IMPLEMENTATION OF INVERSE PERSPECTIVE MAPPING ALGORITHM FOR THE DEVELOPMENT OF AN AUTOMATIC LANE TRACKING SYSTEM

[1]Anuar Mikdad Muad, [1]Aini Hussain, [1]Salina Abdul Samad,
[1]Mohd. Marzuki Mustaffa, [2]Burhanuddin Yeop Majlis
[1]Department of Electrical, Electronic and Systems Engineering
Faculty of Engineering,
[2]Institute of Microengineering and Nanoelectronics,
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor, Malaysia

mikdad@vlsi.eng.ukm.my , aini@eng.ukm.my, salina@eng.ukm.my,
marzuki@eng.ukm.my & burhan@eng.ukm.my
Tel: +60-3-8929-6329/6590, Fax: +60-3-8929-6146

ABSTRACT

Vision based automatic lane tracking system requires information such as lane markings, road curvature and leading vehicle be detected before capturing the next image frame. Placing a camera on the vehicle dashboard and capturing the forward view will result in a perspective view of the road image. The perspective view of the captured image somehow distorts the actual shape of the road, which involves the width, height, and depth. Respectively, these parameters represent the x, y and z components. As such, the image needs to go through a pre-processing stage to remedy the distortion using a transformation technique known as an inverse perspective mapping (IPM). This paper will outline the procedures involved.
Keywords: Inverse perspective mapping (IPM), foreshortening factor, vanishing point.

1. INTRODUCTION

According to [1], on 12 March 2003 at the *Dewan Rakyat* debate, the parliamentary secretary for the Transport Ministry cited that the number of fatal road accidents in the year 2002 was 5886 with 1015 of them involving cars. It was also reported that the fatal accident rate for the year 2002 in Malaysia was 4.9% compared to 4.3% in Singapore, 2.8% in Japan, 8.4% in Thailand and 9.1% in Indonesia. These alarming figures have motivated the government to find solutions to save precious lives and it was suggested that the driving school curriculum be reviewed with the aim of producing ethical and competent drivers.

Alternatively, apart from looking at the humanistic aspect, one such measure that can be implemented is by exploiting the advancement in various state-of-the-art technologies to produce an intelligent vehicle system with driving aids. Such a system is currently being developed and to-date a prototype has been tested and proven capable of providing the driving assistance, which help reduce accidents as well as increasing the survivability of the car [2]. An automatic lane tracking system is one of the many approaches implemented to achieve the aim. The system consists of a vision based sensory module mounted on a dashboard of a vehicle, which captures stream of images. This is then followed by a decision-making module. Each decision will be based on the analysis results performed on the images with the aim of keeping a safe distance between the trailing and leading vehicles. As such, this would require the parameters and condition of the road be known a *priori*. As mentioned earlier, the captured image from the sensory module produces a perspective view that distorts the physical conditions of the captured road image and some corrective action is required to remove the distortion

2. PERSPECTIVE PROJECTION GEOMETRY

Fundamental operation of a computer vision system involves capturing the image of a 3D object and projects it onto a 2D perspective view. Due to the perspective projection, the end-result (i.e. captured image) will contain some distortion caused by the foreshortening factor and vanishing point problems [3,4,5]. To have a better understanding of the perspective projection geometry, an explanation is provided using a pinhole camera model as shown in Fig. 1. The image plane in a camera lies within the focal distance, *f* behind the projection center with the captured image of the object being projected in its inverse orientation.

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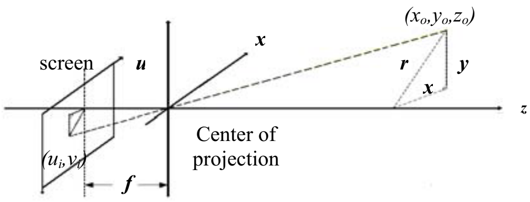


Fig. 1. The pinhole camera model

The captured image position can be described mathematically, either in term of its u component or using both the u and v components, with respect to its actual position in the world space (3D view). Using its single u component, the relationship is given by Equation 1,

$$\frac{u}{x} = \frac{f}{z} \tag{1}$$

While in term of its u and v components, it is given by Equation 2,

$$(u,v) = (f\frac{x}{z}, f\frac{y}{z}) \tag{2}$$

Referring to Fig. 1 of the pinhole camera model, as one move further away along the z-axis, the value of z will increase. From Equation 2, it can be seen that an increase in the value of z will cause the object (of width u and height v) to reduce in size and this phenomenon is known as a *foreshortening factor*. A vanishing point, on the other hand, occurs when a set of projected parallel lines appears to converge and intersect at a point. Fig. 2 illustrates the vanishing point phenomenon.

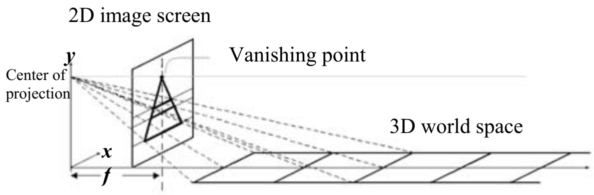


Fig. 2. Vanishing point phenomenon

3. PERSPECTIVE DISTORTION EFFECT

In reality, road boundaries are parallel to each other but in the 2D perspective view, they seem to converge to a common point, which is known as the vanishing point. The perspective projection effect has distorted the shape of the actual road boundaries. The 2D perspective view of the road image captured using a camera that was mounted on the dashboard of a moving vehicle is shown in Fig. 3(a). Additionally, a side-view illustration of the image is depicted in Fig. 3(b).

In Fig. 3(a), the L1, L2 and L3 lines are added and marked on the 2D perspective image to represent the bottom, middle and top pixels of the 2D image, respectively. These line pixels of L1, L2 and L3 corresponds to Fig. 3(b) in such a way that the top pixels correspond to the farthest distance from the vehicle while the bottom pixels correspond to the shortest distance from the vehicle. Due to this, the task of estimating the road parameters (e.g. direction and curvature) becomes more challenging and it will become worse for bend road image.

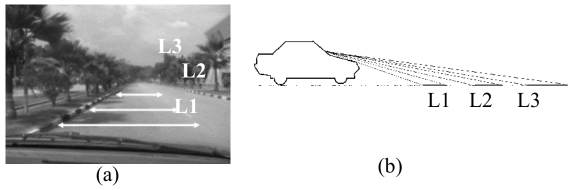
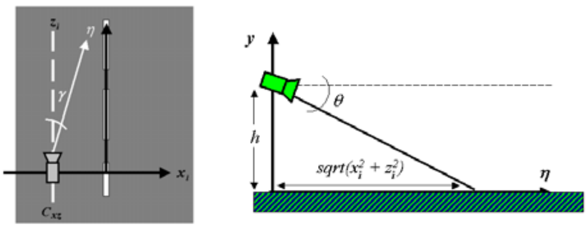


Fig. 3. (a) The 2D perspective road image,
(b). Its corresponding side-view image illustration

4. INVERSE PERSPECTIVE MAPPING

IPM is a geometrical transformation technique that projects each pixel of the 2D perspective view of a 3D object, and re-maps it to a new position and constructs a new image on an inverse 2D planar. Mathematically, IPM can be described as a projection from a 3D Euclidean space, $\boldsymbol{W} = \{(x, y, z)\} \in \boldsymbol{E}^3$ (world space) onto a 2D planar, $\boldsymbol{I} = \{(u, v)\} \in \boldsymbol{E}^2$. This will result in the bird's eye view of the image and thus, removes the perspective effect [6,7,8].



(a (b

Fig. 4. The IPM model

The IPM model is as shown in Fig. 4(a) and (b). Fig. 4(a) represents the top view geometrical model while Fig. 4(b) represents the side view geometrical model. Two equations were derived using the triangulation and trigonometry of the IPM model.

$$u(x,0,z) = \frac{\gamma(x,0,z) - (\Upsilon - \alpha)}{\frac{2\alpha}{n-1}} \tag{3a}$$

$$v(x,0,z) = \frac{\theta(x,0,z) - (\Theta - \alpha)}{\frac{2\alpha}{m-1}} \tag{3b}$$

Where,

$$\gamma = \tan^{-1}\left(\frac{z}{x}\right) \quad . \qquad \theta = \tan^{-1}\left(\frac{h}{\sqrt{x^2 + z^2}}\right)$$

And:

Υ is the angle between the projection of the optical axis on the flat plane, y=0 and axis,

Θ is the angle between the optical axis and the horizon,

α is the camera angular aperture, and
$n \times m$ is the resolution of the image.

5. REMOVING PERSPECTIVE DISTORTION

IPM implementation assumes that the road surface in the perspective image lies flat on the *x-z* plane. Fig. 6 displays the graphically presentation of the IPM implementation. In the 2D perspective image, the value of yaw angle (γ) changes from negative to positive as scanning proceeds from left to right and vice-versa while the tilt angle (θ) is the value that changes vertically. Both γ and θ act as 'projection weighting' factors for all pixels when IPM projects and re-maps the perspective image.

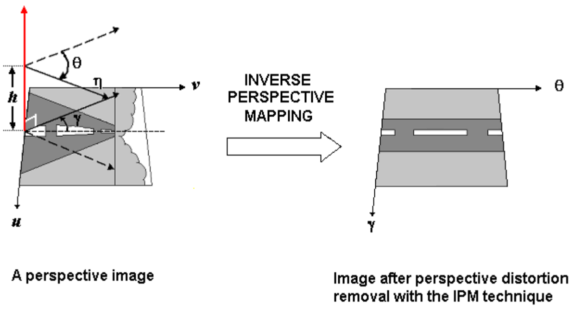


Fig. 6. Graphical explanation of the IPM implementation

6. OTHER FACTORS INFLUENCING IPM

Another factor that needs to be considered when implementing IPM is the positioning of the camera. This can be done manually by placing it correctly such that the camera viewfinder lies in the center of the image and focusing the vanishing point or by offsetting the yaw angle in the IPM procedure. Fig. 6(c) shows the IPM result when the camera is incorrectly position while Fig. 6(f) shows the result for otherwise.
Two lines are drawn vertically and horizontally such that they divide the image into half. The intersection of these two lines acts as the camera viewfinder center point. It can be seen from Fig. 6(a) and 6(b), the placement of the camera is slightly off to the left of the vanishing point (i.e. z-axis) in resulting in a poorly mapped image such as shown in Fig. 6(c).
Similarly, the same result can be obtained by offsetting the yaw, (γ) angle of the original 2D perspective image prior to IPM. Fig. 7 depicts the effect of offsetting the yaw angle in which Fig. 7(a) and 7(b) represent the result before and after offsetting the yaw angle, respectively.
Determining of the correct value of the tilt, (θ) angle is also crucial. With $\Omega = 90^o - \theta$ and if Ω is too narrow, only a small area of the road surface will be displayed in the re-mapped image and if Ω is too wide, it will covers too much of the road surface and produces unwarranted information. Fig. 8 clearly presents the effect of θ on the IPM image.

7. RESULTS

Fig. 9(a) shows a perspective view of a road surface with a set of yellow line markers drawn on its surface to indicate vehicle driver to slow down as it is approaching a bumper. In this perspective, the horizontal lengths of the yellow line markers and the distance between two adjacent lines are unequal. Selecting only the pixels along the region of interest Each peak in the signal represents each yellow line marking covered in the region of interest. It can be seen that the peak-to-peak distance is not equal. (ROI) as indicated by point A and B, the intensity profile of this line of pixels is shown in Fig. 9(b). However, when IPM technique is applied to the image, with the γ and θ are set to $7.5\pi/700$ and $\pi/55$ in radian respectively, the horizontal length and the distance become uniform as shown in Fig. 10.

8. CONCLUSION

In this paper, it has been shown that IPM provides a unique solution to remedy the distortions seen on the road surface of the 2D perspective view. With proper camera placement and correct setting of the yaw (γ) and tilt (θ) angle, IPM can be a very useful technique. IPM produces a bird's eye view of the image and this can be very useful for lane detection task and vehicle navigation development.

9. ACKNOWLEDGEMENT

The authors gratefully acknowledge the funding of this work by the Government of Malaysia under the IRPA code 03-02-02-0017-SR0003/07-03 and the National Science Fellowship council for the scholarship. Special gratitude goes to Mr. Noraidi Tawel for his assistance during data sampling.

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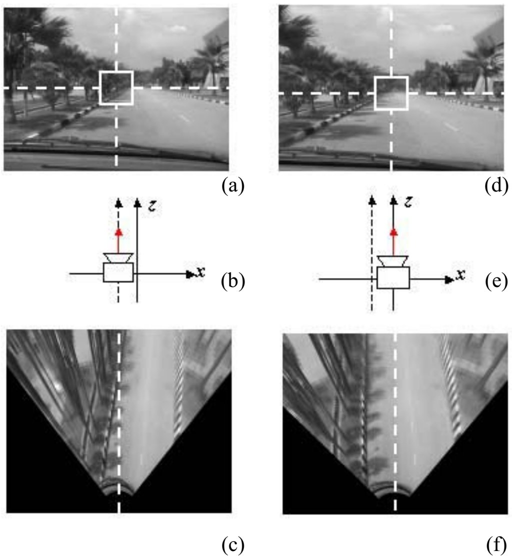

Fig. 6. (a) Original 2D-Perspective image,
(b) top view layout showing the incorrect camera location
(c) a poor IPM transformed image
(d) Original 2D Perspective image,
(e) top-view layout showing correct camera position and
(f) a correct IPM transformed image

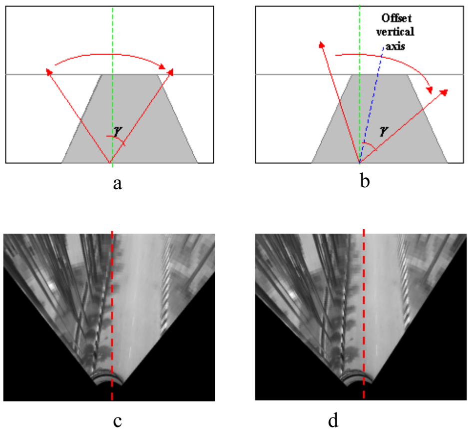

Fig. 7. Offsetting yaw, (γ) angle method to improve IPM result
(a) original γ value and scanning area coverage
(b) corrected γ value and scanning area coverage
(c) and (d) IPM images before and after ofsetting, respectively.

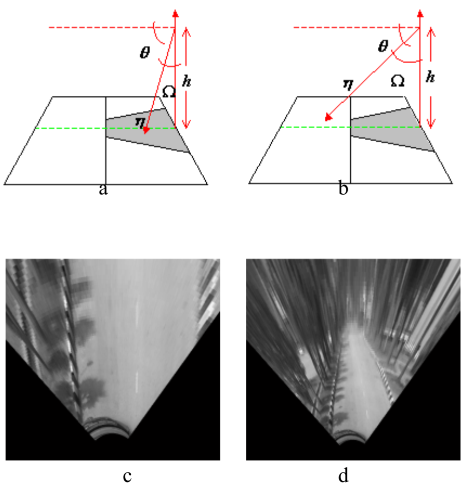

Fig. 8. Effect of θ on IPM (a) when Ω is too narrow and
(b) when Ω is too wide (c) and (d) IPM images before and

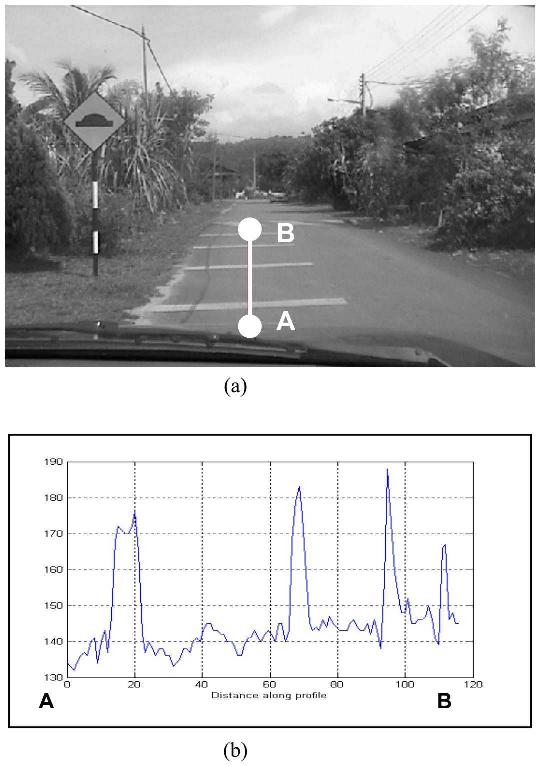

Fig. 9. (a) Original 2D Perspective Image
(b) ROI Intensity profile

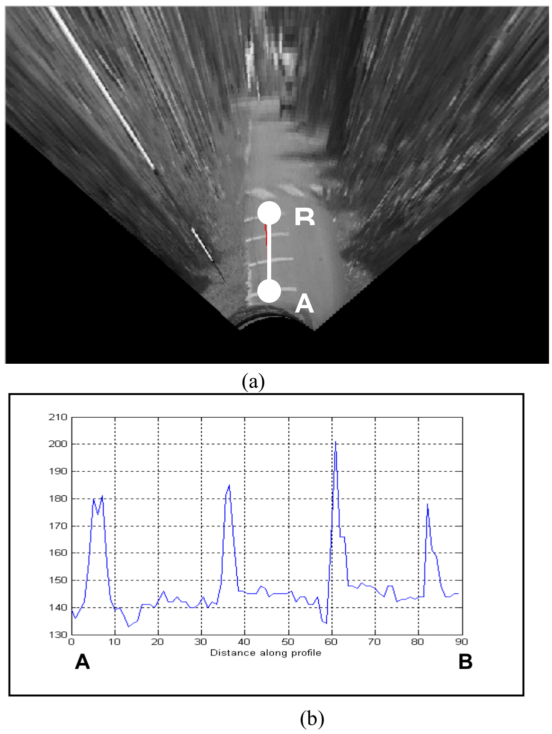

Fig. 10. (a) IPM Image and (b) its ROI intensity profile