Full Paper

DEVELOPMENT OF AN EYE-BLINK DETECTION SYSTEM TO MONITOR DROWSINESS OF AUTOMOBILE DRIVERS

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ABSTRACT

This paper presents a study that employed human-computer interaction (HCI) in the development of an improved driver's drowsiness detection system (DDS) for monitoring the drowsiness of car drivers. The basic process used motion analysis technique for eye detection, which involves the analysis of the involuntary blinks of a user of the system. After the system had been initialized, the eye was tracked using the square difference matching method. The major parameter subsequently used to detect drowsiness was the frequency of blinks, such that an alarm is triggered when it gets to a critical level. The results demonstrated that a low cost webcam, with a capture rate of 30 frames/s and resolution of 320 x 240, was used to achieve a blink accuracy of 94.8%, missed blink error of 2.4%, false positive error of 3%. Also, an eye tracking accuracy of 72% at a distance of about 30cm was obtained. An improvement on the accuracy and reliability of this system over existing ones was achieved.

Keywords: *Drowsiness, blink detection, blinks frequency, drowsiness detection, fatigue*

1. INTRODUCTION

Fatigue is a significant factor in a large number of vehicular accidents. From available statistics, it was estimated that 1,200 deaths and 76,000 injuries could annually be attributed to fatigue related road crashes in the USA alone (Weirwille, 1994). Accordingly, series of studies by the National Transportation Safety Board (NTSB) had pointed to the significance of sleepiness as a factor in accidents involving heavy vehicles (NTSB, 1990; Wang and Knippling, 1994; NTSB, 1995). Subsequently, out of 107 recorded one-vehicle accidents involving heavy trucks, 52% of them were fatigue related, and in nearly 18% of the cases, the drivers admitted to falling asleep.

Driver drowsiness is one specific human error that has been well studied. Studies have shown that immediately prior to the accidents, the driver's eye change in blinking behavior (Thorslund, 2003). The basic parameter used to detect drowsiness is the frequency of blinks, which a system could use to detect micro-sleep symptoms in order to diagnose the onset of driver fatigue. As the driver fatigue increases, the blinks of the driver tend to last longer and drowsiness gradually sets in. Drowsiness affects mental alertness, decreasing an individual's ability to operate a vehicle safely and increasing the risk of human error which could lead to fatalities and injuries. Long hours behind the wheels in monotonous driving environments make truck drivers to be particularly prone to drowsy-driving crashes (Sullivan, 2003). Subsequently, the issue of driver drowsiness in the commercial motor vehicle industry is a formidable and multi-faceted challenge. It is hereby believed that driver drowsiness can nevertheless be effectively managed, thus resulting in a significant reduction in related risk and improved safety on the wheels (Rosekind, 1998).

Addressing the need for a reduction in driver-drowsiness related accidents will require some innovative concepts and evolving methodologies. Available and emerging in-vehicle technological approaches have great potentials if they can detect the onset of fatigue or drowsiness, and hence, serve as relevant and effective tools for developing appropriate early warning systems. Within any comprehensive and effective fatigue management program, an on-board device that monitors a driver's state in real time may have real value as a safety net. Sleepy drivers exhibit certain observable behaviors, including eye gaze, eyelid movement, pupil movement, head movement, and facial expression (Ji et al., 2004). Noninvasive techniques are currently being employed to assess a driver's alertness level through the visual observation of his/her physical condition using remote camera driven state-of-the-art technologies in computer vision (Grauman et al., 2001).

2. THEORETICAL DEVELOPMENT

The proposed algorithm used in this work requires the use of techniques for eye-detection, template creation, eye tracking, blink detection and drowsiness detection (Fig.1).

2.1. Eye Detection

In this stage, the system will locate the position of the eye by a motion analysis technique. This is used to detect the motion of the eye by analyzing the first involuntary blink of the user. A bi-lateral difference image is subsequently created by subtracting the image's previous frame from its current frame for all pixels. The difference image is then converted to a binary image by the process of thresholding in order to show the regions of movement that occurred between the two frames. In this case, each pixel assumes two discrete values of 0 and 1; representing black and white respectively. The resultant image, undergoes the process of "erosion" in order to eliminate noise, which is often caused by naturally – occurring jitter caused by lighting conditions and camera resolution via a 7 x 7 convolution kernel. The "erosion" process is the required fundamental in OpenCV library which provides a fast, convenient interface for carrying out morphological transformations on images. This is followed by recursive labeling of the connected components of the produced binary image which is aimed at extracting the candidate's eye pair. This procedure is expected to yield only a few connected components, with the ideal number being two (the left eye and the right eye). Whenever a greater number of components are produced due to other background movements, the system discards the current binary image in order to maintain its efficiency and accuracy (Rosekind, 1998).

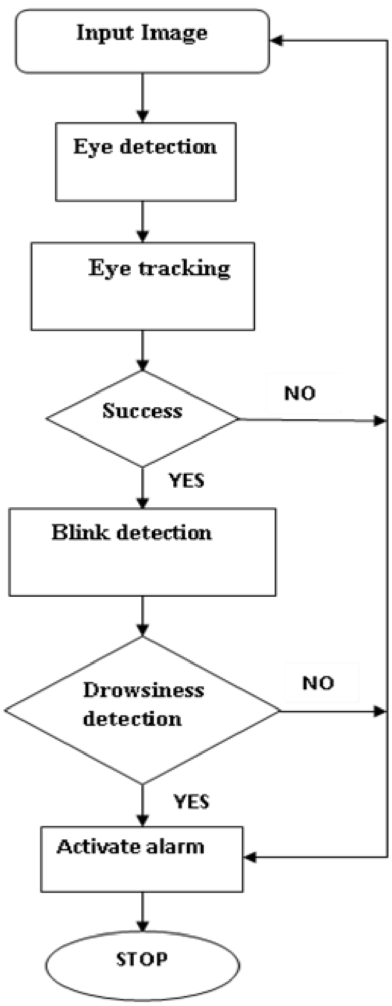


Fig.1: Flowchart of the eye-blink detection system

Once the required number of connected components is obtained, filtering of the unlikely eye pair is carried out based on the computation of each connected component pair. This is based on the computation of six parameters for each component pair: the width and height of each of the two components and the horizontal and vertical distance between the centroids of the two components. At this point, it is proper to determine whether the components are an eye pair or not. This is made up of experimentally derived heuristics for this based on the width, height, vertical distance, and horizontal distance of the components. To make things simple, the process continues if the numbers of the connected components are two (2).

Some set of rules were applied to determine whether connected components are eye pair

i. The width of the components should be about the same i.e.

$$r_1 .width- r_2 \ .width \ \geq \ 5 \tag{1}$$

ii. The height of the components should be about the same i.e.

$$r_1.height - r_2 \ .height \ \geq \ 5 \tag{2}$$

iii. The vertical distance of components should be small i.e.

$$r_1. y - r_2 \ .y \ \geq \ 5 \tag{3}$$

iv. There should be Reasonable horizontal distance ratio, based on the components' width i.e.

$$dist\_ratio = r_1 . x + r_2 . x = r_1.width \tag{4}$$

where r_1 and r_2 are the two selected components. This statistics are used to pinpoint the exact pair that most likely represents the candidate's eyes. Algorithm 1 outlines the basic functions for the eye detection procedure.

2.2. Template Creation

After the connected components have successfully passed through the filter, the larger of the two components will be chosen for template creation. This is due to the fact that the size of the template to be created is directly proportional to the chosen components. The larger the component chosen the more the brightness information it contains. This will result in more accurate tracking and, hence, the system obtains the boundary of the selected component, which will be used to extract a portion of the current frame as the eye template. Since an open eye template is needed, it is proper not to create a template the moment the eye is located. This is because blinking involves closing and opening of the eye and, thus, once the eye is located, some delay is set before creating the open eye template. Algorithm 2 shows the commands and codes for creation of template.

Algorithm 1: Basic functions for eye detection procedure

Listing 1: Opening Morphological operation

```
IplConvKernel* kernel;
kernel = cvCreateStructuringElementEx
(3, 3, 1, 1, CV_SHAPE_CROSS, NULL);
cvMorphologyEx(diff, diff, NULL, kernel, CV_MOP_OPEN, 1);
```

Listing 2: connected component labeling

```
CvSeq* comp;
int nc = cvFindContours
(
   diff,          /* the difference image */
   storage,       /* created with cvCreateMemStorage() */
   &comp,         /* output: connected components */
   size of(CvContour),
   CV_RETR_CCOMP,
   CV_CHAIN_APPROX_SIMPLE,
   cvPoint(0,0)
);
```

Listing 3: motion analysis to detect eye blinks

```
CvSub (gray, prev, diff, NULL);
cvThreshold(diff, diff, 5, 255, CV_THRESH_BINARY);
```

Algorithms 2: Commands and codes for online template creation

```
cvWaitKey(250);
cvSetImageROI(gray, rect_eye);
cvCopy(gray, tpl, NULL);
cvResetImageROI(gray);
```

2.3. Eye Tracking

Eye detection is not enough to give the desired accurate blink information desired, since there is a possibility of head movement from time to time. An eye tracking procedure is needed to maintain the exact knowledge about the eye's appearance. Having the eye template and a live video feed from a camera makes it possible for the system to search and locate the candidate's eye in the subsequent frames using template matching. This is limited to a small search in order to commit a suitable amount of computational resources to the process.

The eye tracking algorithm utilizes the square difference matching method, which matches the squared difference so that a perfect match will be zero and bad matches will be large (Chau and Betke, 2005; and Http://www.nashrudden.com). The equation is given by:

$$R_{sqdiff}(x,y)=\sum_{x',y'}[T(x',y')-I(x+x',\times\ y+y')]^2 \qquad (5)$$

where
$$T(x,y)=T(x',y')-\tilde{T}$$
$$I(x+x',y+y')=I(x+x',y+y')-\tilde{I}(x,y)$$

$T(x,y)$ is the brightness of the pixel at (x,y) in the template and source image respectively, and $\check{T}$ is the average value of the pixels in the template raster and $\tilde{I}(x,y)$ is the average value of the pixels in the current search window of the image. At any time the squared difference exceeds a predefined threshold the tracker is believed to be lost. For this event, it is critical that the tracker declares itself lost and re-initialize by going back to eye detection. Algorithm 3 shows the codes for locating the eye in subsequent frames.

The number of times the tracker appears in thirty seconds, expressed in percentage which is given as:

$$\%\,eye\ \ tracking\ accuracy=\frac{T_x}{T_y}\times 100\% \qquad (6)$$

where T_x is the number of times the tracking was successful within a specified period of time, and T_y is the total number of times the eye was tracked.

2.4. Blink Detection

A human being must periodically blink to keep his eyes moist. Blinking is involuntary and fast. Most people do not notice when they blink. However, detecting a blinking pattern in an image sequence is an easy and reliable means to detect the presence of a face. Blinking provides a space-time signal which can be easily detected.

Algorithm 3: Codes for locating the eye in subsequent frames

```
/* get the centroid of eye */
point = cvPoint
(
   rect_eye.x + rect_eye.width / 2,
   rect_eye.y + rect_eye.height / 2
);
/* setup search window */
window = cvRect
(
   point.x - WIN_WIDTH / 2,
   point.y - WIN_HEIGHT / 2,
   WIN_WIDTH,
   WIN_HEIGHT
);
/* locate the eye with template matching */
cvSetImageROI(gray, window);
cvMatchTemplate(gray, tpl, res, CV_TM_SQDIFF_NORMED);
cvMinMaxLoc(res, &minval, &maxval, &minloc, &maxloc, 0);
cvResetImageROI(gray);
```

In algorithms developed in previous works (e.g., Grauman et al., 2001; Bradski and Kaehler, 2008), eye blinks were detected by the observation of correlation scores such that the detection of blinking and the analysis of blink duration are solely based on observation of the correlation scores. This is generated by the tracking of the previous step using the online template of the user's eye. As the user's eyes close during the process of a blink, the similarity to the open eye template decreases. As the user's eye is in the normal open state, very high correlation scores of about 0.85 to 1.0 are obtained. As the user blinks, the scores are expected to fall to values of about 0.5 to 0.55. This scenario is true if the user does not make any significant head movements. If the user moves his head, the correlation score also decreases even if the user doesn't blink, and hence motion analysis is also used to detect eye blinks. Only that at this time, the detection is limited in a small search window, the same window that is used to locating the user's eye. Algorithm 4 shows the basic opencv functions called during the program execution.

Algorithm 4: Blink detection with motion analysis

```
/* motion analysis
 cvSetImageROI has been applied to the images below */
cvSub(gray, prev, diff, NULL);
cvThreshold(diff, diff, 5, 255, CV_THRESH_BINARY);
cvMorphologyEx(diff, diff, NULL, kernel, CV_MOP_OPEN, 1);
/* detect eye blink */
nc = cvFindContours(diff, storage, &comp, sizeof(CvContour),
              CV_RETR_CCOMP,
CV_CHAIN_APPROX_SIMPLE, cvPoint(0,0));
```

2.5. Drowsiness Detection

Blinking is defined as the rapid closing and opening of the eyelid. The average duration of an eye blink is 0.3 to 0.4 seconds, with a frequency varying from once in every two seconds up to once in several tens of seconds. The blinking rate can also be affected by external stimulus such as fatigue, eye injury, medication or disease. Eyelid movement is characterized by two different processes. First a change of blinking frequency related to the changes of attention and secondly a change of blinking duration connected with the development of drowsiness.

According to Galley and Schleicher (2004), the blink frequency is strongly correlated to psychological factors like mood state and task demands. Typical blink frequency is about 15-20 times per minute in a stress-free state, but can go down to three per minute when drowsiness sets in; there are also large individual variations. Mathematically:

$$F = \frac{1}{T} \quad (7)$$

$$F = \frac{number\ of\ blinks}{blink\ duration} \quad (8)$$

where *F* is the frequency of blinks and *T* is the blink duration. In other words as the frequency of blinks is inversely proportional to blinking duration, when a person is highly alert the duration of blinking in a circle is relatively high but as drowsiness set in the blinking duration drop relatively. Invariably this means that when blinking duration is high the frequency of blinks is low and vice-versa

3. METHODOLOGY

A system was developed for detecting and analyzing eye blinks with the aid of a video camera, which had a resolution of 320 x 240 at a frame rate of 30 per second (5 Megapixels) as its capture device. This system was used to locate an eye by automatically considering the motion information between consecutive frames and to determine if this motion was caused by a blink. Once found in this manner, a gray scale template will be extracted from a blink location of an eye. The eye is then tracked and constantly monitored to establish to what extent it opened or closed at each frame. Subsequently, the system was used to monitor the blink rate and duration in order to keep track of the blinks in order to reach a logical decision. The system determines the blink rate by counting the number of consecutive frames in which the eye remains closed. The system is design to trigger a warning signal via an alarm once the early stages of drowsiness is detected.

Based on this procedure, an algorithm was developed. The developed algorithm was implemented in C language, Microsoft Speech Software Development Kit (SDK) and Open Computer Vision (CV) library. For the sake of experimental evaluation, a graphic user interface of the system is designed to accommodate the major variables of the parameter used in this work (Fig. 2).

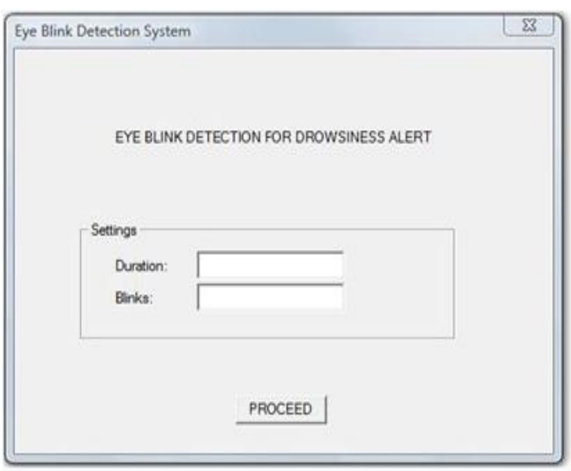


Fig. 2: User interface for the Eye-blink detection system

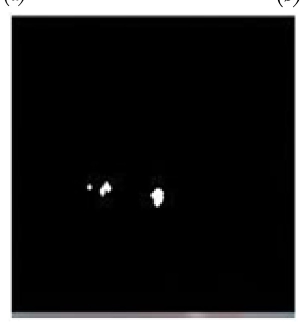
In order to evaluate the eye tracking accuracy of the system, specifically this experiment was conducted by placing a candidate at varying distance from the camera. A time constraint of 30 seconds was placed on the system to effect the automatic initialization of the tracker, consisting of two small bonding boxes, which tend to appear on the image. If the tracker does not appear within a period of 30 seconds, the tracker is believed to be lost. This was conducted with distances of 30, 60, 90, 150 and 180 cm.

In order to ascertain blink detection accuracy, ten (10) different candidates were used, since a more standard measure of the overall accuracy of the system should be across a broad range of users. In a captured video sequence of each of the test subjects sitting at 60 m away from the camera. They were required to blink naturally but frequently and exhibit mild head movements

4. RESULTS AND DISCUSSION

Fig. 3 shows a typical transition during eye detection. A total of 500 true blinks of the candidate were analyzed, in which each candidate produced 50 blinks. During this evaluation session, the system encountered two types of errors which are the missed blink error and false positive blink error. Missed blinks occur as a result of the system not being able to detect the subject's blink when there was actually a blink which can be attributed to instances when the tracker is lost due to rapid head movements. False positive blinks occur when the system detects a blink when there was none produced by the test subject.

(a) (b)



(c)

Fig. 3: (a) Grayscale image captured by the camera (b) The corresponding thresholded difference image before erosion (c) Thresholded difference image after undergoing erosion.

Twelve (12) blinks were missed out of 500, resulting in an initial accuracy of 97.6%. Furthermore 15 false positive blinks were encountered making the overall accuracy of the system to be 94.6%. Table 1 shows the summary of result. From the foregoing, the capture rate of the camera, which is 30 frames/second, was used to produce a blink accuracy of 94.6% with a 3% false positive error. This result is comparable to the work of Danisman *et al.* (2010) that employed a camera with a capture rate of 110 frames/second for a

320x240 resolution in order to obtain an accuracy of 94.8% and a 1% false positive error.

Fig. 4 shows a plot of the percentage tracking accuracy against distances from the plot, at a distance of 30cm the accuracy is 72%, and at a distance of 182cm the accuracy drops to 10%. The tracking accuracy of the system enables us to ascertain the sensitivity of the system at varying distances. Since there are possibilities of slight movement of the driver's head from time to time, this can result in varying distance of the driver from the camera fixed location. In conclusion, as the distance from the camera increases the tracking accuracy of the system decreases progressively. Fig. 4 enables the estimation of the best position the camera can be placed in other to obtain the highest degree of tracking accuracy for a short period of time.

Table 1: Summary of results

Total number of blinks analyzed	500
Total number of missed blinks	12
% Initial accuracy of the system	15
% Overall accuracy of the system	97.6%
% Missed blinks error	2.4%
% False positive blinks error	3.0%

Furthermore, compatibility test was carried out on the system. And it was discovered that it is compatible with operating systems like windows XP and windows vista and performed satisfactorily well.

5. CONCLUSION

This work presents a non-invasive method of carrying out an early detection of the drowsiness of car drivers by the continuous monitoring of the psycho-physiological status. The application uses a standard monitor mounted webcam to track the driver's eye dynamics. The developed algorithm uses the motion analysis to detect the eye which is automatically initialized by the involuntary blink of the driver. Furthermore, a subsequent location of the eye due to movement of the head is detected using the squared difference matching method. When the frequency of blinks gets to a critical level, the system is programmed to provide an early warning signal, which is detected with high certainty by presenting a verbal secondary task via recorded voice, to alert the driver.

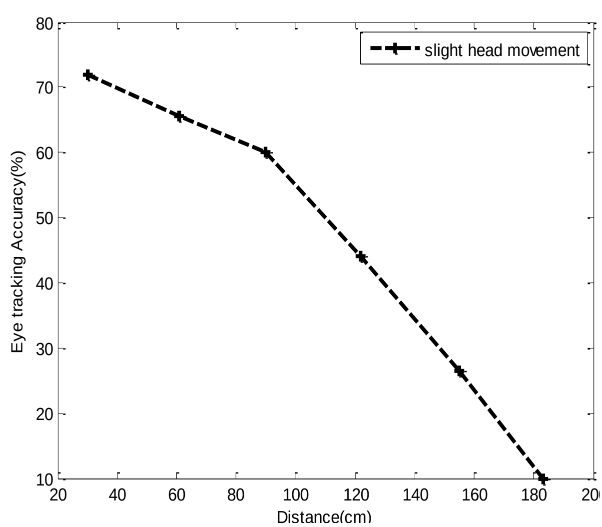


Fig. 4: Percentage eye tracking accuracy at varying distances

The achieved results demonstrated that blink detection is a suitable technique for initializing and tracking the location, in successive frames of an image sequence. The system has worked in real-time and is robust with respect to variations in scaling and lighting conditions, different orientations of the head and presence of eye glasses. With the high degree of accuracy achieved in this system, a reduction in the rate of accidents caused by drowsiness on the highways would be an achievable target.

In other to enhance the tracking accuracy of the system, it is recommended that the camera should have an automatic zooming capability. This will go a long way to improve the sensitivity of the system when tracking at varying distances. By doing this, the tracking accuracy of the system will be fairly constant and predictable. It is also recommended that adaptive binarization should be used to eliminate the need for the noise removal function. This is expected to cut down on the computations needed to find the eye, and hence, enhance the adaptability of the system to changes in ambient light.

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