Image-Based Height Measuring System

WEI-YEN WANG[1], MING-CHIH LU[2], CHIN-TUN CHUANG[3], JEN-CHI CHENG[4]

[1] Institute of Applied Electronics Technology, National Taiwan Normal University, Taipei
TAIWAN

[2] Department of Electronic Engineering, St. John's University
Tamsui, Taipei County
TAIWAN

[3] Department of Mechanical and Computer-Aided Engineering, St. John's University
Tamsui, Taipei County
TAIWAN

[4] Department of Electronic Engineering, Fu-Jen Catholic University, Taipei
TAIWAN

Abstract: - In this paper, a new distance measuring method to measure the height of a building is proposed. Traditionally, distance measuring using CCD is based on the parallax method. This paper puts forward a method of measuring the width and height of a building regardless of the distance of the camera or the angle between optical axis and ground. By using two parallel laser spots, the distance from the camera to the building and the height of the building can be determined in a single photo session and with a single picture. Experiments show that even highly non-orthogonal pictures taken from a short distance can be used to determine the height of a building. The result will not be affected by the angle between the camera's optical axis, the ground and the measured surface.

Key-Words: - CCD, Image-Based Distance Measuring System, height, non-orthogonal images

1 Introduction

Methods of measuring height are divided into two categories: contact and non-contact. Contact methods using measuring chains or tapes are difficult, and have safety problems as well. What's more, measuring wheels [1]-[2] cannot be used. There are two frequently used non-contact methods: ultrasonic [3]-[5] and laser [6]-[9]. The two systems are based on the theory of wave reflection. Ultrasonic systems require a big enough reflection surface to measure the distance between the surface and the measuring tool, and therefore can not be used to measure the height of a building. While the laser system does not require such big surface, the quality of reflection point affects the measuring result. Both of them measure the distance between the measuring point and the tool. To know the height of a building, two measurements must be carried out and the angle between two measurements must be carefully obtained. The height can then be calculated by a triangle formula. Whether ultrasonic or laser, the result cannot be obtained from a single measurement. A third method, using dual CCD cameras and the parallax method, requires a high speed computer and DSP system, as well as image identification techniques. Since the measuring systems are large and expensive, they can never be used as portable image measuring systems.

Based on techniques and experiences from previous research, we have developed IBDMS

(Image-Based Distance Measuring System), which can determine the width and height of a building from a single image.

The rest of the paper is organized as follows. Section 2 focuses on the theory of IBDMS; Section 3 focuses on the method of identifying the laser spots in the image; Section 4 is an explanation of the theory of measuring height from non-orthogonal images; Section 5 is experimental results; Section 6 is conclusion.

2 IBDMS distance measuring theory

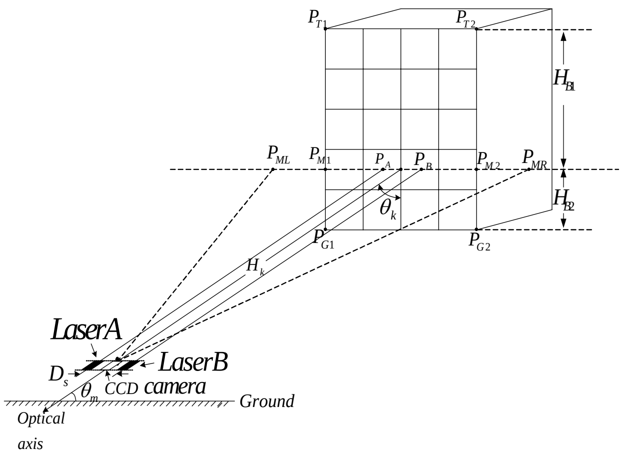

Fig. 1 Illustration of IBDMS distance measuring..

When using a camera to measure height, ideally the film plane should be parallel to the face of the building, and equidistant from all points on the face. Although impossible except at infinity, we can achieve it to a closer and closer approximation as the distance between camera and building increases. However, at larger and larger distances, the building image becomes smaller reducing measurement accuracy. Moving closer increases the image size and thus accuracy, but also increases image distortion due to foreshortening, as the camera has to tilted up to get an image of the whole building. The optical axis forms an angle, θ_m, with the ground and an angle, θ_K, with the vertical surface of the building. $\theta_m + \theta_k = 90°$. When the photography distance H_K changes, θ_m and θ_k also change with it. The image will become a different one.

This research puts forward a method of measuring the width and height of a building regardless of the distance of camera or the angle between optical axis and ground.

First, we will start by measuring width. Cast two bright pixels (P_A and P_B) on the surface by two parallel laser beams. In the image, the two points will be brighter than the background and easy to automatically identify. We know the actual distance between the lasers, D_S, but of course in the image the separation in pixels ($N_{AB}(H_K)$) between the points varies with the distance H_K. Knowing D_S and $N_{AB}(H_K)$ will give us $D(P_{M1}, P_{M2})$, as can be seen in Fig. 2. If we then identify the left and right edges of the building (P_{M1} and P_{M2}) at the same height in the image, then we can calculate the actual width of the building, $D(P_{M1}, P_{M2})$, as given by Eq. (1).

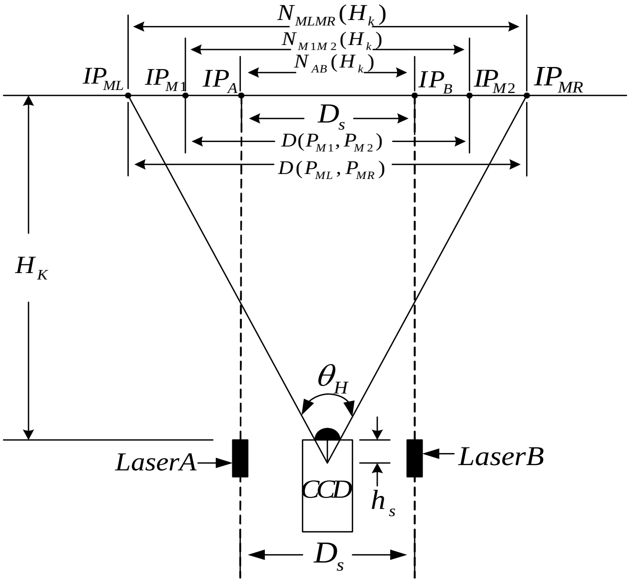

Figure 2 IBDMS distance measuring theory.

$$D(P_{M1}, P_{M2}) = \frac{N_{M1M2}(H_K)}{N_{AB}(H_K)} \times D_S \qquad (1)$$

where $N_{M1M2}(H_K)$ is the number of pixels between IP_{M1} and IP_{M2} in the image at the same distance H_K.

The maximum horizontal scope $D(P_{ML}, P_{MR})$ of the extension of P_{M1}, P_{M2} is

$$D(P_{ML}, P_{MR}) = \frac{N_H(\max)}{N_{AB}(H_K)} \times D_S \qquad (2)$$

Now that we know the scale of the image, we can derive the distance from the camera to the building,

H_K:

$$H_K = \frac{1}{2} D(P_{ML}, P_{MR}) \times \cot\left(\frac{\theta_H}{2}\right) = \frac{1}{2} \frac{N_H(\max)}{N_{AB}(H_K)} \times D_S \times \cot\left(\frac{\theta_H}{2}\right) \quad (3)$$

where θ_H is the camera field of view and $N_H(\max)$ is the width in pixels of the CCD ([14]-[15]).

3 Determination of bright pixels in image

Figures 3 and 4 are pictures with H_K equal to26.94m . Figures 5 show analysis of the image signal of the horizontal scan line containing the laser spots. Figures 6 is actual picture of the measuring system. The analysis shows clearly that the peak of the bright spots in the image. The position of the bright spots can be easily determined from the color and brightness.

Since the two laser beams have been set parallel with each other and with the optical axis, the movement of the measuring system does not affect their relative positions. If the images of the two lasers are adjusted to appear on the same horizontal scan line, they will always appear on the same horizontal scanning line.

The setting of the measuring system enables the image of bright spots to appear only on the middle horizontal scan line $\frac{1}{2} N_V(\max)$. Analyzing the image becomes quite easy. It is not necessary to do full-scale image analysis by a high-speed computer and DSP system. The procedure is given in Figure 7.

Figure (3) picture of H_K =26.94m.

Figure (4) picture of laser spots when H_K =26.94m.

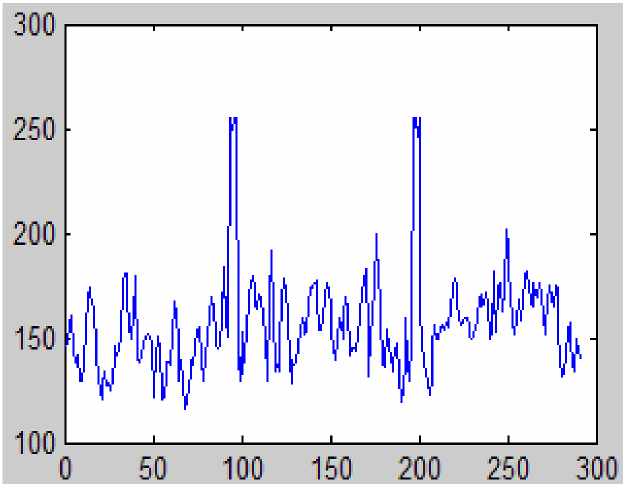

Figure (5) image signal of bright pixels when H_K = 26.94m.

Figure (6) Actual picture of the measuring system.

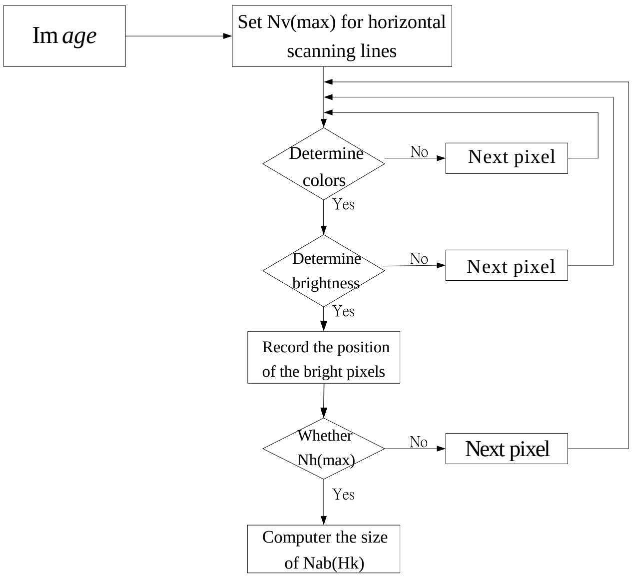

Figure (7) the procedure of dealing with the pixel of bright pixels.

4 Theory of measuring height

Figure 8 shows the building and camera field of view from a position perpendicular to the building. Figure 9 shows the building as it appears in the image. The building is rectangular, so the width at the bottom is the same as at the top, $\left(\overline{P_{T1}, P_{T2}}\right) = \left(\overline{P_{M1}, P_{M2}}\right) = \left(\overline{P_{G1}, P_{G2}}\right)$. The extent of the field of view at $\left(\overline{P_{T1}, P_{T2}}\right)$ is $D(P_{TL}, P_{TR})$ and at $\left(\overline{P_{G1}, P_{G2}}\right)$ is $D(P_{GL}, P_{GR})$.

$$D(P_{TL}, P_{TR}) = \frac{N_H(\max)}{N_{T1T2}(H_K)} \times D(P_{ML}, P_{MR}) \tag{4}$$

$$D(P_{GL}, P_{GR}) = \frac{N_H(\max)}{N_{G1G2}(H_K)} \times D(P_{ML}, P_{MR}) \tag{5}$$

Therefore, the measured height of the building is $H_B = H_{B1} + H_{B2}$

$$\begin{aligned} H_B &= \frac{1}{2}\left[D(P_{TL}, P_{TR}) - D(P_{GL}, P_{GR})\right] \times \cot\left(\frac{\theta_H}{2}\right) \\ &= \frac{1}{2}\left[\frac{N_H(\max)}{N_{T1T2}(H_K)} - \frac{N_H(\max)}{N_{G1G2}(H_K)}\right] \\ &\quad \times \frac{N_H(\max)}{N_{AB}(H_K)} \times D_s \times \cot\left(\frac{\theta_H}{2}\right) \end{aligned} \tag{6}$$

Knowing width of building $D(P_{M1}, P_{M2})$ from Eq.(1) and photography distance H_K from Eq. (3), the height H_B can be calculated from Eq.(6), which means the distance measuring from the camera to the building and the height of the building can be determined by merely one photo session and one picture.

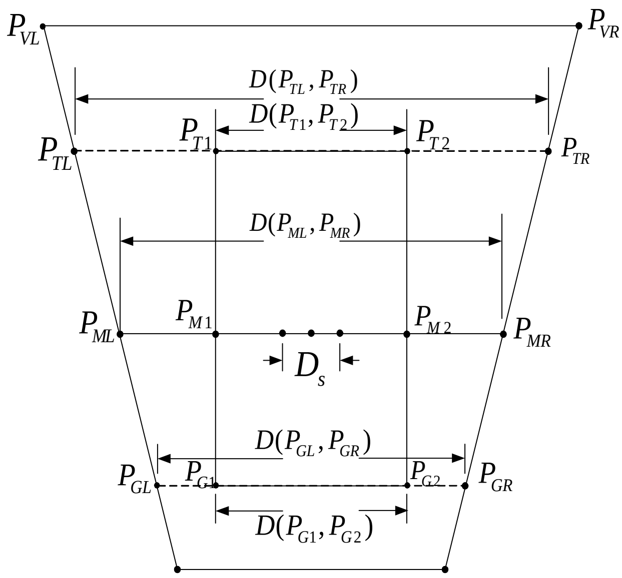

Figure (8) relationship picture of horizontal angle of view.

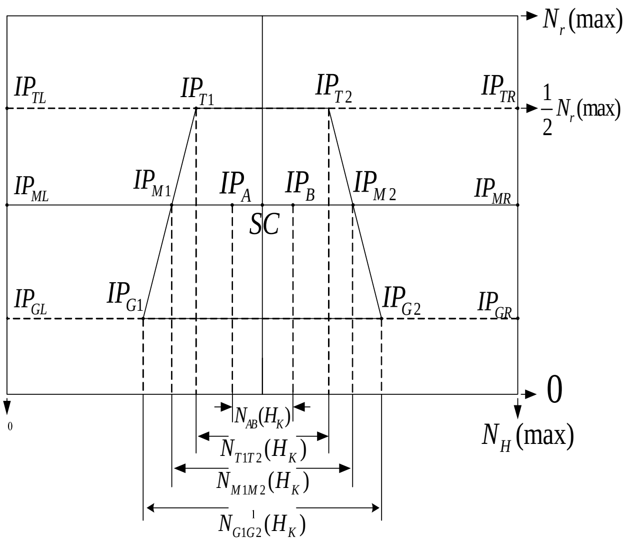

Figure (9) Relationship picture of pixel of pictures.

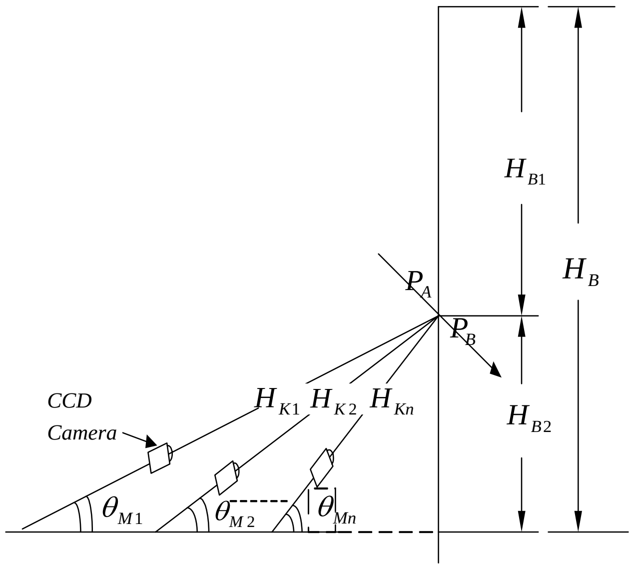

Figure (10) illustration of experiment planning of height measuring.

5 Experimental Results

(a) Camera used

<1>PANASONIC factory LumixDMC-FZ30mode

<2>Maximum horizontal pixel $N_H(\max)$=3264

<3>Maximum vertical pixel $N_V(\max)$=2448

<4>The position of optical origin h_0=1.121cm

<5>Horizontal angle of view $\theta_H = 25.35^\circ$

, $\cot\left(\frac{\theta_H}{2}\right)$=2.11

(b) Actual size of the measured building

<1>The façade horizontal width $D(P_{G1},P_{G2})$=260cm

the actual width obtained by measuring with taping on the ground

<2>The façade vertical height

H_B=652cm,822cm,1017cm,1419cm

**the actual height obtained by measuring with long rope from the roof to the ground **

(c) Experiment planning

Figure 10 illustrates the height measuring experiments. For these experiments, we tried 3 different camera positions and 3 values for θ_M .

Table (1) the result of façade horizontal width measuring.

distance of photography H_K (cm)	2654	2694	2744	2744	2882	2882
$N_{AB}(H_K)$	526.1	517.2	508.3	508.5	486	490.3
$D(P_{M1},P_{M2})$ (cm)	264.7	263.8	262.8	261.8	263	262.6
deviation (%)	1.83	1.46	1.07	0.7	1.18	1.02

Table (2) the result of façade vertical height measuring

distance of photography H_K (cm)	2654	2694	2744	2744	2882	2882
$N_{AB}(H_K)$	526.1	517.2	508.3	508.5	486	490.3
$N_{T1T2}(H_K)$	601.9	593	579.6	579.6	557.3	548.7
$N_{G1G2}(H_K)$	655.4	659.9	659.9	668.8	673.3	677.7
Actual height (cm)	652	822	1017	1017	1419	1419
height of measurement (cm)	619.9	794.7	992.8	1087.9	1479.9	1475
deviation (%)	-5.06	-3.04	-2.54	6.97	4.29	4.01

As you can see, the height of the building can be obtained by knowing the building width and assuming the building is rectangular. The characteristic of the experiment is that there is no need of vertical photography (i.e., the optical axis of the camera need not be perpendicular to the building). Photographs at any angle are capable of measuring the distance between the camera and the building, and the building width and height..

6 Conclusions

This paper has described a method of measuring width and height of tall buildings from a short distance at any height and any angle, regardless of the height of the camera holder and not using angle measuring equipment. The experimental results show the theory, and that the error is within reasonable limits. As well, the method does not need image processing equipment. It is a small, cheap, and portable image-based distance measuring device. With the addition of two lasers and upgraded camera software, cameras from any factory can have a three-dimensional measuring function.

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References :

[1] http://www.honestsensor.com.tw/

[2] http://www.omron.com.tw/

[3] M. Parrilla, J. J. Anaya, and C. Fritsch, "Digital signal processing techniques for high accuracy ultrasonic range measurements," *IEEE Trans. Instrum. Meas.*, vol. 40, pp.759-763, Aug. 1991.

[4] D. Marioli, C. Narduzzi, C. Offelli, D. Petri, E. Sardini, and A. Taroni, Digital time-of-flight measurement for ultrasonic sensors," *IEEE Trans. Instrum. Meas.*, vol. 41, pp.93-97, Feb. 1992.

[5] Caarullo and M. Parvis, "An ultrasonic sensor for distance measurement in automotive applications," *IEEE Sensors Journal*, vol. 1, no. 3, pp. 143-147, Oct. 2001.

[6] K. Osugi, K. Miyauchi, N. Furui, and H, Miyakoshi, "Development of the scanning laser radar for ACC system," *JSAE Rev*. 20, pp. 579-554, 1999.

[7] H.-T. Shin, "Vehicles Crashproof Laser Radar," *M.S. thesis, Opt. Sci. Center, National Central Univ.*, Chung Li City, Taiwan, R.O.C., 2000.

[8] S. A. Sviridov and M.S. Sterlyagov, "Sea surface slope statistics measured by laser sensor," *Proc. Ocean Engineering for Today's Technology and Tomorrow's Preservation*, vol. 1, pp.I/900-I/905, 1994.

[9] Y. M. KlimKov, "A laser Polarmetric sensor for measuring angular displacement of objects," in *Proc. Eur. Conf. Lasers and Electro-Optics*, Sep. 8-13, 1996, pp.190-190.

[10] R. Cucchiara, M. Piccardi, and P. Mello, "Image analysis and rule-based reasoning for a traffic monitoring system," *IEEE Trans. Intell. Transp. Syst*., vol. 1, no. 4, pp.119-130, Mar. 2000.

[11] D. Katsoulas and A. Werber, "Edge detection in range images of piled box-like objects," in *Proc. 7th Int. Conf. Pattern Recognition*, vol. 2, 2004, pp.80-84.

[12] M.-C. Lu, "Image-based height measuring system for Liquid or particles in tanks," *ROC patent of invention*, No.201536, 2004.

[13] Ming-Chih Lu, Wei-Yen Wang, and Chun-Yen Chu, "Image-Based Distance and Area Measuring Systems," *IEEE Sensors Journal*, vol.6, no.2, pp. 495-503, April 2006.

[14] Ti-Ho Wang, Ming-Chih Lu, Chen-Chien Hsu, and Yin-Yu Lu, "Image Ruler and Its Applications in Distance and Area Measurement," *WSEAS Transactions on Systems*, Issue 5, Volume 6, May 2007, pp. 901-907. .(ISSN 1109-2777)

[15] Wei-Yen Wang, Ming-Chih Lu, Ti-Ho Wang, and Cheng-Pei Tsai, , and Yin-Yu Lu, "Image- and Robot-Based Distance and Area Measuring Method," *WSEAS Transactions on Systems*, Issue 5, Volume 6, May 2007, pp. 914-919.