An Adaptive and Robust Implementation of a Fatigue Detection System

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Abstract: Advanced driver assistance systems are the need of the hour. One component, the fatigue or drowsy driver detection system has been an ongoing development effort. This paper aims to propose one such cost effective yet accurate system which localizes the areas of the eyes and the mouth to determine whether a person is experiencing fatigue by computing certain fatigue metrics. The paper also aims to show how the method of binarization along with a few image processing algorithms can be a strong ensemble for such a system.

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Keywords: fatigue detection, drowsy driver, automotive safety, ADAS

1. Introduction

The Federal Motor Carrier Safety Administration (FMCSA), the trucking industry, highway safety advocates, and transportation researchers have all identified driver fatigue as a high priority commercial vehicle safety issue. It affects mental alertness, decreasing an individual's ability to operate a vehicle safely and increasing the risk of human error that could lead to fatalities and injuries. Furthermore, it has been shown to slow reaction time, decreases awareness, and impairs judgment. Long hours behind the wheel in monotonous driving environments make drivers particularly prone to drowsy-driving crashes. Successfully addressing the issue of driver drowsiness in the commercial motor vehicle industry is a formidable and multi-faceted challenge.

Not only is drowsiness an issue of great concern for the roads, but it is of great significance for pilots in aviation. Negligence of pilots in air travels can result in incidents having disastrous consequences. Add to it the long hours of flight and different time zone crossings, we have in our hands completely fatigued and overworked officers whose condition to pilot a plane can be easily questioned by a concerned traveler. Addressing the need for a reduction in crashes related to driver fatigue in transportation will require some innovative concepts and evolving methodologies. Invehicle technological approaches, both available and emerging, have great potential as relevant and effective tools to address fatigue. Within any comprehensive and effective fatigue management program, an on-board device that monitors driver state in real time may have real value as a safety net. Sleepy drivers exhibit certain observable behaviors, including eye drooping, blinking, yawning, headdrooping which can be used as parameters in the design.

2. Research

There are many techniques which can be used to implement the fatigue detection system. Most of them are based on Fuzzy Logic, Neural networks or only direct Gaze and Eye tracking. But, techniques that employ a single methodology for fatigue detection can display a higher chance of false alarms or may require higher accuracy. Technologies like thermal imaging and ESP provide much better results but at a higher cost which is certainly not implementable for everyday people.

In the proposed system, we have introduced a unique implementation method of the fatigue detection system. After a lot of literature and product survey we have come up with the idea that the entire system can be designed just based on the binarized segments of the image. Though not as highly accurate as some benchmarked processes, it is much simpler and cost efficient. [1] and [3] says that in the case of eye segmentation the area of white obtained after the traversing the image are more in the case when the eyes are closed than when the eyes are open. Similarly in the case of mouth segmentation, the area of black obtained after traversing the image is found to be more in the case when the mouth is open rather than when it is closed. We made use of this theory in our proposed system. Most other systems using eye tracking method lose track of the eye if the person wears dark glasses or sunglasses. The proposed system, even if it loses track of the eyes, keeps track of other parameters which would aid in detecting the state of fatigue. This is a major advantage of this system.

3. Design

This section aims to present our proposed design of the Fatigue Detection System. Each design decision will be presented and rationalized, and sufficient detail will be given to allow the reader to examine each element in its entirety.

Concept Design

As seen in the references [2], [4], [6] and [7], there are several different algorithms and methods for eye tracking, and monitoring. Most of them in some way relate to features of the eye (typically reflections from the eye) within a video image of the driver. The original aim of this project was to use the retinal reflection (only) as a means to finding the eyes on the face, and then using the absence of this reflection as a way of detecting when the eyes are closed. It was then found that this method might not be the best method of monitoring the eyes for two reasons. First, in lower lighting conditions, the amount of retinal reflection decreases; and second, if the person has small eyes the reflection may not show. With progress, the idea to use the changes in intensity formulated. One similarity among all faces is that eyebrows are significantly different from the skin in intensity, and that the next significant change in intensity, in the y-direction, is the eyes. This facial characteristic is the center of finding the eyes on the face, which will allow the system to monitor the eyes and detect long periods of eye closure.

System Configuration

Background and Ambient Light

Since the eye tracking system is based on intensity changes on the face, it is crucial that the background does not contain any object with strong intensity changes. Highly reflective object behind the driver, can be picked up by the camera, and be consequently mistaken as a facial feature.

Camera

The fatigue detection system consists of a camera that takes images of the driver's face. This type of drowsiness detection system is based on the use of image processing technology that will be able to accommodate individual driver differences. The camera is placed in front of the driver, approximately 30 cm away from the face. The camera must be positioned such that the following criteria are met:

- The driver's face takes up the majority of the image.
- The driver's face is approximately in the center of the image.

The video is shot at a resolution of $\underline{320x240}$ since the quality of the video obtained at this resolution is more than sufficient to provide all the information related to contrast and light intensity distribution.

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4. Algorithm Implementation

System Process

Eye and Mouth Detection Function

After the facial image is taken as input, pre-processing is first performed by noise removal and binarizing the image. The top and sides of the face are detected to narrow down the area of where the eyes and the mouth exist. The obtained image is then segmented into two halves, one where the eyes exist and one where the mouth exists.

Further, the average intensity value for each half is calculated. Changes in the intensity are used to define the criteria for judging whether a driver is experiencing fatigue or not. It is noticed that the hair portion is always binarized to black and the forehead takes up major part of the face which is always binarized to white, unless the person is very dark or under non ambient lighting conditions, hence majority of the changes in the image are observed only due to the eyes or the mouth.

Another point to note is that the algorithm doesn't stress on eye detection. Surely, inclusion of eye detection guarantees higher accuracy. But, since the upper half of the face mostly consists of the forehead and eyebrows whose binary intensities are constant, the same decision can be obtained in this similar fashion as well.

Figure 1, depicts the system flow diagram.



Figure 1: Fatigue Detection System flow

Let us look at each step in detail.

Step 1: Binarization

The first step after localizing the face from the entire image is binarizing it. Binarization is converting the RGB or grayscale image to a binary.



Figure 2: Step 1: Binarizing the face image

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International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

(A binary image is an image in which each pixel assumes the value of only two discrete values. In this case the values are 0 and 1, 0 representing black and 1 representing white. With the binary image it is easy to distinguish objects from the background. The output binary image has values of 0 (black) for all pixels in the original image with luminance less than level and 1 (white) or all other pixels)

Thresholds are often determined based on surrounding lighting conditions, and the complexion of the driver. After observing many images of different faces under various lighting conditions a threshold value of 0.6 was found to be effective. The criteria used in choosing the correct threshold was based on the idea that the binary image of the driver's face should be majority white, allowing a few black blobs from the eyes and the mouth.

Step 2: Segmentation

After binarization, the next part is to segment those areas where the eyes and the mouth exist. Under the assumption that the face occupies maximum part of the image, after initial face detection, the image is halved. So the upper part of the image will contain the eyes and the lower part will contain the mouth.

Step 3: Detection and Determining Fatigue Condition/

Eye Closure

In Figure 3, it can be seen that (considering surrounding areas are the same) the area of white on the face is more when the eyes are closed than when the eyes are open. The eyeballs and some portions of the edges of the eyes tend to form black areas as can be observed. These parts are the one which tend to become white when the eyes are closed. The simulation results give the exact idea of the area difference in the two images. Knowing this, we can determine when the eyes would be open/closed.



Mouth Opening / Yawn Detection:

Yawn detection is also a very important factor which has not been implemented till date in most of the existing systems. In Figure 4, it can be seen that when the mouth is closed a majority or almost whole of the image is white leaving the background portions. When the mouth is open or a person yawns the area of the mouth which is open is treated as binary black. Hence the white area from the overall image reduces. Using this condition, we can judge when a person is yawning.



Head Drooping

This is another important parameter which is a necessity to be taken into account. If the driver is very drowsy, his/her head may droop down and go out of the vision of the camera. In the case that this happens the camera may not be able to capture the eyes or the mouth. In the case of the above happening (assuming that the background is dark) majority of the image is considered black and only a minor part of the image (if the face is captured) is white. If the black portion takes up 60% or more in the image and stays so for a stipulated amount of time then a warning is issued to the driver.

Step 4: Judging Drowsiness

This system considers certain time based factors have been based on a study of the human behavior to warn the driver if he is drowsy. Some of the simple rules are as below:

- If the eyes and the mouth fatigue conditions are found for 10 counts, may or may not include consecutive frames, approximating to about 25-30 seconds then the fatigue condition is met.
- If the head droops and this condition is obtained for a time period of 3 seconds then the fatigue condition is met.
- If the count is not incremented for a time period of 7 seconds then the system is reset.
- The reference frame is updated when the consecutive changes are minuscule. The reference frame is not updated periodically since a case may arise that the driver is initially droopy or may remain droopy for a long period of time. In this case, if every previous frame is taken as a reference, the system will fail to recognize the fatigue condition. Hence, the reference frame is updated periodically only when certain conditions are satisfied.

Automatic Contrast Adjustment module

Under poor lighting conditions it is necessary that the image be pre-processed in order to have a better image for feature extraction. A mathematical solution was developed in order to calculate the image adjustment factor to enhance the contrast of an image based on the current pixel values present in the image and the external lighting conditions. The module was tested under various conditions and it seemed to give fairly significant results.

An existing method was using the CLim^[5] or the color mapping property, also known as the caxis adjustment method. This property was very useful in adjusting the contrast of the gray images using pixel level mapping but the drawback of this was that image storage was becoming a difficult task hence this method was withdrawn.

For this system, the image adjustment tool was used along with the mathematical solution we developed. The steps which have been followed are as below.

- Obtain the image.
- Convert the image to grayscale.
- Obtain the maximum and minimum values of the gray pixel values in the image.
- Now using the mathematical solution we came up with, we obtain the image contrast adjustment factor.

Volume 6 Issue 2, February 2017

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Image Adjustment Factor $(I_{adj}) = \left(\frac{G_m}{G_{mi}}\right)^{-1}$ –

 $\left(\left(\frac{G_m}{G_{mi}}\right)^{-1}/4\right)$

where, $G_m =$ Maximum Gray level value. G_{mi} = Maximum Gray level value in the image.

• Now this Image adjustment factor is used in the image adjustment tool which is used to adjust the contrast and obtain the final image.

Currently, this method is being used for contrast adjustment before the actual detection part begins so that it gives the system an easier image to work on. We are still pursuing research and tests on this solution to come up with more optimized results.



Figure 5: Automatic Contrast Adjustment

Figure 5, depicts images after being passed through the contrast adjustment module.

5. Conclusion

A non-invasive system to localize the eyes and the mouth and monitor fatigue has been proposed. Information about the face, eyes and mouth position is obtained through various solutions developed. During the monitoring, the system is able to decide if the eyes are opened or closed and the same e): 2319 for the mouth. When the eyes have been closed for too long or the mouth has been opened (yawning) for more than required, a warning signal is issued.

Other conclusions which can be made are:

- Image processing achieves highly accurate and reliable detection of fatigue.
- Image processing offers a non-invasive approach to detecting fatigue without the annoyance and interference.
- A fatigue detection system developed around the principle of image processing judges the driver's alertness level.
- A very important parameter is the response time accuracy trade off of the system. These two factors are always mostly inversely proportional to each other. This system designed is balanced in terms of both, showing good accuracy and a fast response time.

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