be 1 and issue a warning signal to the driver. If $area\_VS_i \leq 10$, compute $area\_HS_i$ and $ccog\_HS_i$ by

$$area\_HS_i = \sum_{p=1}^{17} \sum_{q=1}^{170} f\_HS_i(p, q), \tag{7}$$

$$ccog\_HS_i = \begin{cases} 0, & \text{if } area\_HS_i = 0, \\ \dfrac{\sum\limits_{p=1}^{17} \sum\limits_{q=1}^{170} q \times f\_HS_i(p,q)}{\sum\limits_{p=1}^{17} \sum\limits_{q=1}^{170} f\_HS_i(p,q)}, & \text{otherwise,} \end{cases} \tag{8}$$

and inspect Criterion II:

$$\text{Criterion II:} \quad area\_HS_i > 35 \text{ and } 42 \leq ccog\_HS_i \leq 127. \tag{9}$$

If it is true, set $warning_i$ to be 1 and issue a warning signal to the driver.

Figure 3 shows the two ROIs f_H_i and f_V_i in Step 2 of HLDA. The f_H_i and f_V_i are regions of size 17×170 and 50×16 respectively. Segmentation of f_H_i and f_V_i by Equations (3), (4), computing their areas by Equations (5), (7), and computing the column coordinate of COG of f_HS_i by Equation (8) are all simple operations and performed on the two small areas. Hence, the computational complexity of HLDA is very low.

FIGURE 3. f_H_i and f_V_i

If the driver's head is in the normal position, the LEDs in f_H_i and f_V_i are completely covered by the driver's head. There is nothing in f_HS_i and f_VS_i. The values of $area\_HS_i$, $area\_VS_i$ and $ccog\_HS_i$ are all zero; hence HLDA judges the driver's head is in normal position. If the driver's head leans, the LEDs in f_H_i and f_V_i appear. Hence, HLDA can detect driver head leaning and issue a warning signal to the driver.

3. **MATLAB Simulation Results.** To demonstrate the performance of the proposed DHLDS, the system is set up in an automobile. Two strips of SMD LED are sited on the back cushion behind the driver's head. The vehicle video recorder CASA HDR-550 is used to record the region around the driver's head. The adopted video is of length about 59 seconds and includes the following two driving environments. 1) The driver wears the sunglasses. 2) The vehicle goes through the tunnel two times.

898 frames of size 540×960 in total are extracted from the video by the software "Free Video to JPG Converter". The acquisition rate is 15 frames per second. According to HLDA, MATLAB simulation is performed on all the 898 frames.

Use f_{326} as a representative to demonstrate the simulation results. The frame f_{326} is shown in Figure 4(a). The horizontal and vertical ROIs f_H_{326} and f_V_{326} are enlarged and shown in Figures 4(b) and 4(c) respectively. After segmenting f_H_{326} and f_V_{326} by Equations (3), (4), the results f_HS_{326} and f_VS_{326} are shown in Figures 4(d) and 4(e) respectively. According to HLDA, the related values of f_{326} are listed in Table 1. From

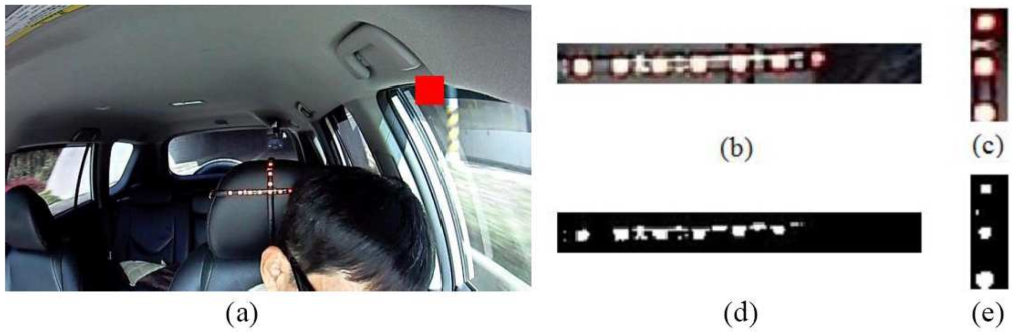

Figure 4. (a) f_{326}, (b) f_H_{326}, (c) f_V_{326}, (d) f_HS_{326}, (e) f_VS_{326}

Table 1. The related values of f_{326} according to HLDA

Frame no. i	f_V_i	f_H_i		$warning_i$
	$area\_VS_i$	$area\_HS_i$	$ccog\_HS_i$	
326	65	260	60	1

Table 2. The related values of the eight representative frames according to HLDA

Frame no. i	f_V_i	f_H_i		$warning_i$
	$area\_VS_i$	$area\_HS_i$	$ccog\_HS_i$	
30	0	0	0	0
51	108	148	130	1
104	174	438	70	1
155	43	0	0	1
326	65	260	60	1
350	0	0	0	0
471	11	0	0	1
511	30	65	129	1

Table 1, we have $area\_VS_{326} = 65$, $area\_HS_{326} = 260$ and $ccog\_HS_{326} = 60$. Both Criteria I and II are true. HLDA judges that driver head leaning occurs. Hence, set $warning_{326}$ to be one and issue a warning signal.

To demonstrate the performance of DHLDS when the vehicle is in poor and normal illumination, the frames f_{30}, f_{51}, f_{104}, f_{155}, f_{326}, f_{350}, f_{471}, and f_{511} shown in Figure 5 are used as representatives. In the eight frames, driver head position can be classified into four categories, normal position, left leaning, right leaning, and front leaning. According to HLDA, the related values of the eight representative frames are listed in Table 2. If Criterion I or II is true, that is, $warning_i$ is equal to 1, we mark a red square on the middle right region of the frame f_i. All the warning results are also demonstrated in Figure 5. The complete simulation results of all the 898 frames are concatenated to a video again by the application software "Vegas Pro 8.0". The video is uploaded to YouTube [15] and can also be played in Figure 6.

In the acquired video, there are twelve times of driver head leaning and two times of actions that the driver watches the rear-view mirror. Inspecting the demonstrated video [15], all the leaning behaviors are warned exactly and the actions the driver watches the rear-view mirror are judged to be normal. The video also clearly demonstrates the features of the proposed DHLDS. The driver wears the sunglasses and the automobile goes through the tunnel two times. At the moment that the automobile enters or leaves the tunnel, the illumination variation outside the vehicle is very fierce. Even so, DHLDS overcomes the two challenges and makes correct detection.

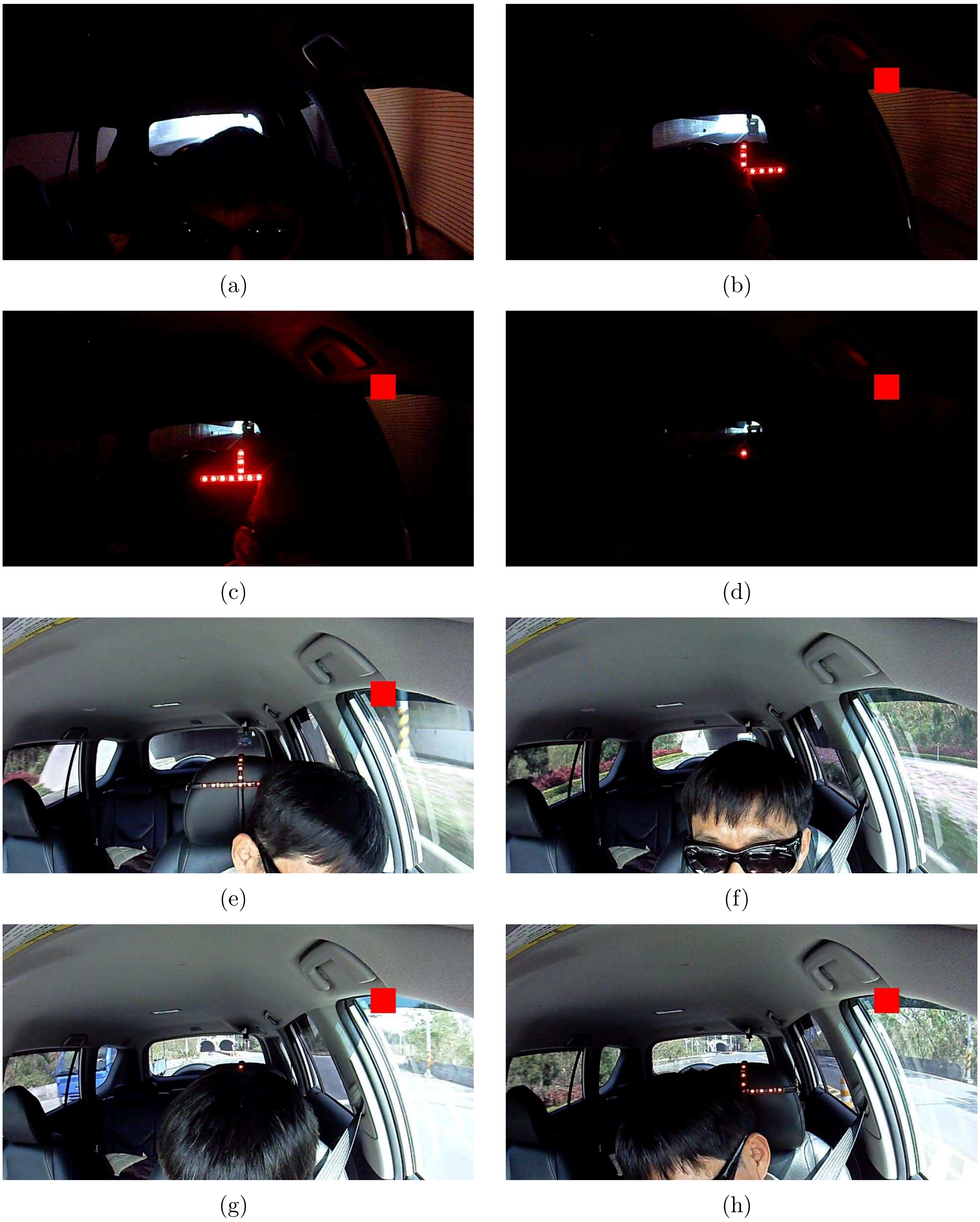

FIGURE 5. The warning results of (a) f_{30}, (b) f_{51}, (c) f_{104}, (d) f_{155}, (e) f_{326}, (f) f_{350}, (g) f_{471}, (h) f_{511}

In the real system, the warning signal issued to the driver can be the sound from loudspeaker, figures in screen, music from player, light from source, vibration from vibrator, and so forth.

4. **Conclusion.** In the paper, the good-performance driver head leaning detecting system has been proposed. The features of the proposed system are as follows. 1) The system can overcome the violent illumination variation when the vehicle goes through the tunnel. 2) It is not influenced by sunglasses the driver wears. 3) The action the driver watches the rear-view mirror is judged to be normal. 4) The computational complexity of HLDA is very low. In the future research, we will implement HLDA in an embedded system

Figure 6. The video of the simulation results uploaded to YouTube [15]

to make the system become a product. Finally, we believe that the active safe driving system can greatly benefit by adopting the proposed system.

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