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Robust Image Measurement and Analysis Based on Perspective Transformations

Bing-Fei Wu, *Senior Member, IEEE* and Chuan-Tsai Lin, *Student Member, IEEE*

Abstract—**In the paper, perspective transformation is used to project points from the front horizon of the camera to an image plane and thus to measure the distance between the detected object and the camera. With the information about points on the ground, the projective positions of every tip in a rigid object can be figured out through transformation. Features of the object's projection at different distances, such as size and shape, can also be predicted. Besides, the paper has analyzed difference in the result of the measurement and errors caused by the application of different parameters. The information assists engineers of vision-based detection system in determining the parameters of the system and identifying features of an object's projection to accelerate the detection. Also, the camera parameters compensate automatically when being influenced by outer force to promote the effects of detection and make a robust system.**

Index Terms – Image measurement, Error analysis, Perspective transformation.

I. INTRODUCTION

THIS paper aims to detect the positions and the sizes of objects through perspective transformation; to estimate the projective position, shape and size of the detected object and to analyze the error. The results are provided as reference for designers of the vision-based detection system to determine parameters of the camera, reduce the error and recognize features of an object's projection. The proposed approach offers a method to compensate automatically to make the results of detection more precise when extrinsic parameters of the camera are influenced by outer force.

Vision-based detection system is applied extensively in many situations, such as in surveillance system and driving-assistance system [1]-[5]. Computer vision can be considered to be used in occasions, which made use of human vision before. The measurement of the front object's distance was done by laser or radar in the past [6] [7]. Stereo Vision can be used in distance measurement as well. A comparison of the disparities in two images helps to detect obstacles and measures their distances [8]-[10]. The cost and the complexity of the system can be reduced greatly if only one camera is exerted. Some researchers calculate the distance by using a geometry model [11][12]. However, the result of measurement done by a single camera is subject to the parameters of the camera and more errors may come about.

Some researchers often identify an object through its features, size and shape [13][14]. Pang[15] analyzed the projections of vehicles with geometry and divided their overlap in the images to provide essential information to the traffic surveillance system. Broggi et al.[16][17] exerted inverse perspective mapping to transfer the images of the front driving lanes into an overlook of parallel driving lanes to help detect and identify vehicles with the bounding box. However, the recognition of images is often time-consuming; as a result, it is difficult to be applied in a real-time system. When an object is projected onto the image, its projective size and shape vary with changes in the relative positions between the object and the camera. In this paper, the projective size and shape of the objected object is estimated through perspective transformation, which greatly accelerates the detection.

The use of image measurement may generate errors because of the following factors.

1) Aberration: Aberration means the formation of real projection differs from the transformation of geometry projection because of certain factors. There are many kinds of aberration, which can be adjusted by optical zoom lens systems [18].
2) Quantization errors: Quantization errors derive from image digitization. [19][20].
3) Errors of variation in camera's parameters: Camera's parameters, such as the tilt or the focal length of the camera, have a direct influence on the measured results. The mistake in these parameters will lead to errors of calculation. This problem can be solved by the self-calibration of the camera [21]-[23].
4) Errors of detection: When the point detected by the automatic detection system is not the point in the real projection, the errors generated are call errors of detection. Besides, changes of the illumination in the surroundings and the variation of an object's features may also cause errors in the detection.

In this paper, quantization errors, errors of variation in parameters and detection errors are analyzed to promote the stability of the vision-based detection system.

This paper is organized as follows: Section 2 presents image analyses using perspective transformation; Section 3 explores results in the measurement, and analyzes the generated errors. Section 4 proposes the way of self-calibration with the obtained information to cope with changes in angles of the camera. In section 5, the real position

Bing-Fei Wu is with the Department of Electrical and Control Engineering, National Chiao Tung University1001, Ta Hsueh Road, Hsinchu, 30050, Taiwan, R.O.C (corresponding author to provide phone: 886-3-5131538; fax:886-37-470647; e-mail: bwu@cssp.cn.nctu.edu.tw).

Chuan-Tsai Lin is with the Department of Electrical and Control Engineering, National Chiao-Tung University, Hsinchu, Taiwan (e-mail:chuantsai@cssp.cn.nctu.edu.tw).

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and size of an object's projection is measured and the result of measurement is compared with the result of calculation. Section 6 is the conclusion.

II. Image Analysis Using Perspective Transformation

Any point in a 3-D world coordinate can be projected to a 2-D image plane through perspective transformation [8]. As seen in Fig.1, o is the original point of world coordinates (X, Y, Z) and image-plane coordinates (x, y), p is the center of the lens, λ is the focal length of the lens, and h is the height of the camera. The same symbols are used in the following figures of this paper. Mapping a 3-D scene onto the 2-D image plane is a many-to-one transformation. The Y and Z coordinates are related to the position of points projected onto the y-coordinate, while the X and Z coordinates concern the projection onto the x-coordinate. As shown in Fig.1, every point in $\overline{z_1 p}$ is projected onto y_1. However, mapping a point on the front horizontal plane of the camera onto an image plane is a one-to-one transformation. Since the point is known to be on the horizontal plane, its Y–coordinate can be inferred, and, therefore, The Z-coordinate determines mapping of the point to the y-coordinate. Fig. 1 shows z_1 is the only point in the horizontal plane projected to y_1. Besides, the equation of transformation can be generated through geometric calculation.

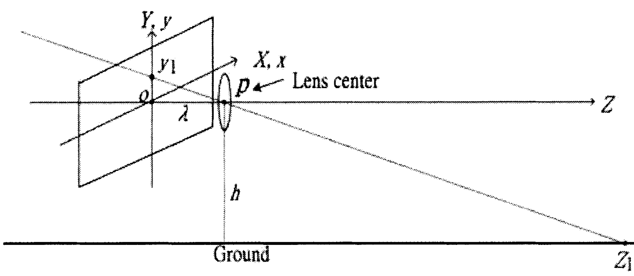


Fig. 1. A model of perspective transformation.

A. Distance measurement

Mapping a point on the front horizontal plane of the camera onto an image plane is a one-to-one transformation. Mapping relation between the y-coordinate and the Z-coordinate can be shown by an equation. Therefore, if the projective position in the image mapped by a point in the horizontal plane is known, the vertical distance between a point in the horizontal plane and the camera can be calculated based on the position of the y-coordinate. Fig. 2 shows the relation between the Z-coordinate and the y-coordinate, when the horizontal plane is front of the camera is projected to the image, where o, p, λ, h are symbols present the same meanings as the previous definitions. $\overline{pE}$ is the optical axis and α is the angle between the optical axis of the camera and the horizontal plane.

When the required point z_1 is behind the point E, the equation is shown in (1).

$$\overline{Dz_1} = h \cdot \tan\left((\pi/2 - \alpha) + \tan^{-1}\left(\overline{oy_1}/\lambda\right)\right) \tag{1}$$

When the required point z_1 is in front of the point E, the equation will be (2).

$$\overline{Dz_2} = h \cdot \tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overline{oy_2}/\lambda\right)\right) \tag{2}$$

Combine equations (1) and (2), let the point y in the image plane be the projection of the point Z whose distance to the camera is $\overline{DZ}$ as shown in (3).

$$\overline{DZ} = h \cdot \tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overrightarrow{oy}/\lambda\right)\right) \tag{3}$$

where

$$\overrightarrow{oy} = \begin{cases} \overline{oy}, & if\ y > 0; \\ -\overline{oy}, & otherwise, \end{cases}$$

As shown in (3), if the projective position in the y-coordinate mapped by a point in the front ground of the camera is known, the vertical distance between the point Z and the camera, $\overline{DZ}$, can also be calculated.

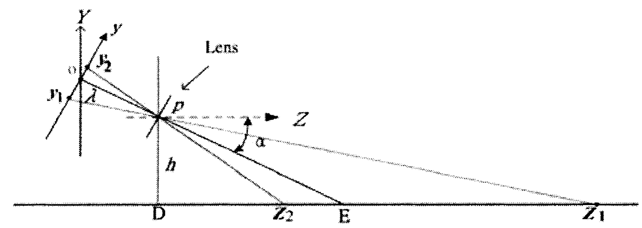


Fig. 2. Relation between the y-coordinates and the Z–coordinate.

B. Measurement in the position of horizontal projection

The X and Z coordinates can affect where an object is projected in the x-coordinate. If knowing the vertical distance, then the position of the object in the Z-coordinate is also known. Therefore, only the X-coordinate can affect the projective position in the x–coordinate. This is a one-to-one mapping.

Fig. 3 shows an object whose width is $\overline{A_1B_1}$ has a projection whose width is $\overline{a_1b_1}$ in the image. As shown in (3), if knowing either point of A_1, B_1 projects onto y_1 in the y-coordinates, then $\overline{Z_1p}$, the vertical distance between p and $\overline{A_1B_1}$, can also be obtained. Based on similar triangles, relation between $\overline{A_1B_1}$ and $\overline{a_1b_1}$ is shown as (4)-(6)

$$\overline{A_1Z_1} = \overline{oa_1} \cdot \overline{Z_1p} / \lambda \tag{4}$$

$$\overline{B_1Z_1} = \overline{ob_1} \cdot \overline{Z_1p} / \lambda \tag{5}$$

$$\overline{A_1B_1} = \overline{a_1b_1} \cdot \overline{Z_1p} / \lambda \tag{6}$$

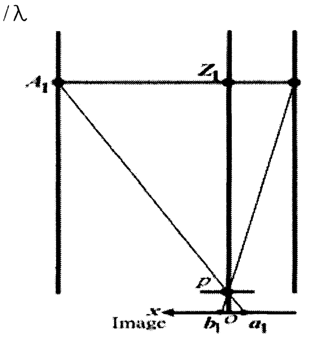


Fig.3. The projection of the horizontal axis.

According to (4)-(6), if knowing the position in the x-coordinate projected by an object's right and left tips, A_1, B_1, $\overline{A_1Z_1}$, the horizontal distance between the camera and A_1 is to be calculated and likewise, $\overline{B_1Z_1}$ the distance between the camera and B_1; $\overline{A_1B_1}$ the distance between A_1 and B_1. Similarly, if knowing the width of an object, based on this, the width of the object's projection can also be estimated.

C. Size measurement

Suppose an object O_1 contacts with the ground in the point z_1. Let the projective position of z_1 be r_1. The position of z_1 in the real world coordinates can be computed with geometry calculation if r_1 has been detected. Therefore, the distance between any point z_1 and S_1 on the object O_1, can be figured out through their projective positions in the image coordinates. Similarly, if knowing the distance between the two points and the projective position in the image mapped by either of the points known, the projective position of another point can also be obtained and then predict projective features of the object in the image, such as its shape and size.

1) Height: In Fig. 4, the height of an object is h_1, and its distance to the camera is $\overline{DZ_1}$. Then, the contacting point between an object and the ground, z_1, is projected to y_2; its highest point W is projected to y_3. Equations (7)-(9) are inferred from their geometric relationship.

$$\overline{oy_3}=\lambda\left\{\left[(h-h_1)\cdot\tan(\pi/2-\alpha)-\overline{DZ_1}\right]/\left[(h-h_1)+\overline{DZ_1}\cdot\tan(\pi/2-\alpha)\right]\right\} \quad (7)$$

$$\overline{oy_2}=\lambda\left\{\left[h\cdot\tan(\pi/2-\alpha)-\overline{DZ_1}\right]/\left[h+\overline{DZ_1}\cdot\tan(\pi/2-\alpha)\right]\right\} \quad (8)$$

$$h_{image}=abs(y_2-y_3) \quad (9)$$

where h_{image} means the vertical projective height of $\overline{WZ_1}$ in the image.

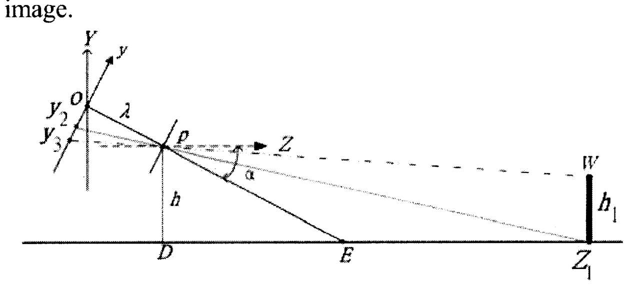


Fig.4. The projection of an object whose height is h_1.

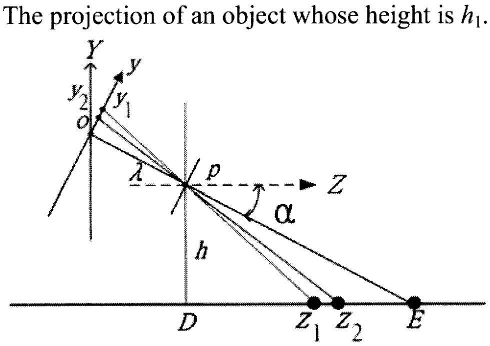


Fig. 5. The projection of the road pattern.

As known in (7)-(9), if knowing the distance and height of a known object, then the position and vertical height of its projection in the image can be calculated. In the same way, if knowing the projective position of an object's top and bottom tips and the vertical height of the object's projection, then it's possible to estimate the object's real height.

2) Length: Fig. 5 shows the projection, which is projected by objects lying flat on the ground such as road patterns or shadows. Suppose a road pattern whose length is N meters. One tip of the pattern lies in z_1 and the other tip is z_2, then the vertical distance of its projection in the image, l_{image}, can be calculated with (10)-(13).

$$N=\overline{DZ_2}-\overline{DZ_1} \quad (10)$$

$$\overline{oy_1}=\lambda\left\{\left[h\cdot\tan(\pi/2-\alpha)-\overline{DZ_1}\right]/\left[h+\overline{DZ_1}\cdot\tan(\pi/2-\alpha)\right]\right\} \quad (11)$$

$$\overline{oy_2}=\lambda\left\{\left[h\cdot\tan(\pi/2-\alpha)-(N+\overline{DZ_1})\right]/\left[h+(N+\overline{DZ_1})\cdot\tan(\pi/2-\alpha)\right]\right\} \quad (12)$$

$$l_{image}=abs(y_1-y_2) \quad (13)$$

III. Distance Measurement and Error Analysis

Errors may exist in the measurement because of incorrect parameters of the camera. Even if the set parameter is precise at first, it varies with the increasing time of using, outer force, or the consumption of mechanical devices. This leads to difference between the calculating value and the real value. The result and errors of the measurement will be discussed in this section.

A. Quantization error

Quantization errors come about in the process of image digitization. The digitization of (3) generates the equation (14).

$$\overline{DZ}=h\cdot\tan\left((\pi/2-\alpha)-\tan^{-1}\left(\overrightarrow{nd_1}/\lambda\right)\right) \quad (14)$$

where

$$\overrightarrow{nd_1}=\begin{cases} nd_1, & \text{if } y>0; \\ -nd_1, & \text{otherwise,} \end{cases}$$

d_1 means pixel size (the length or width)

n is the number of pixels from o to y (between $\overrightarrow{oy}$)

The paper analyzes the result of distance measurement with the camera, Hitachi KP-F3. The pixel size is 7.4(H) $\times$7.4(V) μm; that is d_1 is 7.4 μm, the number of pixels is 644$\times$493, and the height is set to be 1.3m. The result of calculation is shown as Fig.6. *I*-coordinate is used in the following context to present the vertical axis of the image coordinates. The bottom pixel of an image is represented by *I*=0, and the value of *I*-coordinate increases from bottom to the top. Besides, *I*-coordinate ranges form 0-492, and *I*=246 means the middle of the image. Fig. 6(a) shows the distance calculated with different camera parameters when *I*=0-229. When *I*=0, by observing the start point of every curve, a conclusion is drawn that when the focal length is shorter or the tilt is bigger, mapping of the points on the ground closer to the camera can also be found in the image. When *I*=229, the measured distance of the curve (A) is 163m, while that of the curve (D) is about 25m. That shows different distances are measured in the same point of the image with different focal lengths and tilts.

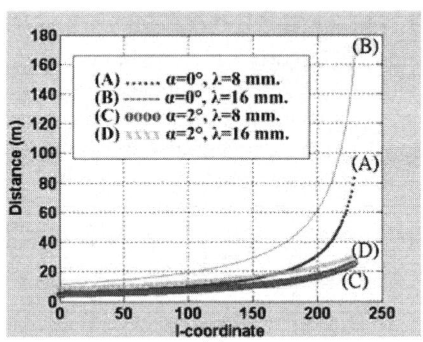
Image digitization causes quantization errors. In distance measurements, errors are caused by spatial quantization, and are within ± 1/2 pixels. The results of distance measurements are dominated by y_1, the projective y-coordinate of Z_1 in the image. Therefore, the biggest quantization error is calculated with errors of y_1 ranging ± 1/2 pixels. Let the calculated distance of the projection in y_1 be $\overline{DZ_1}$. Based on (14), the real distance ranges from $\overline{DZ_{11}}$ to $\overline{DZ_{12}}$ as shown in (15) and (16). In (17), e_q is the percent of the biggest quantization error.

$$\overline{DZ_{11}} = h\cdot\tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overline{(n-0.5)d_1}/\lambda\right)\right) \tag{15}$$

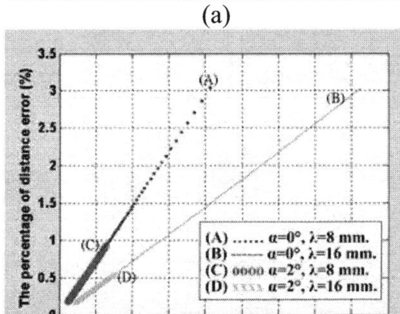
$$\overline{DZ_{12}} = h\cdot\tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overline{(n+0.5)d_1}/\lambda\right)\right) \tag{16}$$

$$e_q = \max(|Z_1 - Z_{11}|, |Z_1 - Z_{12}|)/Z_1 \tag{17}$$

The horizontal axis in Fig. 6(b) means the measured distance I=0-229, and the vertical axis is the percentage of the biggest quantization error in the distance measurement. The figure reveals that the farther the distance is, the bigger the percentage of measured error is. They show a direct proportion. The longer the focal length of the camera is, the smaller the value of the error appears. Whether the optical axis of the camera is horizontal or with a tilt, quantization errors remain the same when the distance is unchanged.



(a)



(b)

Fig. 6(a)(b) Error analysis of distance measurement.

B. Detection error

Image processing techniques is able to automatically detect the projective position of the contacting point between the front object of the camera and the ground. As shown in Fig. 4, Z_1 is projected to y_2, a position applied to calculate the distance between the object and the camera. However, some factors, such as the surrounding illumination or aberration, may cause error between the detected and the real y_2. According to (14), if the automatically detected contacting point lies in n_2 of the y-coordinate, its calculated distance is $\overline{DZ_2}$ in (18). If the projected position is n_1, then its real distance would be $\overline{DZ_1}$ in (19); the detected error is Z_d in (20) and the percentage of error is e_p in (21).

$$\overline{DZ_2} = h\cdot\tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overline{n_2 d_1}/\lambda\right)\right) \tag{18}$$

$$\overline{DZ_1} = h\cdot\tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overline{n_1 d_1}/\lambda\right)\right) \tag{19}$$

$$Z_d = abs\left(\overline{DZ_1} - \overline{DZ_2}\right) \tag{20}$$

$$e_p = Z_d / \overline{DZ_1} \tag{21}$$

Here the height of the camera is set as 1.3m and the focal length λ=16mm. The real projected point is n_1 and the automatically detected point is n_2. Their errors are analyzed as Fig. 7. The horizontal axis represents the measured range of distance. The vertical axis is, e_p, the percentage of error in distance measurement. The figure shows when a difference of more pixels is between n_1 and n_2, or the object is farther from the camera, their errors increase accordingly. When being 60m away from the camera, the percentage of the error is 2.19% with a difference of one pixel between n_1 and n_2. However, when the percentage of the error is 4.46%, the difference between the two points would be two pixels.

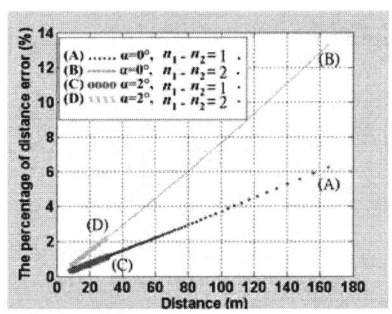


Fig. 7 The analysis of detection error

C. The influence of the camera's height

If the projective position of the contacting point between an object and the ground, n_1 in the x-coordinate, is detected, then the distance between the object and the camera is $\overline{DZ_1}$ derived from (19). However, if the height of the camera changes from h to h_2 with the up and down vibration during the measurement, then the real distance should be $\overline{DZ_{1h2}}$ in (22); the error is Z_{dh} in (23), and the percentage of error is e_{ph} in (24). Accordingly, there are fewer errors caused by changes of height, when the height of the camera is set to be higher or when the change of its height gets smaller.

$$\overline{DZ_{1h2}} = h_2\cdot\tan\left((\pi/2 - \alpha) - \tan^{-1}\left(\overline{n_1 d_1}/\lambda\right)\right) \tag{22}$$

$$Z_{dh} = (h - h_2)\left\{\tan\left[(\pi/2 - \alpha) + \left(\tan^{-1}(n_1 d/\lambda)\right)\right]\right\} \tag{23}$$

$$e_{ph} = Z_{dh} / \overline{DZ_{1h2}} = (h - h_2)/h_2 \tag{24}$$

D. The influence of the camera's angle

If the previously set tile changes from α to α_1 because of the vibration during the measurement, then the real distance is $\overline{DZ_{\alpha 1}}$ in (25). However, if the detection system fails to adjust accordingly and continues to calculate with the original tilt α, then the result of calculation would still be $\overline{DZ}$ in (14); the error is $Z_{d\alpha}$ in (26), and the percentage of error is $e_{p\alpha}$ in (27).

$$\overline{DZ_{\alpha 1}} = h\cdot\tan\left((\pi/2 - \alpha_1) - \tan^{-1}\left(\overline{n d_1}/\lambda\right)\right) \tag{25}$$

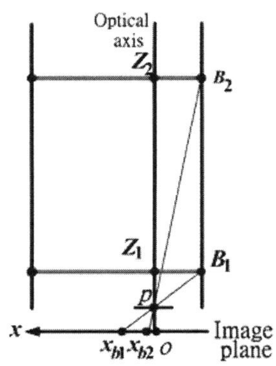
$$Z_{da} = abs\left(\overline{DZ_{\alpha 1}} - \overline{DZ}\right) \tag{26}$$

$$e_{pa} = Z_{da} / \overline{DZ_{a1}} \tag{27}$$

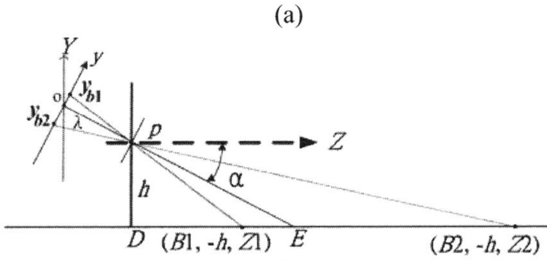
When camera h=1.3m, λ=8 mm, the bias of angle is 1° and the distance is 50m, calculated with (27), the value of error is about 40%. Therefore, changes in the angles have a great influence on the distance measurement.

IV. AUTO COMPENSATION OF CAMERA PARAMETERS

An analysis of errors shows that changes in the angles of the camera has a great effect on the result of the detection. If the angle of the camera can be adjusted automatically, errors can be improved greatly. Suppose that the angle of the camera can be figured out based on the information of the image, and then it's easy to achieve the goal of automatic modification. In this paper, an approach is proposed to use a known straight line to compute the angle of the camera. In the surveillance of the traffic, if a driving lane parallel to the optical axis of the camera is found, then this approach can be applied to compute the tilt of the camera.



(a)



(b)

Fig. 8(a)(b) The projection of an object in the x and y axes.

As shown in Fig. 8, suppose $\overline{B_1B_2}$ is a line parallel with the optical axis of the camera; the vertical distance between B_1 and p is $\overline{Z_1p}$, while $\overline{Z_2p}$ between B_2 and p. The height of the camera is set to be h; the center of the lens is p, and the focal length $\lambda = \overline{op}$. B_1 and B_2 project respectively to x_{b1} and x_{b2} in the x-coordinate and to y_{b1} and y_{b2} in the y-coordinate of the image coordinates. The application of (3) generates $\overline{Z_1p}$ and $\overline{Z_2p}$ as shown by (28) and (29) individually. (30) derives from the use of (5) and similar triangles. The combination of (28)-(30) gets (31) and (32).

Let $a = \overline{ox_2} / \overline{ox_1}, b = \overrightarrow{oy_{b1}} / \lambda, c = \overrightarrow{oy_{b2}} / \lambda, d = \tan(\pi / 2 - \alpha)$.

Then (33) and (34) are generated. Thus the tilt of the camera can be obtained. The detection of camera's tilt can offer more correct parameters to the detective system to reduce errors.

$$\overline{Z_1p} = h\cdot\left(\tan\left((\pi/2-\alpha) - \tan^{-1}\left(\overrightarrow{oy_{b1}}/\lambda\right)\right)\right) \tag{28}$$

$$\overline{Z_2p} = h\cdot\left(\tan\left((\pi/2-\alpha) - \tan^{-1}\left(\overrightarrow{oy_{b2}}/\lambda\right)\right)\right) \tag{29}$$

$$\overline{Z_1p} = \left(\overline{ox_{b2}} / \overline{ox_{b1}}\right)\cdot \overline{Z_2p} \tag{30}$$

$$\tan\left((\pi/2-\alpha) - \tan^{-1}\left(\overrightarrow{oy_{b1}}/\lambda\right)\right) = \left(\overline{ox_{b2}} / \overline{ox_{b1}}\right)\cdot\left(\tan\left((\pi/2-\alpha) - \tan^{-1}\left(\overrightarrow{oy_{b2}}/\lambda\right)\right)\right) \tag{31}$$

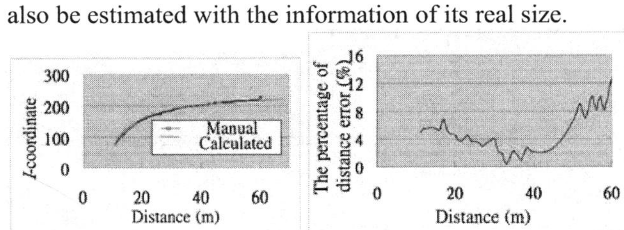
$$\frac{\tan(\pi/2-\alpha) - \left(\overrightarrow{oy_{b1}}/\lambda\right)}{1+\left(\overrightarrow{oy_{b1}}/\lambda\right)\cdot\tan(\pi/2-\alpha)} = \left(\overline{ox_{b2}} / \overline{ox_{b1}}\right)\cdot\frac{\tan(\pi/2-\alpha) - \left(\overrightarrow{oy_{b2}}/\lambda\right)}{1+\left(\overrightarrow{oy_{b2}}/\lambda\right)\cdot\tan(\pi/2-\alpha)} \tag{32}$$

$$d = \frac{-(1-bc-a+abc) \pm \sqrt{(1-bc-a+abc)^2 - 4(c-ab)(ac-b)}}{2(c-ab)} \tag{33}$$

$$\alpha = \pi / 2 - \tan^{-1}(d) \tag{34}$$

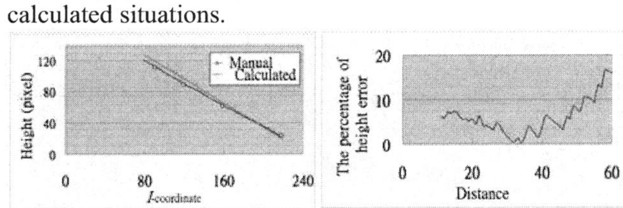
V. APPLICATION

The proposed approach of distance measurement in the paper can be applied to driving assistant system to detect the distance between obstacles and the host car equipped with the detection system. First, detect the projective position in the image projected by the contacting point between the front obstacle and the ground, and then compute the distance between the obstacle and the camera according to this projective position. The size of the obstacle's projection can also be estimated with the information of its real size.



(a) (b)

Fig. 9(a)(b) A comparison of the distance in real and calculated situations.



(a) (b)

Fig. 10(a)(b) A comparison of the size in real and calculated situations.

An experiment is conducted to detect the position of the projection projected onto the I-coordinate in the image coordinates by the contacting point between a sample and the ground. The height of the sample is 1m; the parameters of the camera, Hitachi KP-F3, are set to be α=0°, 1.3m in height and a focal length of 10mm. An image is taken in every meter of a distance ranging from 11-60m. The result is shown as the curve 'Manual' in Fig. 9(a), where the curve 'calculated' is the result of calculation with (14). As shown in the figure, the curve 'manual' isn't smooth because of the aberration and man-made errors in real distance measurement. The two curves match each other approximately, which means that the real situation corresponds with the result of calculation. Fig. 9(b) shows the difference between the real and the calculated distance varies with distance. The greatest error, 12.6%, lies in the distance of 60m. Those errors should be taken into consideration when designing driving assistant system.

In Fig. 10(a), the curve 'manual' presents that the projective height changes with the variation of the sample's position in the images taken in the distance of 11-60m during the detection. The horizontal axis stands for the projective position, in the *I*-coordinate, projected by the contacting point between the sample and the ground. The vertical axis is the height of the projection. The curve 'calculate' shows the projective height derived from the calculation of (7)-(9). The figure reveals the two curves of the real situation and the result of calculation match each other approximately. Fig. 10(b) indicates the comparison between the two curves in different distance. The biggest error is 16.4% in the distance of 58m. Man-made errors and the aberration are reasons making the curves not smooth.

VI. Conclusions

Vision-based detection system automatizes tasks, which used to done by human labor. It is often applied to an object's motion estimation and measurement. An approach is proposed in the paper to compute the distance between an object and the camera through the position of the object's projection. The projective size of the object in the image can also be estimated to help identify features of its projection during the detection.

In this paper, errors of distance measurement are analyzed. The analytical results of quantization errors and detection errors are summarized as follows. The value of error increases when the distance gets farther. If the applied focal length is longer, the error gets smaller in the distance measurement. However, the view of the detection may become smaller and, as a result, make features of the detected object incomplete. When the measurements are carried out at the same distance, the higher the camera is set, the smaller the error would be. Whether the optical axis of the camera is horizontal or has a tilt, the errors remain the same.

When designing a vision-based detection system, parameters of the camera should be chosen properly to promote efficiency and to meet requirements of the work. This paper analyzes the influence of camera's parameters and provides the result to designers of vision-based detection system for reference. Besides, an approach of calibration in the camera's tilt is offered to reduce errors.

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