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ATTENTION DETECTION OF THE DRIVER TO ENSURE SAFE DRIVING

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KeyWords

Visual focus of attention, eye center localization, gaze detection, sustained attention.

ABSTRACT

Abstract- In this paper, we have tried to detect the focus of attention of the driver from his/her head movement and orientation of pupil detection. If the driver changes his/her gaze, the corresponding coordinate of pupil also changes. The frontal view of the person is divided into three regions corresponding to three target objects and the gaze directions are detected based on in which region the coordinate of pupil is located in the eye area. In our technique we have used a camera to capture video frames of the target person. The frames are converted into grey image and processed pixel by pixel. A 3D head tracker is used to extract the facial regions from the image. From the facial regions face points and eye regions are detected. Using a Vector Field of Image Gradient (VFIG), the pupil of eye is detected. In our approach, we have used the face points to create a rectangle outside of the eyes to detect the gaze of driver by applying different techniques under different lighting conditions and different distances from the camera. For non-frontal face, sometimes situation arises when we cannot detect the pupils efficiently. In this case, we have used the head orientation for gaze detection. The head rectangle has been divided into three regions. We estimate the gaze based on which region the middle of the head falls with varying head rotation time. To ensure a safe driving we need to detect sustained as well as transient attention very carefully and efficiently. To detect the body movement, we have used the optical flow feature and verified this approach in controlled environment. Our result in controlled and real time experiments reveal that, we can efficiently track the focus of attention of the driver from the coordinate of the pupil of the eye combining with head position and consequently we can detect the sustained attention together with transients very effectively and control the attention by deploying an alarming system if inattention is detected.

I. Introduction

Analysis and understanding of human behavior, particularly of head and eye gaze behavior, has been a subject of interest for many years [1] in cognitive psychology, neurophysiology and object [2] detection- especially in the field of detection and controlling of drivers' focus of attention [3]. However, a full understanding of the detail insight of human's visual focus of attention (VFOA) to incorporate human– machine interfaces (HMI) for building up an intelligent system is still a subject of active research. Visual attention and its controlling process can be integrated in a system to autonomous driving and collision avoidance. In such a system, a processing in real time is necessary. Similar to the visual system in humans this can be achieved by focusing the limited resources of a system to those parts of an image that are relevant to the task of the target human. From the very beginning there is always an extreme demand of an accurate method to accomplish this task.

Every year there are over one million traffic-related fatalities worldwide due to driver's inattention. According to the police report **40,927** road accidents occurred during **2001-2010** in Bangladesh. These accidents killed **32,261** persons. The estimated cost of road accidents is about **7500** crore Bangladeshi taka. But a matter of hope is that, recent advances have promoted the integration of driver behavior analysis into Intelligent Driver Assistance Systems to counteract inattention and poor driving behavior. The analysis of body language in critical situations, such as the time prior to a lane change, becomes central in giving these systems the ability to predict the context of the situation.

There are different works already done in this field [4][5][6]. Unfortunately, most of the existing methods of controlling driver's attention use sensors based head mounted devices to estimate the attention level [7][8].Although the sensor-based approaches are accurate, however these approaches require technology applicable to controlled environment. Moreover, to track the visual attention, the researchers used solely head tracking [9] or eye tracking [10] [11] [12] techniques. But we have combined the both to estimate the attention of driver and it requires a very low cost senor (such as a USB camera) situated in front of a driver (celling of the car).Thus our technique is applicable in real time environment and also offers cost efficiency.

Since the road accident is a major problem in Bangladesh due to the low level of driving attention, thus, by implementing such a system in a vehicle and alarming the driver when s/he looks at other than the target object, our proposed technique will contribute in reducing the number of road accidents caused by the drivers' fluctuation of visual focus of attention. In this way, for potentially dangerous situations such as driving and flying, our proposed active perception of human's focus of attention has a large role to play in improving comfort, saving lives and reducing the cost due to road accidents.

II. Methodology

The research methodology is divided into three consecutive parts. Which are described as follows-

2.1 Head and Eye Center Detection

In this work we have used a low quality camera (resolution- 5 mega pixels) to capture continuous image of the driver. The continuous images are then fed to the system for processing. For easier processing, the images are converted into grayscale. Histogram equalization is performed on each image so that we can continue our operation when there is slight lack of proper lighting. 6 to 8 images are processed each second. After that the frames are resized.The processed frames are saved as a continuous video file in AVI format at the rate of 7 fps (Frame per Second). These stored video files are analyzed to get the results. The step by step analysis to detect the iris center from the image is described in the following section-

2.1.1 Head Pose Detection by 3-D Head Tracker

A human head has non-planar geometry. Also, it has curved surfaces. A simple model for representing a human head such as a plane would not track the 3D head motion accurately. 2D planar model is simple but not effective for representing a human head because it cannot represent curved surfaces well. Therefore, 3D head tracking with a planar model is not robust to out-of-plane rotations. On the other hand, a complex actual head model would require a very exact initialization and suffer from computational burden. Therefore, to build a 3D model of a human head approximately, a cylinder or an ellipsoid has been often used [13]. Among them, we adopt an ellipsoidal model for representing the human head.

Since a cylinder model does not represent vertically curved surfaces, compared with a 3D ellipsoid model, the latter is more suitable for representing a human head. A 3D ellipsoid itself is parameterized by the lengths of its major axes. We assume that the width r_x is 1. Thus we only need to determine the ratios between the width r_x to the height $r_y$and the width to the depth r_z. In our approach, we statistically obtain these ratios from the sample data of human heads to represent curved surfaces of a human head more generally. Let the origin of an object coordinate frame be placed at the center ofa human head and the frontal face looks at the positive Zaxis of an object coordinate frame. Let $[X_o\ Y_oZ_o]^T$ be the coordinates of a surface point P_o in the object reference Frame.Then, the surface point of a 3D ellipsoid can be easily defined like below-

$X_o = r_x \sin\alpha \sin\beta$

$Y_o = r_y \cos\alpha$

$Z_o = r_z \sin\alpha \cos\beta$

Compared with other ellipsoidal models, we only use the partial regions of a human head with a range of about $60^o \leq \alpha \leq 135^o$ and $-90^o \leq \beta \leq 90^o$ to express a human face more precisely and exclude disturbing regions such as hairs and background outliers.

2.1.2 Face Points Extraction by Active Shape Model

Our modeling method works by examining the statistics of the coordinates of the labeled points in the head rectangle [14]. In order to be able to compare equivalent points from different shapes, they must be aligned with respect to a set of axes. We achieve the required alignment by scaling, rotating and translating the shape so that they correspond as closely as possible. In this technique, we aim to minimize a weighted sum of squares of distances between equivalent points on different shapes.

We first consider aligning a pair of shapes in the head rectangle. Let x_i be the vector describing the n points of the *i*th shape in the set:

$X_i = (x_{i0}, y_{i0}, x_{i1}, y_{i1,\ldots,}x_{ik}, y_{ik,\ldots,}x_{i\,(n-1),}\ y_{i\,(n-1)})^T$

Let $M(s,\theta)[x]$ be a rotation by θ and scaling by s. Given two similar shaper x_i and x_j, we can choose θ_j and and s_j and translation $(t_{xj,}\, t_{yj})$ mapping x_i onto $M(s_{j,}\, \theta_j)[x_j] + t_j$ so as to minimize the weighted sum.

$E_j = (x_i - M(s_j, \theta_j)[x_j] + tj)^T W = (x_i - M(s_j, \theta_j)[x_j] + t_j),$

Where,

$t_j = (t_{xj}, t_{yj}, \ldots\ldots, t_{xj}, t_{yj})^T$ and W is the diagonal matrix for each point.

The weights can be chosen to give significance to those points which tend to be more stable in the set- the ones those move the least with respect to the other points in the shape. We have used a weight matrix defined as follows- let R_{kl} be the distance between the points k and l in the shape and V_{Rkl} be the variance in this distance over the set of shapes. We can choose a weight W_k for the *k*th point using-

$W_k = (\sum_{i=0}^{n-1} P)^{-1}$ where, $P = V_{Rkl}$

If a point tends to move around a great deal with respect to the other points in the shape, the sum of the variances will be large and a low weight will be given. If a point wants to stay fixed with respect to the other, the sum of the variances will be small and a large weight will be given. We match such points in the shape to extract the face points.

2.1.3 Iris Center Detection by Vector Field of Image Gradient

The VFIG iris center detection technique is described as follows-

Let I_c be the possible iris center and I_{gi} be the gradient vector in position I_{xi}. If I_{di} is the normalized displacement vector, then it should have some absolute orientation as the gradient I_{gi}. We can determine the optical center I_c^* of the iris (darkest position of the eye) by computing the dot products of I_{di} and I_{gi} and finding the global maximum of the dot product over the eye image:

$I_c^* = \text{argmax } I_c\{\frac{1}{N}\sum_{i=1}^{N}(P\ )\}$

Where, $P = (I_{di}^{T} I_{gi})^2$

$I_{di} = (I_{xi} - I_c) / (||I_{xi} - I_c||_2)$

i =1, 2,...,N and the displacement vector I_{di} is scaled to unit length in order to obtain an equal weight for all pixel position in the image.

Figure 1: Face points extraction

Figure 2: Head, eye region and eye center detection

2.2 Gaze Detection of the Driver

The visual field of the driver is divided as the following diagram-

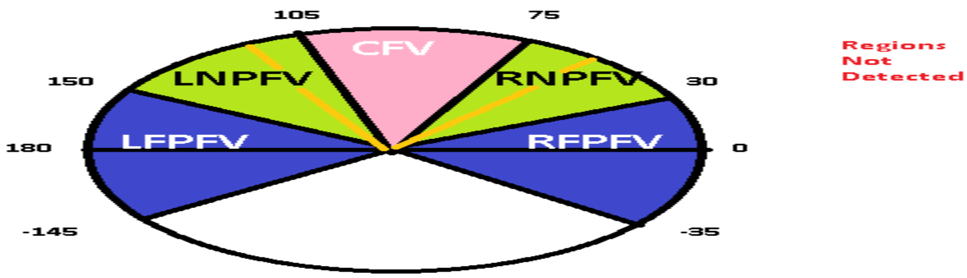

Figure 3: Failure to detect Near Peripheral Field of View (NPFV) correctly

If we can track the pupil of the eye efficiently, then from the variation of the coordinate of pupil of the driver we can detect on which direction he is focusing. From the face points eye rectangle is created around the eye region. For simplicity, we shall consider the coordinate of only left eye because we know that the pupil of the two eyes move simultaneously. The width of eye rectangle is divided into three regions: left, monitor and right. If the driver changes his focus from central field of view (CFV) to any of the near peripheral field of view (NPFV), the corresponding x coordinate of pupil also changes. Within the eye rectangle we shall detect on which region the x coordinate of eye falls and thus detect the gaze of the driver. To accomplish this, we have used **Unequal Partitioning of Eye Rectangle Leaving the Uncovered Regions** method [15].

In this technique we leave the uncovered regions and the width of the left, monitor and right regions are not the same. To detect the slight change of focus from Central Field of View (CFV) to the left or right, the width of the monitor region is decreased and hence the width of the left as well as the right regions increases so that they can accommodate the slight change of focus in Near Peripheral Field of View (NPFV) and enhance the total accuracy. The threshold detection for left, monitor and right regions are discussed below-

Let the width of the left eye rectangle be 60 pixels and it is divided into five equal parts as before.

A rough threshold for the five regions are defined as follows-

Left uncovered1 = {X: X > 300 and X < 312}

Left1 = {X: X >= 312 and X < 324}

Monitor 1= {X: X >= 324 and X <= 336}

Right1= {X: X > 336 and X <= 348}

Right uncovered 1= {X: X > 348 and X < 360}

Now the length of the monitor region is divided into 4 segments. If the length of the Monitor region is 12 pixels, the length of each of the segment, d = 12 / 4 = 3. Now the new threshold is estimated as-

Left uncovered = $\mathbf{\{X: X > 300 \text{ and } X < 312\}}$

Left = $\mathbf{\{X: X >= 312 \text{ and } X <(324 + d)\}}$

$\mathbf{=\{X: X >= 312 \text{ and } X <327\}}$

Monitor = $\mathbf{\{X: X >= (324 + d) \text{ and } X <= (336- d+1)\}}$

$\mathbf{=\{X: X >= 327 \text{ and } X <= 334\}}$

Right= $\mathbf{\{X: X >(336-d+1) \text{ and } X <= (348+d-1)\}}$

$\mathbf{=\{X: X >= 334 \text{ and } X <= 350\}}$

Right uncovered = $\mathbf{\{X: X >(348+d-1) \text{ and } X < 360\}}$

$\mathbf{=\{X: X >= 350 \text{ and } X < 360\}}$

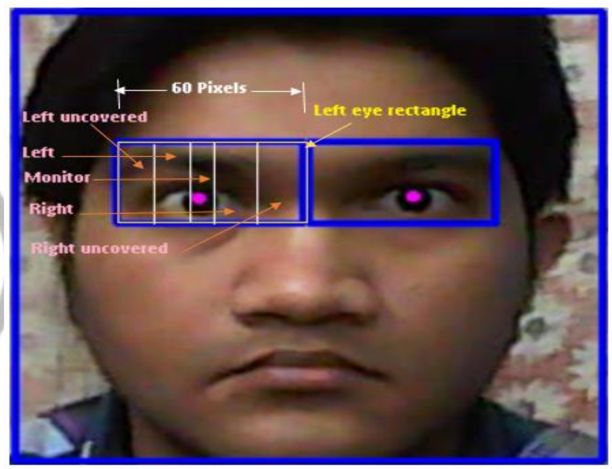

Figure 4: Unequal Partitioning of eye rectangle leaving the uncovered regions

If the driver's gaze is in far peripheral field of view (FPFV) or near this zone, head movement occurs. In this case we cannot detect the eyes for gaze estimation very accurately. So depending on the head movement, we decide on which object the driver is looking. To accomplish this, the width of the head rectangle is divided into three regions: Front, Left side and Right side. From the detected face points, the middle of the face is detected and it is basically the middle of the eye rectangle. Now if we move our head, this middle line of our face also moves with respect to the head rectangle. We decide whether the driver is looking on left, front or right based on in which head region the middle line of the face falls. For example let us consider that the width of the head rectangle is 180 pixels. It is divided into five equal segments. The length of each segment, $s = 180 / 5 = 36$ pixels. If the x coordinate of the head rectangle starts from 300, the threshold values for the three head regions are defined as follows-

Left side = $\mathbf{\{X: X > 300 \text{ and } X < (300 + 2 * s)\}}$

$\mathbf{=\{X: X > 300 \text{ and } X <372\}}$

Front = $\mathbf{\{X: X >=(300 + 2*s) \text{ and } X <= (300 + 3* s)\}}$

$\mathbf{=\{X: X > 372 \text{ and } X < 408\}}$

Right side =**{X: X > 408 and X < (300 + 5 * s)}**

={X: X > 408 and X < 480}

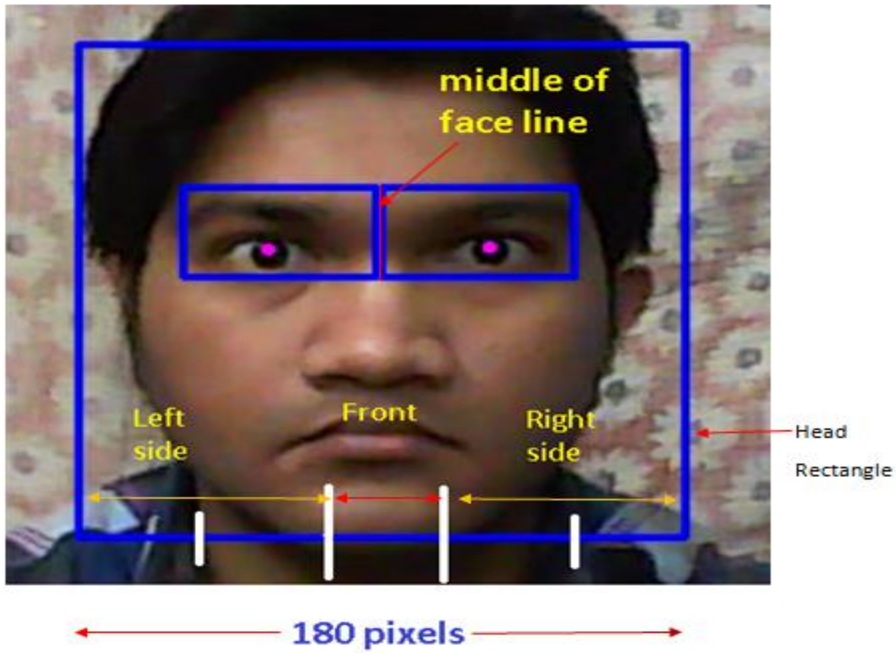

Figure 5: Gaze detection using the head rectangle

2.3 Sustained and Transient Focus of Attention Detection

Selective sustained attention, also known as focused attention, is the level of attention that produces the consistent results on a task over time. However, the time span of sustained attention varies with different type of tasks. On the other hand, transient attention is a short-term response to a stimulus that temporarily attracts/distracts attention.The minimum time for sustained detection is 8 seconds [16], because the maximum time for transient attention is 8 seconds. Detection of sustained and transients are very important to ensure a safe driving. For a given time span while driving, if we can detect that the transient attention of the driver are occurring very frequently, we can ensure the inattention of the driver and give an alarm to alert the driver. To ensure a safe driving most of the attention must be sustained. No transients also mean inattention. Because while driving a driver need to look at the back view mirrors at least twice per minute which are also transient attention. For one minute time span during driving, we can ensure a safe driving if it belongs more than two transients. The threshold values of time for transient and sustained focus of attention detection are given as follows-

Transient **= {T: T >0 and T < 8}**

Sustained **= {T: T > 8}**

2.4 Body Movement Detection using optical flow feature

The American psychologist James G. Gibson gave the concept of optical flow in 1940[17]. To materialize the visual stimulus provided to animals, he considered the pattern of apparent motion in a visual scene. The considered motioin is caused by the relative speed between the observer and the scene. To estimate the optical flow we need the sequences of the ordered images. This approach tries to evaluate the motion between the two consecutive images taken at time t and t+ Δt. In our approach, we have used

Lucas-Kanade method. For a pixel under consideration, it considers the optical flow constant in it's neighbourhood. Using the least square criterion, it solves all the optical flow equation for all of the neighbourhood pixels. To distinguish among different image elements, we have used The Shi and Tomasi corner detection algorithm. The intersection of two edges can be defined as a corner and used to detect the interesting points that have a well defined position and can be robustly tracked. For feature extraction, we have used the Kanade–Lucas–Tomasi feature tracker. Basically, feature extraction is done to deduct the amount of resources needed to narrate the image. With it we can save a lot of computer memory and power.

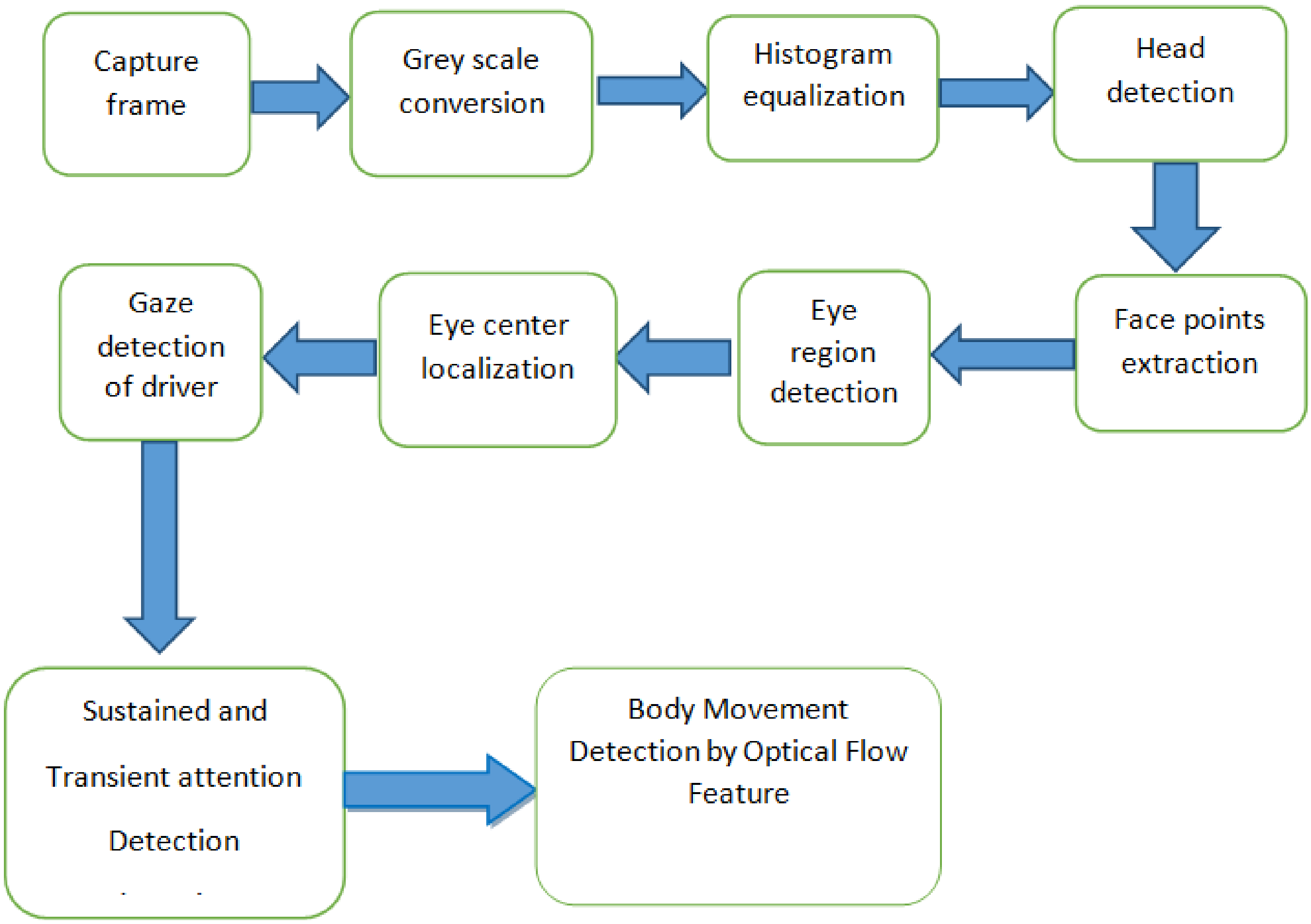

Figure 8: Block diagram representation of the system

III. Data Collection

We conducted separate experiments applying different techniques under different lighting conditions and distances from camera. Data were taken using different participants. This section describes the overall data collection approach step by step.

3.1 Participants

There were total 3 male nonpaying participants with the age 25, 24 and 22 years respectively. For data collection of real time driving, the age of the participant was 40 years.

3. 2 Procedure of Gaze Detection Based on Object Detection

For different experiments, the data collection procedure is described as follows-

3. 2.1 Head and Eye Center Detection

In head and eye pupil tracking experiments, the participants were asked to seat at different distances from the camera under different lighting conditions. They sat at 30cm, 40cm, 50cm, 60cm, 70cm, 80cm, 90cm and 100cm away from the camera. Different lighting conditions were provided by deploying different number of (1, 2, 3 and 4) 32 Watt energy bulbs that provides lamination of different level. The area of our room was $4m^2$. The average video length was 2 minutes.

3. 2.2 Visual Focus Detection

For gaze detection through applying different techniques, these participants were asked to seat 70 cm away from the camera and to look at different target objects with varying head rotation time (1, 2, 3 seconds). These objects are situated 0.5m apart from each other. One of the three objects is located in the central field of view (CFV) and the other two in the near peripheral field of view (NPFV). The average video recording time was 2 minutes. The provided illumination was 200 Lux.

3.2.3 Sustained and Transient Focus of Attention Detection

In sustained and transient attention detection experiments, the participants were asked to look at the left object and the right object for a very short duration so that they may be considered as transients. The duration of transients was also varied during different experiments. The average video recording time was 2 minutes.

3.2.3 Procedure of Real Time Data Collection

We videotaped 3 experiments while driving a car. In the first experiment the participant (age 40 years) was asked to drive the car slowly (35 km/h). In the second experiment the driver (the participant) drove the car comparatively fast(40km/h) through a busy road. In the final experiment the driver drove at the speed of 55 km/h. The distance between the driver and the camera was 0.7 m. Since the day was sunny, proper illumination was provided. The length of recorded video was 3 minutes 33 seconds, 4 minutes 20 seconds and 6 minutes 17 seconds respectively. The frame rate was 30fps (Frame per second).

Figure 9: Video capturing from real time driving

3.2.4 Procedure of body movement detection

The participant was asked to stand by the side of wall and move his body with a low speed. To reduce the image noise, we ensure that there is no background object. The provided illumination was 200 Lux.

Figure 6: optical flow direction when the head is in rest position.

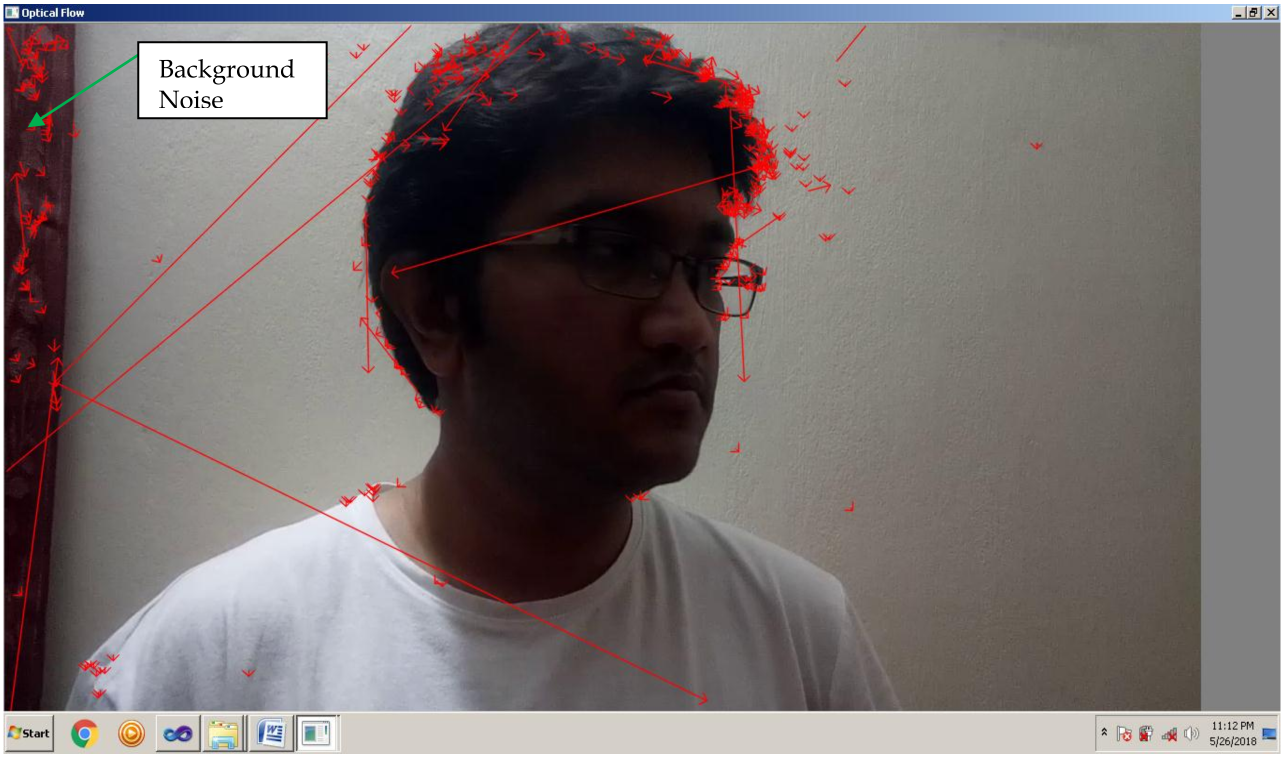

Figure 7: optical flow direction when the head is moving

IV. Performance Evaluation

4.1 Performance matrices

4.1.1 Accuracy of Head and Eye Center Detection

We conducted different experiments with different distance from the camera and with different lighting conditions. For the best lighting condition, the accuracy in head and eye center detection is expressed as follows-

$$\textbf{Accuracy}_{\textbf{varying distance}} = \frac{\text{Total number of trials in which head and eye center is detectd}}{\text{Total number of trials at a particular distance from camera}} \times 100\% \qquad (1)$$

The performance of head and eye center detection also depends on the lighting condition. For a given distance from the camera, the accuracy of detection is expressed as follows-

$$\textbf{Accuracy}_{\textbf{varying illumination}} = \frac{\text{Total number of trials in which head and eye center is detectd}}{\text{Total number of trials at a particular lighting condition}} \times 100\% \qquad (2)$$

4.1.2 Accuracy of Visual Focus Detection

While detecting the gaze from the coordinate of the pupil, the performance is evaluated in terms of "Accuracy" which is defined as follows-

$$\textbf{Accuracy}_{\textbf{FVOA}} = \frac{\text{Total number of gaze detection in a particular direction}}{\text{Total number of gaze occured in that particular direction}} \times 100\% \qquad (3)$$

4.1.3 Accuracy of Sustained and Transient Focus of Attention Detection Combined With Head Pose

The accuracy for sustained/sustained detection is defined as follows-

$$\textbf{Accuracy}=\frac{\text{Total number of sustained/transient attention detected}}{\text{Total number of sustained/transient attention occured}}\times 100\%\ldots\ldots(4)$$

The accuracy for head pose detection is defined as follows-

$$\textbf{Accuracy}_{\textbf{head}}=\frac{\text{Average number of head movement detection at a particular direction in 30 seconds}}{\text{Average number of head movement occured at that direction in 30 seconds}}\times 100\%\ldots\ldots(5)$$

4.1.4 Accuracy of Body Movement Detection

To derive the accuracy of body movement, we have taken the average of features taken from 5 consecutive frames. The accuracy is expressed as follows-

$$\textbf{Accuracy}_{\textbf{Body Movement}}=\frac{\textbf{Average Number of Features found in the direction of body movement}}{\textbf{Total number of features found}}\times 100\%\ldots\ldots(6)$$

4.2 Experimental Results

Figure 10 and 11 shows the Accuracy of Head and Eye Center Detection based on equation (1) and (2) as follows-

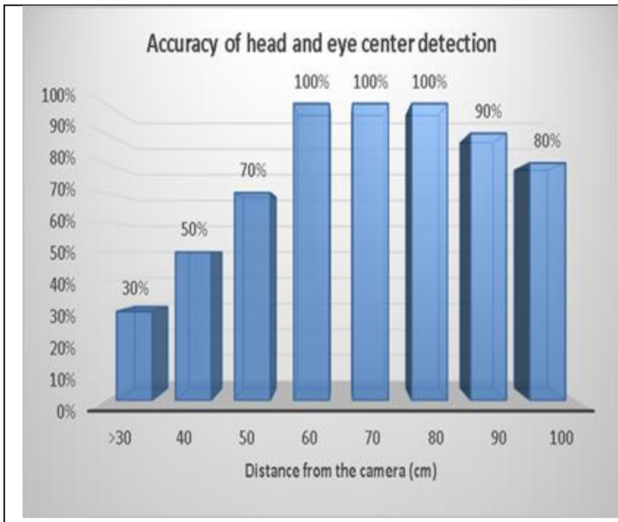

Figure 10: Accuracy of the head and eye center detection with varying distances from the camera

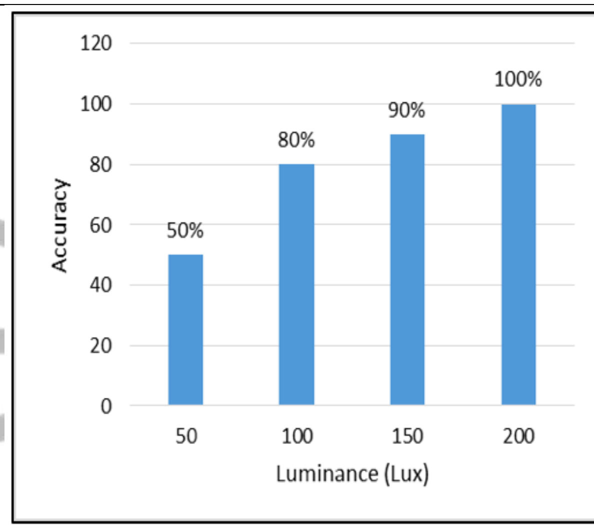

Figure 11: Accuracy of the head and eye center detection with varying lighting conditions

Figure 12 shows the FVOA tracking efficiency based on equation (3)-

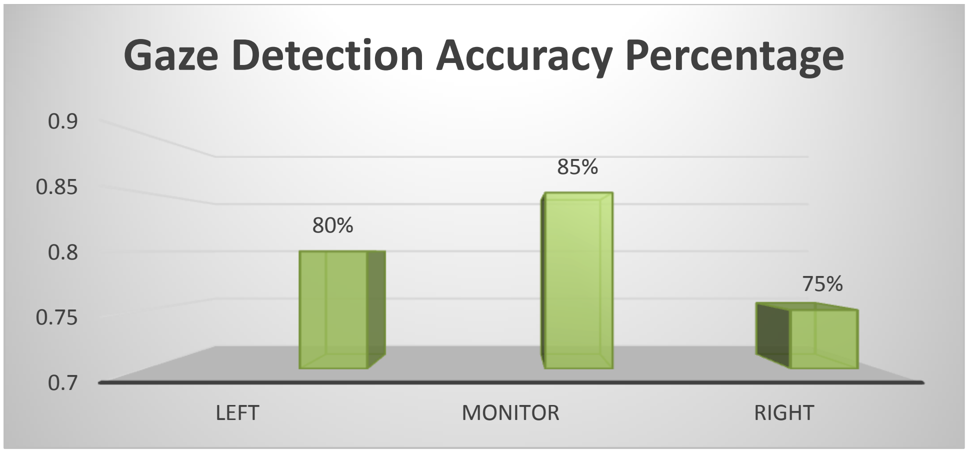

Figure 12: Gaze detection accuracy

Based on Equation (4) and (5), Accuracy of Sustained and Transient Focus of Attention Detection Combined with Head Pose is illustrated in figure 13, 14, 15 and 16 respectively. The accuracy of body movement detection is depicted in figure 17.

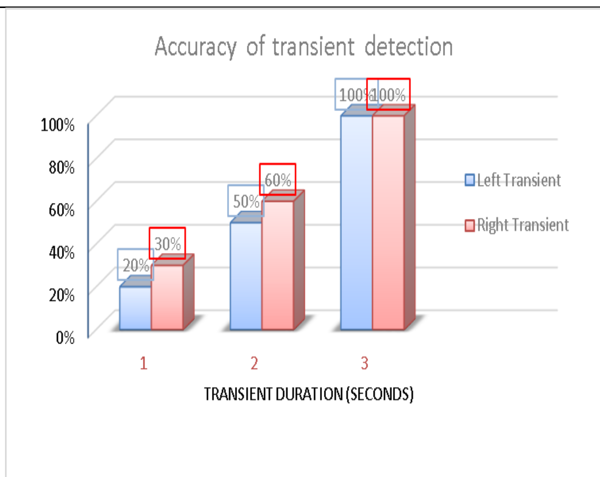

Figure 13: Transient detection accuracy

In controlled environment

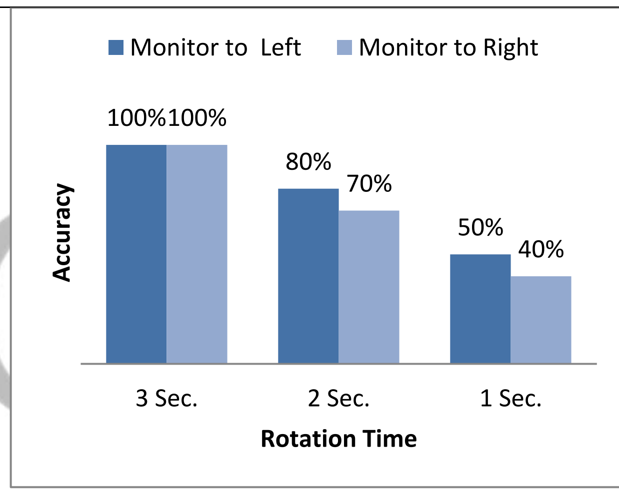

Figure 14: Head rotation detection accuracy

In controlled environment

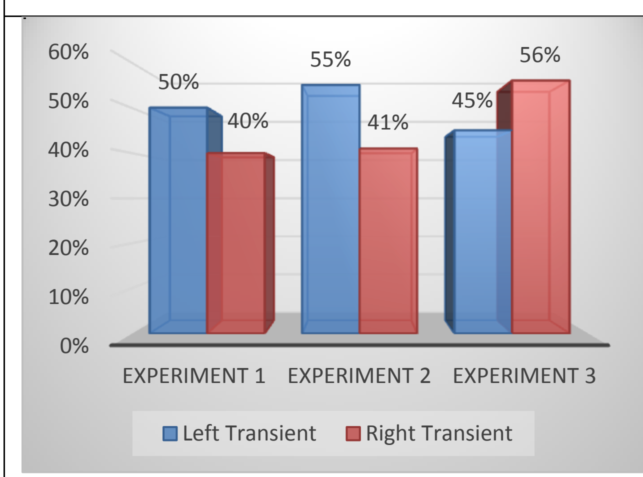

Figure 15: Accuracy of transient attention detection in real time car driving

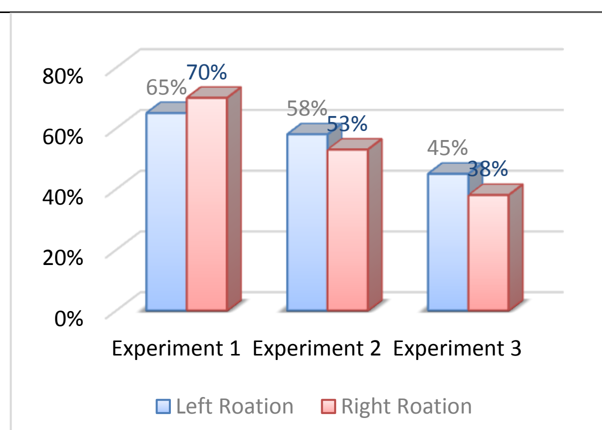

Figure 16: Accuracy of head movement detection in real time car driving

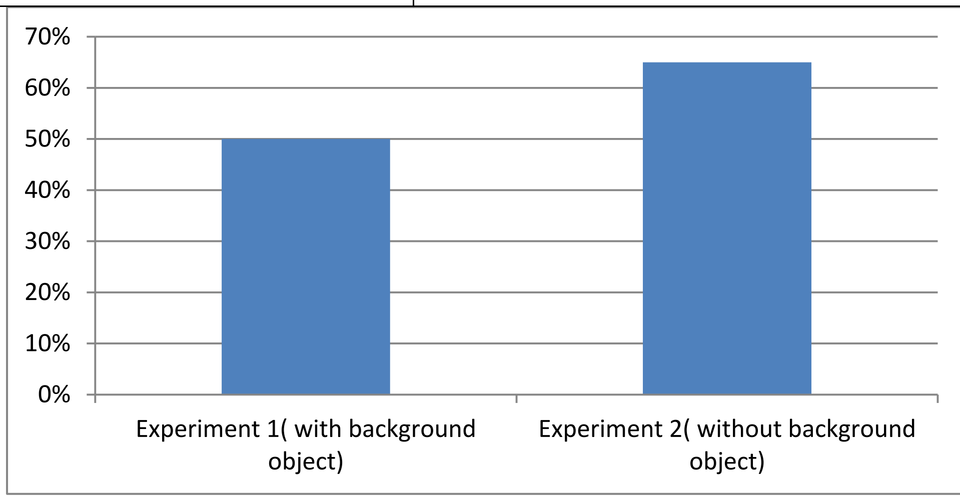

Figure 17: Accuracy of body movement detection

V. Conclusion and Future Works

This research basically focuses on gaze detection as well as body movement detection of the driver under different conditions and applying varying techniques and evaluation of their performance in controlled and real time experiments. There are a lot of scopes for visual attention detection. Due to short time we cannot do all of these. In the near future some of the other experiments will be done. Some of them may be:

1. Developing a new technique for gaze detection with more accuracy of detection.
2. Developing a technique that can track the gaze with optimum accuracy with the head rotation time for 1 or 2 seconds.
3. Developing a new technique to track the transients with more accuracy for the transients with the duration of 1 second.
4. Develop a system that can track the head and eye in low illumination.
5. Apply our proposed techniques in real life environments and increase the real time gaze detection performance.

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