ISSN:0975-9646
Apoorva Joglekar et al, / (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 2 (4) , 2011, 1758-1763

Depth Estimation Using Monocular Camera

Apoorva Joglekar#, Devika Joshi#, Richa Khemani#, Smita Nair*, Shashikant Sahare#

Dept. of Electronics and Telecommunication,
Cummins College of Engineering for Women, Karvenagar, Pune: 411052, India.

*Centre for Research in Engineering Sciences and Technology,
KPIT Cummins Infosystems Limited, Hinjewadi, Pune: 411057, India.

Abstract- **The paper presents a novel approach for distance estimation using a single camera as input. In particular we discuss a method for depth estimation using camera parameters and also image geometry. The system has been implemented for specific camera parameters. This is a novel concept which uses road geometry and point of contact on road. Using a single forward facing camera located typically near the rear view mirror, our method can estimate distance of any vehicle on the road.**

Keywords— **Depth, dead zone, optical axis, oblique distance, vanishing point, field of view**

I. INTRODUCTION

Recent advances in driver assistance systems such as Lane Departure warning (LDW), Dynamic High Beam (DHB), Forward Collision Warning (FCW) etc., use monocular camera for their applications. Many of the existing systems (available in high end models such as Mercedes E Class, BMW 7 series etc.,) have bundled some of the above applications together in a single embedded platform providing easy of hardware usage, with overall cost reduction. Considering the above trend, monocular camera systems are in high demand and it's become a necessity to process images obtained from single camera.

Depth estimation is a crucial task in applications such as collision avoidance systems, dynamic high beam assist systems etc., Depth using single camera is challenging since the camera image is subject to perspective distortions. A much better estimate can be achieved using the road geometry and the point of contact of the vehicle and the road [7]. Our proposed approach assumes a planar road surface and a camera mounted so that the optical axis is parallel to the road surface.

Traditional approach of depth estimation uses stereo cameras [10] but has limitation on range and cost. The paper presents a novel approach to estimate the in-path and oblique distances of the objects using a single forward looking camera mounted on the dash board Based on the camera properties and geometry applied to the input images, relation between 2D and actual 3D view of the image is estimated. The depth estimation technique uses two different approaches to compute the in-path distances and oblique distances.

The remaining paper is organized as follows. Section 2 provided a brief background on the camera parameters required for depth computation. Section 3 provides the detailed algorithm for in-path distances followed by computation of oblique distance in Section 4. Section 5 provides the experimental setup and results followed by conclusion and future work in Section 6.

II. BASIC CONCEPT

Camera properties include height of camera, focal length, angle of tilt of camera, pixel resolution. These camera parameters are related to respective camera only. The image captured is in the 2-D plane and the relation between 2-D image and the actual 3-D view of the image can be found out to estimate the distance. The camera can be attached in the car which will determine the exact distance of the obstacle for avoiding road accidents.

As the data is collected from a single camera, range must be estimated by using perspective. There are two cues which can be used: size of the object and position of the bottom of the object. Since the width of the object can vary, range estimate based on width will have only about moderate accuracy for e.g.: In case of a vehicle. A much better estimate can be achieved using the road geometry and the point of contact of the vehicle with the road [7].

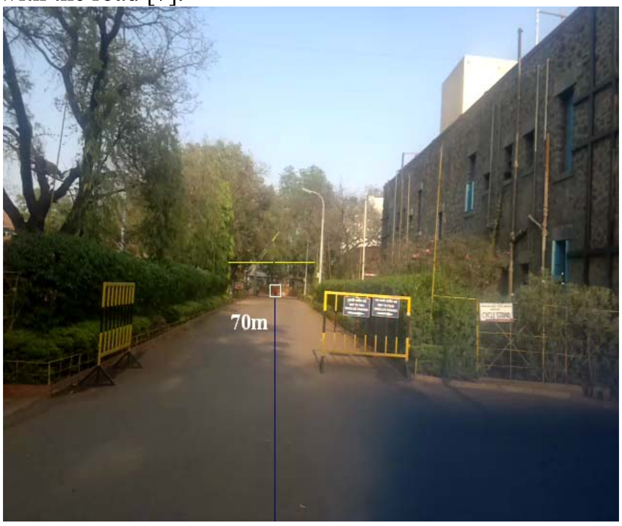

Figure 1: An image showing the depth estimation at 70m.The object is marked with white rectangle and the yellow line contains the vanishing point.

Planar road surface is assumed and a camera is mounted such that the optical axis is parallel to the road surface. A point on the road at a distance Z in front of the camera will project to the image at some height [7].

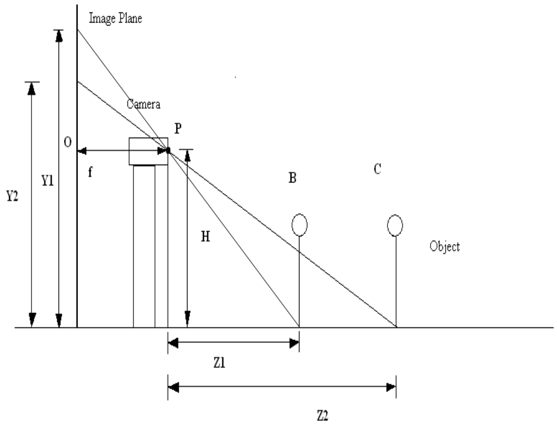

Figure 2: Image showing the basic concept

Figure (2) shows a diagram of a schematic pinhole camera comprised of a pinhole (P) and an image plane (I) placed at a focal distance (f) from the pinhole. The camera is mounted on vehicle (A) at a height (H). The rear of vehicle (B) is at a distance ($Z1$) from the camera. The point of contact between the vehicle and the road projects onto the image plane at a position (Y1). The focal distance (f) and the image coordinates (Y) are typically in *pixels* and are drawn here not to scale. Equation (1) can be derived directly from the similarity of triangles. $Y/f=H/Z$. (1)
The point of contact between a more distant vehicle (C) and the road projects onto the image plane at a position ($y2$) which is smaller than ($y1$).

III. CAMERA PARAMETERS

The following section explains the basic concepts used for calculating the distance.

A. *Field of view of camera*

Focal length of the camera can be calculated using the field of view. The angle α as shown in figure below is used to calculate the field of view. The parameter ‘f’ is the focal length of the camera which can be obtained from field of view of camera.

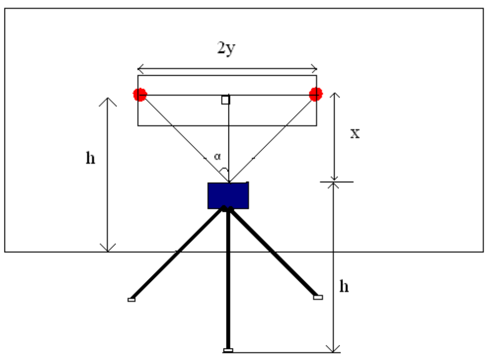

Figure 3: Figure showing method to find out field of view and focal length

$$\alpha=\arctan\left(\frac{y}{x}\right) \quad (2)$$

$$FOV° = 2\left(\tan^{-1}\left(\frac{y}{x}\right)\right) \quad (3)$$

$$FOV° = 2\left(\tan^{-1}\left(\frac{x}{2f}\right)\right) \quad (4)$$

B. *Concept of vanishing point*

Figure 4: Figure showing vanishing point

Due to perspective error, the straight roads on the ground plane seem to converge at a point in the image plane. The converging point in the image is known as the Vanishing point. With the camera axis parallel to the optical plane, we have assumed the vanishing point to be the centre of the image plane. As indicated in the Figure 4, centre pixel position (320,240) represents the vanishing point. ‘Y’ is the distance of the point of contact of the object in the image from the vanishing point.

C. *Concept of deadzone*

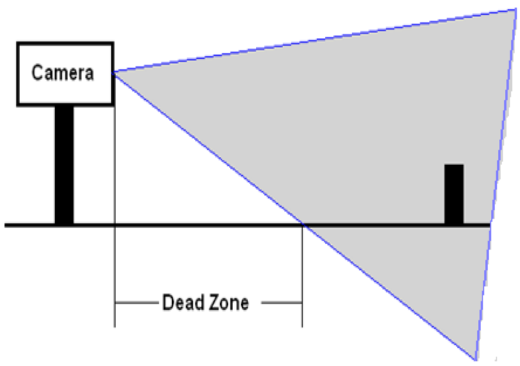

Figure 5: Figure showing the dead zone

As in Figure 5, dead zone is the actual ground region that is not seen in the image taken by the camera. The actual distance cannot be estimated unless this dead zone is corrected. The proposed method satisfies this dead zone error to estimate the distance.

IV. ESTIMATION OF IN-PATH DISTANCES

The distances in optical axis of the camera are called as the in-path distances. The in-path distances have relatively less horizontal and vertical errors as compared to the oblique distances. Horizontal errors are those which are orthogonal to the optical axis of the camera and increase as the distance from the camera increases. The vertical errors are the errors along the optical axis of the camera and they are maximum when the object is nearer to the camera. The algorithm used to compute the in-path distance is as follows -

1. Given an image, identify the point of contact of the object with the ground.
2. Obtain the co-ordinates of this point.
3. Compute the angle between the optical axis and the line joining camera point to the position of the object (Angle β) in Fig.8.
4. Obtain Zcalc which is the intermediate reading for distance, by projecting its corresponding Y on the graph (refer figure 6).
An example is shown for the point N (50, 26.92).
5. Obtain the Zact which is the actual in-path distance, by projecting its corresponding Zcalc on the graph (refer figure 7) for the actual in-path distances. An example is shown for point M (26, 22)
6. The actual in-path distance is then divided by cosine of angle β to get oblique distance. But this oblique distance has errors.
7. The horizontal and vertical errors in Zact are then corrected to get corrected oblique distance.

The polynomial equation is obtained by plotting the graph of Zcalc V.S. the pixel difference 'Y'.

TABLE I

Y	173	92.01	64	50	43
Zcalc	7.78	14.63	21.03	26.92	31.3
Zact	5	10	16	22	28
Y	38	34	32.5	31.5	28.28
Zcalc	35.42	39.59	41.399	42.74	47.6
Zact	34	40	46	50	70

Experimental results showing the 'Y', Zcalc and Zact

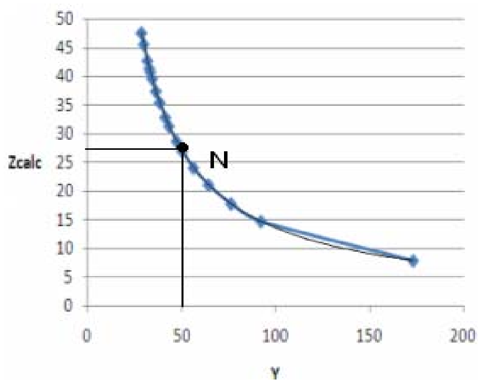

Figure 6:Graph of Zcalc vs Y

$$Zcalc = \frac{1346}{Y} \quad (5)$$

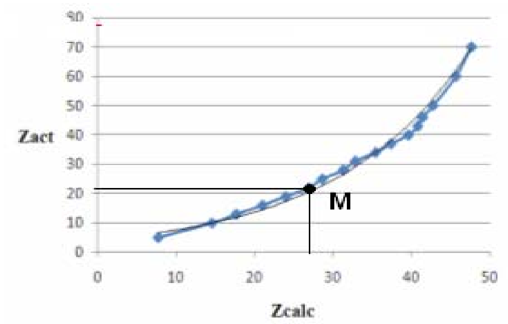

Figure 7:Graph of Zact vs Zcalc

$$Zact = 4.168e^{0.059*Zcalc} \quad (6)$$

V. ESTIMATION OF OBLIQUE DISTANCES

The distances of the objects which not are situated on the optical axis of the camera are called as the oblique distances. The oblique distance of any object has relatively high amount of horizontal and vertical errors. These errors are introduced due to the perspective distortion as the object moves away from the camera position.

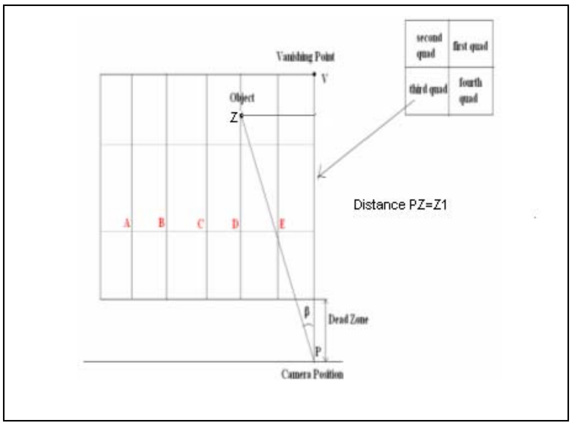

Figure 8:Figure showing concept used for oblique distance calculation.

1. Find the corresponding optical axis distances as explained above.
2. Find the angle β (refer figure 8).
3. Find oblique distance Z1 which is the distance between actual camera position and the point of contact of object with ground, by dividing distance obtained in step1 by cosine of β.
4. The error in Z1 is corrected by finding the horizontal and vertical errors.

A. Horizontal error correction

The errors introduced in the distance when we go away from the optical axis in the horizontal direction are known as horizontal errors. The equation is obtained by plotting the graph given in Figure 9.

1. The oblique distance is calculated as explained in above steps for points A, B, C, D, and E.
2. This error in distance is calculated at all the five points.
3. Graph of %err (horizontal) Vs Horizontal pixel distance is found out. (Refer Figure 9))
4. Due to symmetry in the image same procedure is followed in the fourth quadrant.

TABLE II

x	64	128	320	512	576
err	57.19	37.45	9	37.45	57.19

Experimental results showing errors obtained for various values of x

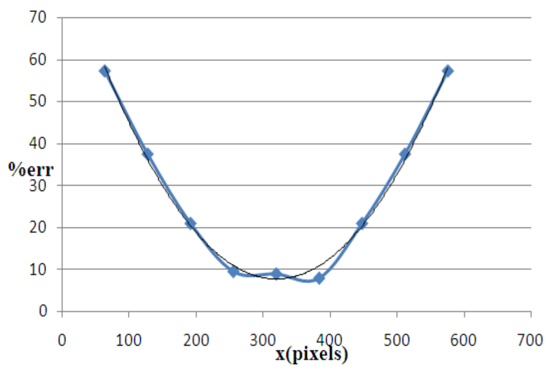

Figure 9:Graph of %err vs x(pixels)

$$\%err = 0.0008x^2 - 0.4929x + 87.56 \quad (7)$$

B. Vertical error calculation

The errors introduced in distance along the optical axis as we go away from the camera position are called vertical errors. The equation is obtained by plotting the graph given in Figure 10.

1. Error between actual and obtained distance is the vertical error.
2. %err in vertical direction is calculated using graph of %err vs. obtained oblique distance (Z1). (Refer Figure 10)

TABLE III

Z1	15.02	21.29	27.21	31.59	35.94
%err	50.2	33.0625	23.6818	12.8214	5.1176
Z1	37.77	41.1	42.42	43.81	46.78
%err	1.891	-4.41	-7.78	-12.38	-22.03

Experimental results showing errors obtained for various values of Z1

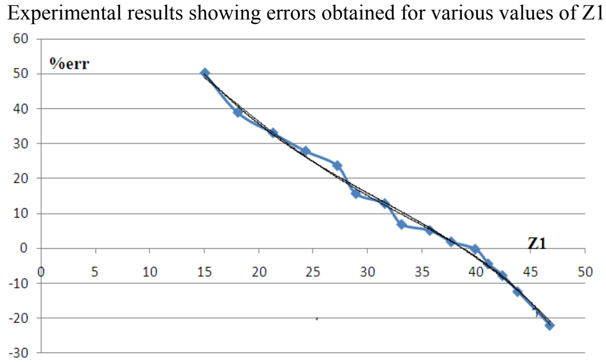

Figure 10:Graph of %err vs Z1

$$\%err = -0.002Z1^3 + 0.192Z1^2 - 7.672Z1 + 128.6 \quad (8)$$

VI. LIMITATIONS

A.. Error introduced in distance estimation due to variation in the selection of object pixels:

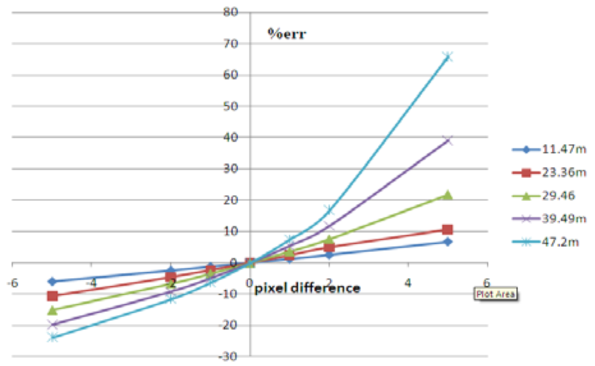

Figure 11: *Graph showing effect of pixel change on distances:*

Due to noise there is always an error in marking exact point of contact of object with ground. The above graph (Figure 11) shows percentage error for pixel differences of 1, 2 and 5 for their corresponding accurate distances. The %errors increase with increase in pixel difference at larger distances.

B. Error introduced in distance estimation due to variation in the height of the camera:

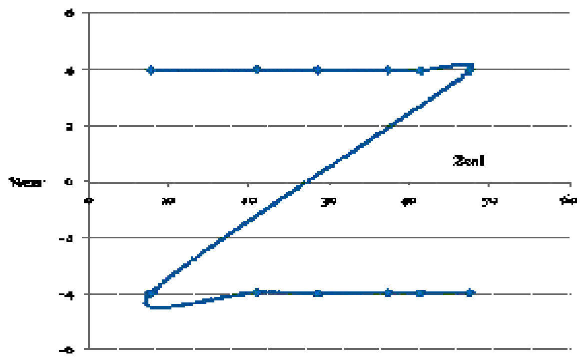

Figure 12: *Graph showing effect of change in height of camera*

When the vehicle travels on the bumpy roads or roads with variable gradient then there is variation in height of camera. The above graph shows the variation in height by +/- 5cm. The graph shows that the error remains constant (around +/- 4) even when there is change in height of the camera. Hence, by calculating error for a single reading of distance, the same can be applied throughout to compensate the inconsistencies.

Out of all these methods our approach gives the distance up to 70m and oblique distance up to 60m with highest accuracy. Hence it is chosen of all the above methods.

VII. EXPERIMENTAL RESULTS

Comparison of various methods

TABLE IV

Methods	Distance on optical axis	Oblique distance	Dead zone correction	Accuracy	Nature of method
Depth from defocus [3]	165cm	No	No	95%	Nonlinear
Mobileye method($y = \frac{fH}{Z}$)	80m	No	Not required	92%	Linear
Depth estimation using Monocular Camera for stationary vehicles	70m	Up to 60m	Done	96%	Nonlinear

A table showing the comparison of various methods

VIII. EXPERIMENTAL IMAGES

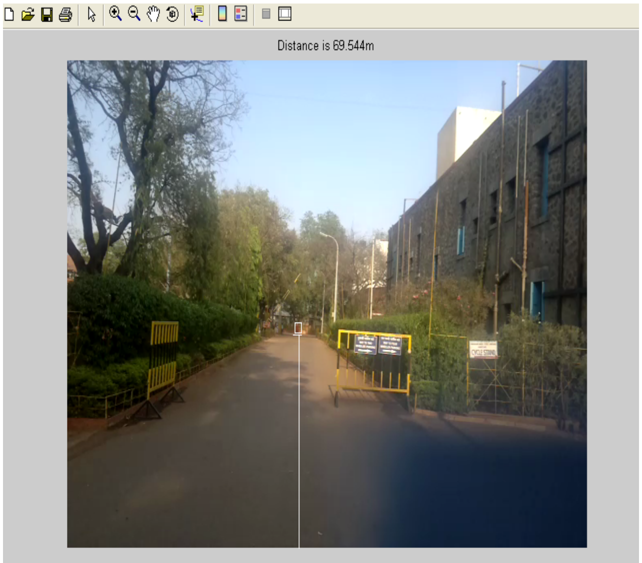

Figure 13. An image showing the distance of the object marked by a box as 69.544m. The actual distance is 70m.

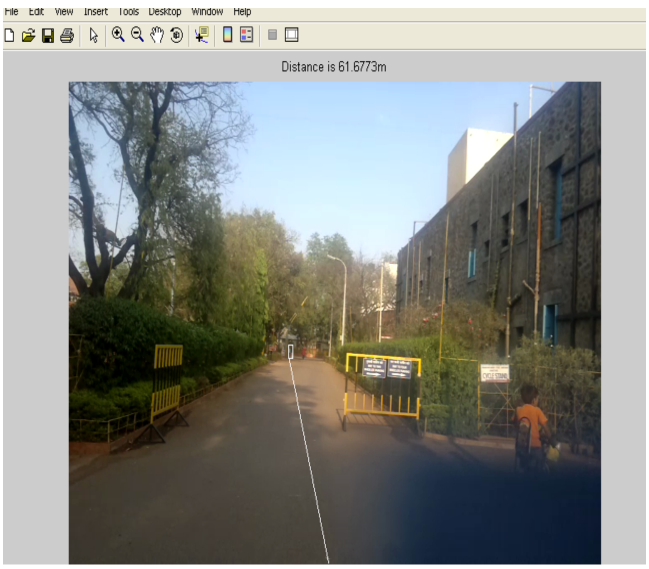

Figure 14. An image showing the distance of the object marked by a box as 61.677m. The actual distance is 60m. The distance of marked object is oblique distance.

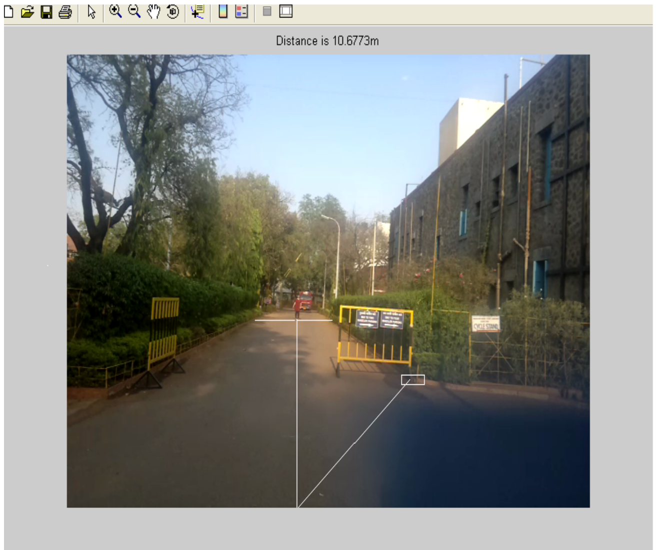

Figure 15. An image showing the distance of the object marked by a box as 10.6773m. The actual distance is 10m. The distance of marked object is oblique distance

The object marked by the box (Fig.13) is the object on optical axis of camera. Hence the distance is calculated using the in-path distance method explained in section IV. The actual distance is 70m while the calculated distance is 69.544m.

The above images (Fig. 14 and Fig. 15) show the object marked with the white box which is not in the optical axis of camera. Hence the distance is calculated using the method proposed in section V. The actual distance in Fig. 14 is 60m while the obtained distance is 60m. In Fig. 15 the actual distance of the marked object is 10m and the calculated distance is 10.6773m.

IX. CONCLUSION

The paper presents a Depth Estimation approach which uses a single camera as input. .This system can be installed in cars which will help the driver to avoid accidents. In order to avoid accidents, a safe distance has to be maintained between the host vehicle and other cars, for this critical distance has to be estimated which has been done by our method. Given a camera of higher resolution the same approach can be extended for much larger distances. Also the approach can be further developed for the steep gradients and the curved roads.

REFERENCES

[1] Gonzalez R.C, Woods R.E, Digital Image Processing, 2nd edition, Prince Hall India.

[2] Gonzalez R.C , Woods R.E, Eddins S.L, Digital Image Processing Using MATLAB, 3rd edition , Prince Hall India

[3] Shang-Hong Lai, Chang-Wu Fu, *Student Member, IEEE,* and Shyang Chang, *Member, IEEE,' A Generalized Depth Estimation Algorithm with a Single Image', ,* IEEE Transactions On Pattern Analysis And Machine Intelligence, Vol. 14, No. 4, April 1992

[4] Sukhan Lee, Sang Chul Ahn, Ashok Meyyappan, *Depth from Magnification and Blurrin*g, Proceedings of the 1997 IEEE International Conference on Robotics and Automation Albuquerque, New Mexico - April 1997

[5] Cassandra Swain, Alan Peters, and Kazuhiko Kawamura, *Depth Estimation from Image Defocus using Fuzzy Logic*

[6] Björn Barrois and Christian Wöhler DaimlerChrysler Group Research, *3D Pose Estimation Based on Multiple Monocular Cues*, Environment Perception.

[7] Itay Gat, Meny Benady, Amnon Shashua, *'A Monocular Vision Advance Warning System for the Automotive Aftermarket',* September 29, 2004.

[8] Erez Dagan, Ofer Mano, Gideon P. Stein, and Amnon Shashua, '*Forward Collision Warning with a Single Camera',*

[9] L. Jagannath, C.V. Jawahar, *'Perspective Correction Methods for Camera Based Document Analysis'.*

[10] Saurav Kumar, Daya Gupta, Sakshi Yadav, 'Sensor Fusion of Laser & Stereo Vision Camera for Depth Estimation and Obstacle Avoidance, 2010 International Journal of Computer Applications (0975 - 8887) Volume 1 – No. 26