# EFFECT ON VISUAL ACUITY AND DISCOMFORT FROM HIGHBEAM GLARE IN NATURALISTIC CONDITIONS ON INDIAN ROADS

**Rohan Bhatial and Kavitha Vemuri**
International Institute of Information Technology Hyderabad
rohan.bhatial@research.iiit.ac.in & kvemuri@iiit.ac.in

## ABSTRACT

Our study is to understand whether pupil diameter changes and gaze point fixation time affects biological (majorly pedestrian) motion detection in mesopic light conditions and high-beam glare of an oncoming car from the context of Indian roads. Eye movement data and pupil dilation data was collected with a wearable eye tracker (Tobii Eye Glasses I) in naturalistic conditions by conducting a set of controlled and uncontrolled experiments. In the controlled experiment drivers (amateurs and professionals) were exposed to rapid sequence of head lamp light intensity from a stationary car on the adjacent lane, stationed at a fixed distance from the experimental (participant's) car. Our findings showed that: 1) Pedestrian detection and tracking measured as a function of eye fixation time was very low (~0.5s) when the oncoming car had a high-beam on, 2) Rate of change of pupil size during light intensity transitions was high and led to partial blindness as the participant's eyes were unable to accommodate such rapid changes in the intensity of light. In the second experiment, the data was collected while driving in real-time traffic . The findings supported the observations made in the previous experiment and pointed out possible effect on decision making that might lead to fatal accidents. Pupil data revealed that the multi-lane roads with proper lighting were far low in risk in comparison to undivided two lane roads. The data also showed that in the absence of external street lights the visual acuity increased when the experimenting car had high beam on, thereby leading to better chances of spotting a pedestrian and detecting his/her movement. Hence, to reduce the disabling and discomfort glare on self, the drivers turn-on the high beam. The findings support the indirect effect of glare on visual system and hence possible cause of accidents and help in building innovative solutions.

## KEY WORDS

Pupil diameter, gaze point, disability glare, discomfort glare, eye-tracker, biological motion detection

## INTRODUCTION

Glare from a high-beam, a setting of the headlight which outputs maximum light intensity used by drivers during night, can cause flash blindness, (Theeuwes et al., 2002) a temporary vision loss and post exposure to the glare results in negative afterimages – dark spots. The duration of the afterimages is subjective and can last upto several minutes during which time detection capability of the driver to obstacles or pedestrians on the road is significantly impaired. Glare's effect on humans has been categorized as either disability glare, which reduces contrast sensitivity or discomfort glare which is more subjective and occurs when one looks directly at the light. In simple terms, discomfort glare is glare which causes discomfort, without leading to a decrease in vision. In contrast, disability glare may not cause any discomfort but leads to some

loss of vision (Smith,2002). Studies conducted in European countries and the US where high-beam usage is fairly regulated, report that drivers experience either disability glare which leads to fatal accidents due to sudden braking or discomfort glare leading to lowering of contrast detection. As per international standards, permitted glare illuminance from oncoming headlights is below 0.1 lx at the eye [Bhise et al., 1977], and a value of 3 to 10 lx is when discomfort becomes unbearable [Bullough et al., 2002; Schmidt-Clausen et al., 1974]. The extent of optical discomfort from the glare, from blinding lights is a function of the luminance of the head light, the angle of incidence and refractive index of the windshield of the vehicle and small imperfections on the surface of the glass due to scratches or cracks. Light source spectrum (tested with standard manufacturer fitted lamps) has been found to have little effect during daylight on the disability glare [Flannagan,1999] while it plays an important role in night time driving conditions. The major cause Discomfort glare due to color perception for nearly monochromatic and highly saturated headlamp light has shown that 'yellow' is less glaring than green or blue while high-intensity discharge (HID) results in greater discomfort [Bullough, 2002]. Studies have investigated correlation between visibility/glare and headlamp characteristics like intensity, spatial distribution of beam pattern and spectral power distribution [Clark et al., 2005, Flannagan et al., 1999, 2000, Bullough et al., 2003]. The luminance is dependent on the lamp-type (tungsten-halogen, high-intensity discharge (HID)), the mounting height (vehicle type), the optical system (reflector, projector) and the lamp alignment. The decrease in the background luminance due to the bright light and the angle of incidence of the light increases the effect of the glare (Alferdinck, 1996).
In the human visual system, light enters the eye through the cornea, it then passes through the pupil (controlled by the iris) and is further refracted by the lens. The cornea and lens act together as a compound lens to project an inverted image onto the retina. The iris surrounding the pupil modulates the amount of light . The retina has 2 types of light sensitive cells for vision: cones and rods. Pupil size adapts to changes in light faster, followed by adaptation of the rods and cones. Scotopic vision is the vision at low light conditions facilitated by the rods, which are highly sensitive to light and motion. Photopic vision, or color vision facilitated by the cones work at bright light conditions. Night driving requires both scotopic and photopic vision in addition to the in between range called mesopic vision, as sensitivity to light from panel or external lights and peripheral dark objects should be detected while driving. As the amount of ambient light decreases to mesopic levels, the visual acuity and contrast sensitivity of the human eye also deteriorate and hence human eye is not naturally adaptive to lowlight/night conditions. The light intensity on a surface at a certain distance implies illuminance and the reflective properties of the surface results in luminance. The human eye experiences stray-luminance, which is the illuminance plus the angle between the light-source and direction of sight. Glare is the luminance which occurs within the eye.

Indian roads – city and highways- are dangerous to drive due to unplanned road designs – nonstandard median height, unplanned/unmarked speed breakers, unbanked turns - absence of dedicated pavements, delineation with reflectors, lane markers and undisciplined road sense of the drivers to name a few In addition, learning and the driving license issuance processes in India hardly tests for driving-etiquette and there are no tests conducted even for heavy-vehicle drivers on night-time driving ability. Road Accidents in India in a 2015 report by Transport Research Wing, Ministry of Road Transport and Highways, Government of India,alarming data and trends concerning the safety of Indian roads. The total number of road accidents increased by 2.5

percent from 4,89,400 in 2014 to 5,01,423 in 2015. The total number of persons killed in road accidents increased by 4.6 percent from 1,39,671 in 2014 to 146,133 in 2015, a life lost every 4 minutes, statistically speaking. The data published by TRIPP, IIT Delhi in 2015 shows that motorised two-wheeler and pedestrian death share is relatively high between 8pm – 11pm, which clearly implicates the challenges of night time driving in India. Rumar(2011) reported that, globally 200,000 pedestrians are killed at night each year, which means that better pedestrian detection systems need to be developed to take care of this menace. A lot of experimentation done on pedestrian behaviour (Kwan & Mapstone 2006), the kind of clothes that pedestrians wear (Wood, et al., 2005) and lack of awareness about the factors affecting pedestrian's estimation of recognition distance oncoming cars at night (Rosenberg, 2010) have made vital observations and suggestions, but we have hardly seen such studies being conducted and/or implemented for Indian roads.

The problem starts from drivers are also not tested for visual acuity, visual field sensitivity or the visuo-motor reflexes. The use of nonstandard lamps and almost compulsive application of high-beam during night-time adds to the dangerousness of driving during night in India. Typically, a vehicle is fitted with head lamps that work at low beam and in most cases car manufactures adhere to rules on permitted radiant/luminance flux allowed but the unregulated automobile aftermarket service providers retrofit with non-calibrated high intensity discharge (HID), projector and halogen bulbs which have not been tested for effects on visual sensitivity due to reflection, or scattering from wind-shields. Hence, one can hypothesize that for Indian conditions the discomfort from the oncoming vehicle glare is amplified due to disparate headlamp sizes, multitude of vehicles (2-wheelers, LCV, MCV, 3-wheelers etc), cognitive load due to poor lane delineation etc.

Rules by the Central Motor Vehicles Act of 1989, states that headlights of a car has to be constructed, fitted and maintained in a manner so that it is "permanently deflected downwards to such an extent that it is not capable of dazzling any person." which lays the onus on the manufacturer to design tamper proof headlight system. But, with all these the basic question remains: why do Indian drivers use high-beams? The main reasons are a) Low street lighting in the inner city roads, b) improper lane delineation, c) absence of lighted or well positioned sign boards d) Unpredictable human & animal movement, e) erratic traffic flow f) poor safety norms.

Most of the studies on vehicle type and driving conditions in Europe and US are difficult to extrapolate or make a direct correlation with Indian eco-system. Lack of categorization of accidents from glare driven errors in an impediment to understanding the extent of the problem. Indian road conditions and lack of awareness of safe driving or pedestrian movement compared to other planned countries poses a unique and complex research problem which needs to be investigated before solutions are proposed. This study specifically looks at one of the issues, that of high-beam glare on drivers.

## Method

### *Participants*

There were a total of 7 participants in the study (2 females and 5 males), ranging from 18-50 years of age. All the participants had Indian Government issued driving licenses and had no eye-sight related issues. The participants were divided in two sets for separate experiments. The first experiment had a set of 5 participants (P1, P2, P3, P4, P5) and the second one had a set of 2 participants (O1, O2). P1-P5, were between the age group of 18-24 and had been driving on Indian roads for at-least an year. O1-O2 were between the age-group of 40-50 and had been driving for over 10 years. O2 was a professional driver and had enough years of experience with night time driving.

*Procedure*

Eye tracking is a technology that helps in collecting the gaze/ eye fixation position. For our experiments we have used the Tobii Pro Glasses 1. It is a wearable eye tracker designed to capture natural viewing behaviour in any real-world environment. We exported the values for the pupil diameter (in mm) and gaze point values for both the eyes for the purpose of our analysis. It helped us in getting objective insights into human behaviour by showing what the participants were exactly looking at. Two sets of experiments (E1, E2) were conducted, one stationary, under controlled circumstances and one on real road scenarios.

For E1 the setup was aimed at imitating a standard two lane road without street light with two cars moving in opposite direction. The cars were parked at a distance of 25 meter from each other with a horizontal separation of 5 meter. In one of the cars the participants ( P1-P5)were made to sit in the driving seat wearing the eye-tracker and the other car's head-lamps were used to generate a sequence of high beam, low beam and off situations to create a real road like situation. Two sets of sequence were carried out with each participant, one with the participants' car's head-lamps in low beam on condition and other with high beam on condition. Pedestrian movement was also re-created by making people cross the path in random patterns so as to look at the participant's eye fixations on the pedestrians.

For E2, the participants O1 and O2 were made to drive under real traffic conditions. The route was taken so as to cover different scenarios that exist on Indian roads like 4 lane highways with dividers and 2 lane highways without dividers in variable street lighting conditions.

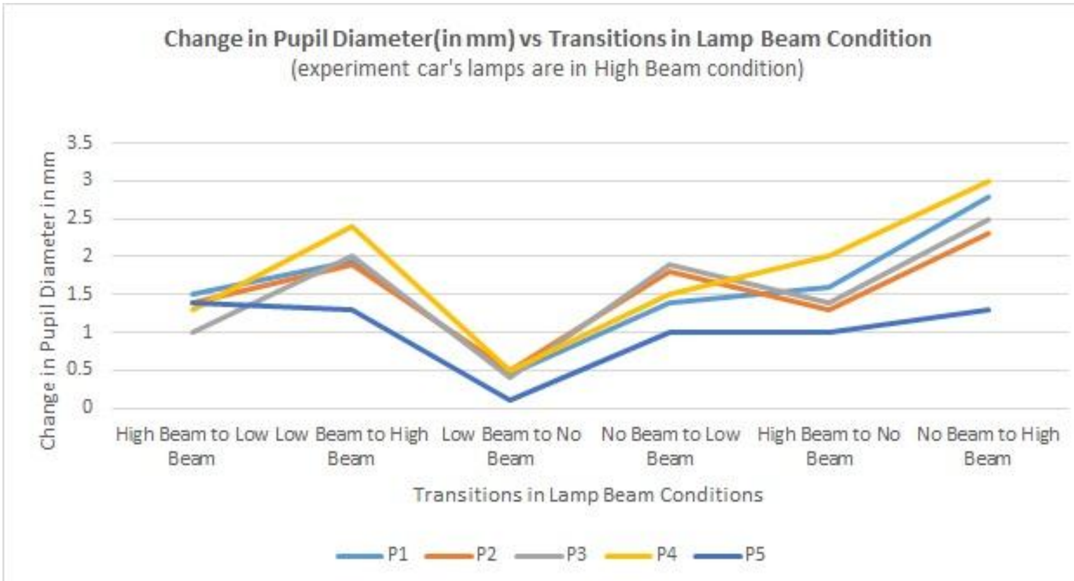
*Data Analysis*

Gaze point data and pupil diameter data for both eyes was recorded at 30 frames per second. The video recording from the eye tracker was analysed frame by frame using the Tobi's studio. Six transition phases for the oncoming car's head-lamps, which include transitions from high beam to low beam, high beam to off, low beam to off and vice-versa were marked across all the videos.

For E1, pedestrian movements were marked and analysed (shown in figure 1) with the gaze point data. The time for which the participant could fixate the gaze points on the pedestrian was also calculated for each participant during different light conditions (shown in Table 1).
For E2, the average pupil diameters were compared for both O1 and O2 for two situations a) road with and without divider b) 2 way road with and without street lights.

**Results**

From the pupil dilation changes (Figure 1) we infer that there is a change in pupil diameter values during each of the 6 transitions across all the participants. When high beam is suddenly switched on, the pupil constriction is quite significant indicating a drop of 2.42 mm when the participant's car is in low beam condition and 1.18 mm (Figure 1 bottom) when it is in high beam condition (Figure 1 top). This is the maximum observed average change in pupil size across all transitions, which is intuitive as the change in intensity of light will be maximum in this case and visual acuity will be low even in comparison to the same transition with the participant's car being in high beam.



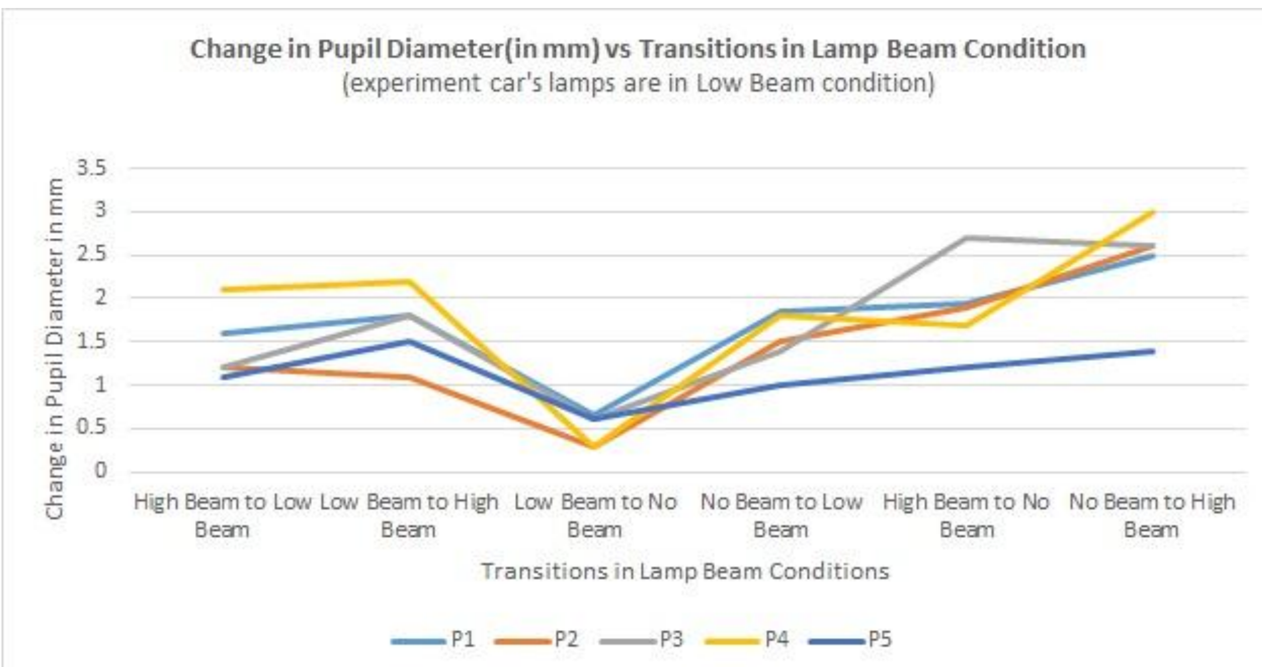




**FIGURE 1 Change in Pupil Diameter (in mm) is plotted against the 6 possible transition light intensity conditions from the headlamps of the oncoming car, once with the participant's' car having high beam (top) on and once with low beam(bottom) on**

Also, these changes in pupil size happen quickly thereby, giving the participant hardly any time to accommodate. The rate of change of pupil size (in mm) with transition time (in second) can go as high as 2.7mm/s, which is high enough to cause partial blindness for as long as a minute. Table 1 shows the average rate of change of pupil size per transition time across all 6 transition conditions in the participant's car being in both high and low beam conditions. This sudden blindness resulting from pupil constriction, occurring from no beam to high-beam condition affects the ability of the driver to detect and track biological motion like pedestrian movement and stray animal movement (as observed in one of the videos where a dog got completely camouflaged with the high beam).

| Participants | High Beam (mm/s) | Low Beam (mm/s) |
|---|---|---|
| $P_1$ | 1.835 | 2.306 |
| $P_2$ | *1.37* | *1.324* |
| $P_3$ | *1.711* | *1.645* |
| $P_4$ | *1.64* | *2.28* |
| $P_5$ | *1.16* | *0.72* |

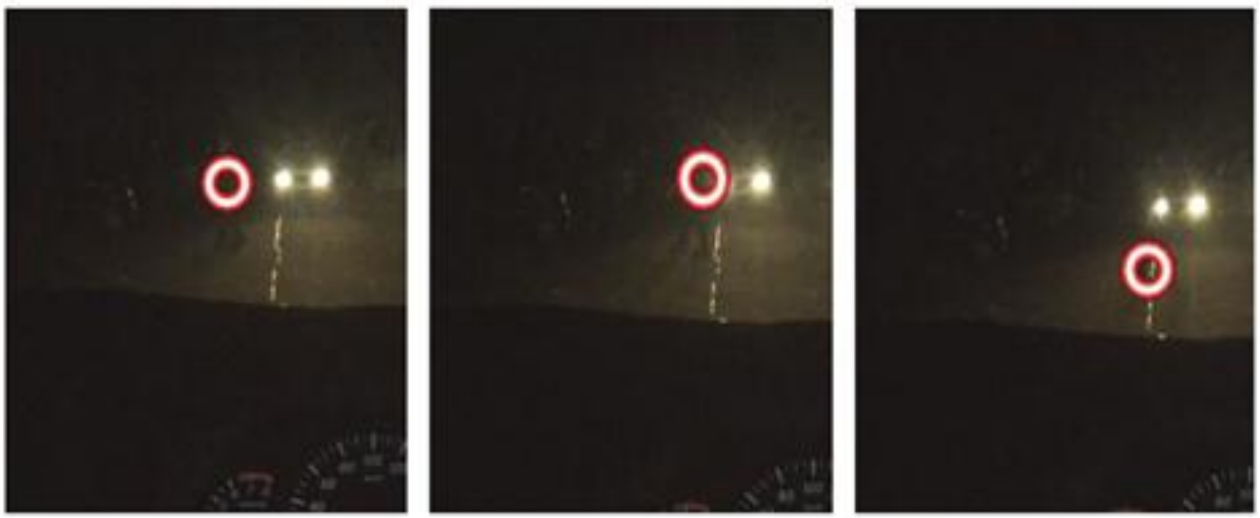
**TABLE 1 Shows the rate of change of pupil diameter (with transition time) averaged over all the 6 transitions, same as figure 1. The transition time is defined as the time taken for the pupil size to go from one stable state to another, depending upon the intensity of oncoming beam.**

Table 2 shows the detectability in terms of gaze point fixation time (in seconds) for all the 5 participants in all the three lighting conditions. The results clearly show that pedestrian detection is easier when the participant's own car is in high beam, which might be a rationale for people driving mostly with high beam condition on Indian roads. It provides better visual acuity and longer viewing distance/angle due to which it becomes easier to detect biological movement. The table also shows that for distances of around 25ft if the oncoming vehicle has high beam on when the pedestrian is moving the fixation time is negligible, hence the pedestrian is not detected in most of the situations. Another interesting observation is that a fixation time of 1 second or more was enough for the participant to detect the pedestrian and predict the motion. Figure 2 shows the gaze point of the driver while he/she is trying to see the pedestrian's movement.

| **Beam Condition (oncoming car)** | **High Beam** | | **Low Beam** | | **No Beam** | |
|---|---|---|---|---|---|---|
| | **Fixation Time(s)** | | **Fixation Time(s)** | | **Fixation Time(s)** | |
| **Participants** | **High Beam** | **Low Beam** | **High Beam** | **Low Beam** | **High Beam** | **Low Beam** |
| $P_1$ | *<0.5* | *<0.5* | *>2.5* | *Clear visibility* | *Clear visibility* | *1.7* |
| $P_2$ | *<0.5* | *<0.2* | *>2.5* | *>1* | *Clear visibility* | *>4* |

| Beam Condition (oncoming car) | High Beam | | Low Beam | | No Beam | |
|---|---|---|---|---|---|---|
| | Fixation Time(s) | | Fixation Time(s) | | Fixation Time(s) | |
| **Participants** | **High Beam** | **Low Beam** | **High Beam** | **Low Beam** | **High Beam** | **Low Beam** |
| $P_3$ | *<0.5* | *No visibility* | *>3* | *>2* | *Clear visibility* | *>1.2* |
| $P_4$ | *<1* | *<0.5* | *>3.5* | *>2.5* | *Clear visibility* | *4* |
| $P_5$ | *<0.5* | *No visibility* | *>3* | *>2* | *Clear visibility* | *>1.6* |

Table 2: *Shows the time for which the participants could detect and track the pedestrians under 3 different possible beam conditions for oncoming car along with the beam condition of the participant's*



**Car**
**FIGURE 2 Driver scan path tracking the pedestrian movement.**

Analysis of the data collected in real-time traffic (E2) confirms the observations from E1. The analysis was based on rough calculations and assumptions as the experiment was in uncontrollable naturalistic conditions. Our first observation was that the pupil was much more relaxed/stable when the participant was driving on a 4 lane highway with divider in comparison to a 2 lane highway without divider. For example, for participant O2, there was a difference of approximately 1.2 mm in both left and right eye pupil diameters in these situations. Our second observation was that street lights played a major role in visual acuity and in general tackling the oncoming high beam. The difference in pupil size was only around 0.2-0.4 mm which does not reveal much, but biological motion detection was severely affected when street lights were not present. It can be seen from the gaze point data that the driver experienced disability from the glare in detecting pedestrians when there was no street light. Roads without street-light with the oncoming vehicle having a high beam on was even more dangerous, similar to our observations in E1. Negotiating turns and overtaking was also observed to be risky but due to lack of controlled data and road geometry estimates, no conclusion can be drawn. A difference of 0.5mm to 1.5mm was seen in pupil sizes when oncoming vehicles were using low beam instead of high beam, hence making our case stronger.

**Discussion and Conclusion**

The aim of the study was to understand the challenges faced by drivers during night time driving on Indian roads. The data collected is extensive and has scope to give us much more in-depth information on quantitatively explaining the dangers of highbeam glare on drivers decision making skills. For example, a lot of accidents are caused while over-taking on roads without dividers. From the measurements of the pupil size variations due to the glare from oncoming traffic on roads without dividers shows that how much riskier are they in comparison with roads with dividers.

Pedestrian detection analysis and related challenges is important to analyse form both the experiments ( E1 and E2). Experiment, E1, clearly showed the inability of participants to detect pedestrians especially during transitions from low beam/off condition to high beam. The scan path of gaze point after the transition is very erratic and clearly indicates the driver was not able to detect and track the movement of the pedestrian.

The results for E2 demonstrate the complexities that exist on Indian roads. Complexities include multiple sources of lights with varying intensities which contribute to disability glare, sporadic movement of vehicles, people and even animals and an overall inefficient design of roads. Another problem that was identified and will be taken as a future work is characterizing problems associated with different lamp types and different vehicle types. Our data collected reveals that some of the vehicles on the road have misaligned head-lamps which lead to much more damaging glare effects on oncoming vehicles. Also, some of the newer and high end car models are coming up with stronger HID head-lamps which are better for pedestrian detection but the effect on discomfort and disability of oncoming vehicles is far more deteriorating and the effects need to be studied so that the regulations and norms can reflect that.

In the current experiments we have not focused on comparative analysis between different participant profiles. For example- age of the participant plays an important role in determining the scattering effects that happen in the eye and are responsible for decreased visual acuity. The cognitive ability of drivers is also a point of research. As a further work it can be useful to try out the same analysis with pedestrians wearing coloured clothes and/or reflective materials so as to give a comprehensive report on pedestrian security. It will also be useful to see the eye movement and pupil diameter data of the pedestrian especially while crossing heavy traffic Indian roads.

As a further research, we propose hardware based solution using cameras and LIDARs to assist the drivers in detecting obstacles by creating rough depth maps in real time and raising warning signs so as to give the driver enough time to react, thereby decreasing the fatality rate on Indian roads.

**REFERENCES**

1. Kwan I, Mapstone J. 2006. Increasing pedestrian and cyclist visibility to prevent deaths and injuries. Cochrane Database Syst Rev.

2. Bhise VD, Farber EI, Saunby CS, Troell GM, Walunas JB, Bernstein A. 1977. Modeling vision with headlights in a systems context. Society of Automotive Engineers Congress and Exposition, Detroit, MI: Society of Automotive Engineers (Paper 770238).

3. Bullough JD, Fu Z, Van Derlofske J. 2002. Discomfort and disability glare from halogen and HID headlamp systems. Society of Automotive Engineers World Congress, Detroit, MI: Society of Automotive Engineers (Paper 2002-01-0010).

4. Bullough JD, Van Derlofske J, Fay CR, Dee P. 2003.Discomfort glare from headlamps: Interactions among spectrum, control of gaze and background light level. Society of Automotive Engineers World Congress, Detroit, MI: Society of Automotive Engineers (Paper 2003-01-0296).

5. Clark, J., Gibbons, RB, & Hankey JM. 2005. Enhanced Night Visibility Series Vol. XV: Influence of Beam Characteristics on Discomfort and Disability Glare [report to the Federal Highway Administration]. Washington, DC: Federal Highway Administration.

6. Schmidt-Clausen HJ, Bindels JTH. 1974. Assessment of discomfort glare in motor vehicle lighting. Lighting Research and Technology 6(2): 79-88.

7. Flannagan MJ. 1999. Subjective and Objective Aspects of Headlamp Glare: Effects of Size and Spectral Power Distribution, Report UMTRI-99-36. Ann Arbor, MI:University of Michigan Transportation Research Institute.

8. Flannagan, MJ., Sivak M, Traube EC. & Kojima S. 2000. Effects of overall low-beam intensity on seeing distance in the presence of glare. Transportation Human Factors 2(4), 313-330.

9. Theeuwes J, Alferdinck JW, Perel M. 2002.Relation Between Glare and Driving Performance. Human Factors, Vol. 44, No. 1, p. 95–10

10. Joanne M. Wood , Richard A. Tyrrell , and Trent P. Carberry, 2003, Pedestrian Visibility at Night: Effects of Pedestrian Clothing, Driver Age, and Headlamp Beam Setting, TRB Annual Meeting

11. Smith George, Disability Glare and its Clinical Significance, p. 34-37

12. Road Accidents in India-2015, Government of India, Ministry of Road Transport and Highways, Transport Research Wing, www.morth.nic.in

13. Brasilia Declaration on Road Safety,2015, 2nd Global High Level Conference on Road Safety.

14. Rosenberg, Rachel, “The Effects of Headlight Intensity and Clothing Contrast on Pedestrians’ Own Estimated Recognition Distances at Night” (2010). All Theses. Paper 876.