Vision-Based Distance and Area Measurement System

Cheng-Chuan Chen, Ming-Chih Lu, Chin-Tun Chuang and Cheng-Pei Tsai

Abstract**—**The objective of this paper is to enable CCD camera for area measuring while recording images simultaneously. Based on an established relationship between pixel number and distance in this paper, we can derive the horizontal and vertical length of a targeted object, and subsequently calculate the area covered by the object. Because of the advantages demonstrated, the proposed system can be used for large-area measurements. For example, we can use this system to measure the size of the gap in the embankments during flooding, or the actual area affected by the landslides. Other applications include the surveying of ecosystems by inspecting how widely spread is a certain type of life form. For places which are difficult or impossible to reach, this system can be particularly useful in performing area measurements. Experiments conducted in this paper have indicated that different shooting distances and angles do not affect the measuring results.

Keywords**—**CCD camera, area measurement system, laser beams, pixels.

I. INTRODUCTION

As far as measuring large surface areas is concerned, most traditional methods use a large measuring tape to measure the vertical and horizontal lengths across an area, section by section, and then convert the results into area measurements. When advanced methods are considered, ultrasonic [1]-[3] and laser [4]-[6] techniques are available to measure the distance from a point to another. In order to measure an area, many set points have to be designated, which is a rather troublesome process. The process becomes even more difficult when attempting to measure an irregular area.

Generally, ultrasonic and laser rangefinders are used only for the measurement of distance between 2 set points. Furthermore, neither of these two methods can be used for distance and area measurement while simultaneously recording images.

The distance measuring method proposed in this paper is an improvement of the studies revealed in previous research [7]-[10], and patents granted [11]-[12]. By using two low-frequency visible-light (red) laser diodes, two parallel laser beams can be projected onto the surface of a targeted object, generating two spots with high intensity. With a CCD camera, images of the targeted object can be taken, where the projected spots have a much higher intensity than the background. Two projected spots will appear in the CCD image. From the difference of the intensity of the image signals between the projected spots and the background, we can easily determine the pixel number between the projected spots, based on which we can derive a particular horizontal length. As long as the CCD camera isn't moved, the taken images will always remain the same. When the projection angle of laser beams is changed, we can determine the horizontal length of another location from the CCD image. This is equivalent in making many rectangles on the area to be measured. By using the equal-length relationship of a CCD camera's horizontal pixel and vertical pixel, we'll be able to find out the (vertical) height for each rectangle. Multiplying the horizontal width by the vertical height for each rectangle, we can calculate the area of the rectangle. Finally, by totaling all the area value of the rectangles, we can obtain the area of the object under measurement. The process of using a stepping motor to drive a gear set in order to gradually adjust the projection angle of the laser beams to achieve the design objective of automatic measurement will be given in details later in this paper.

The organization of this paper is as follows. Section 2 gives the relationship between pixels and distance. Solutions to the laser dispersion phenomenon are provided in Section 3. Area measurement via the proposed method is described in details in Section 4. Experiment results and discussions are provided in Section 5. Finally, conclusion is given in Section 6.

II. THE RELATIONSHIP BETWEEN PIXELS AND DISTANCE

Fig. 1 shows the relationship between pixel number and distance in this paper. From the previous studies [9]-[10], we can easily set up Laser A and Laser B in such a way that laser beams are projected in parallel in a distance d_r. We then carefully adjust the positions of the laser projectors, so that projected points A and B in images are located on the same horizontal scanning line. That is, points A and B projected by

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the laser diodes form a straight line which is parallel to all the horizontal scanning lines in the CCD image. With these settings, image signals of points A and B will fall on the same scanning line, irrelevant of the angle changes made by the laser beams. Referring to Fig. 1, the two signals $P_A(h_i)$ and $P_B(h_i)$ are both located on the K_{th} scanning line. Because the project points are much brighter than the background, the amplitude of intensity of $P_A(h_i)$ and $P_B(h_i)$ are therefore much higher than that of the background. By comparing the amplitude of the intensity signal, we can identify the location of $P_A(h_i)$ and $P_B(h_i)$. That is, we can find out the pixel number $N_A(h_i)$ and $N_B(h_i)$ for $P_A(h_i)$ and $P_B(h_i)$, respectively. As a result, $N_r(h_i) = N_B(h_i) - N_A(h_i)$ can be obtained, where h_i is the shooting distance. We now have:

$$D_M(h_i) = \frac{N_M(h_i)}{N_r(h_i)} \times dr = \frac{\text{Ns(max)}}{\text{Nr}(h_i)} \times dr \tag{1}$$

Note that the maximum pixel value $N_s(\max)$ remains the same irrelevant of the shooting distances of the camera.

When the horizontal length between points P_x and P_y at distance (h_i) is to be measured, a that has a direct relationship with $N_r(h_i)$ listed below can be used

$$D_T(h_i) = \frac{N_T(hi)}{Nr(hi)} \times dr \tag{2}$$

That is, any horizontal distance between projected points A and B can be measured by (2). Tables 1 and 2 show the measuring results h_i at different shooting distances.

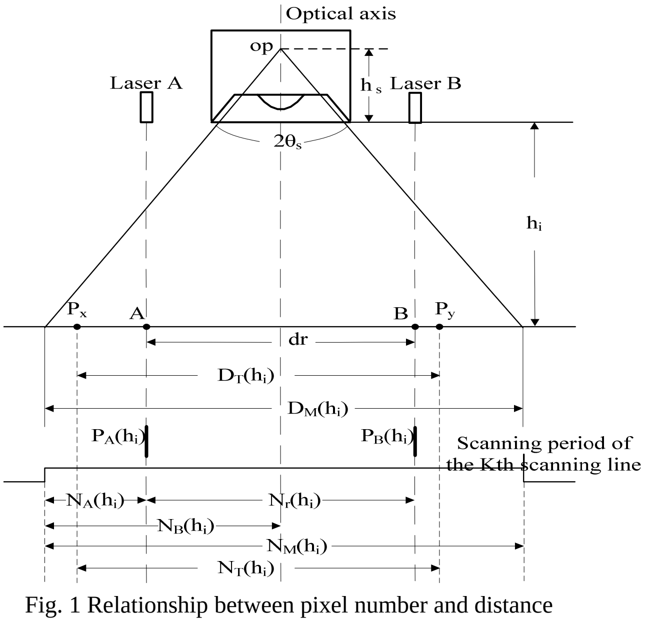

Fig. 1 Relationship between pixel number and distance

Table 1 Measuring results with d_r =10 cm.

Actual distance	220	280	340	400	460
Measured distance	219.9	280.9	342.2	401.4	460.4
Error (%)	0.04	-0.31	-0.64	-0.35	-0.09

Table 2 Measuring results with d_r =30 cm.

Actual distance	220	280	340	400	460
Measured distance	221.8	283.2	339.1	402.9	462.5
Error (%)	-0.82	-1.13	0.03	-0.73	-0.54

As shown in Tables 1 and 2, the measuring errors at various distances are very small. Take d_r =10 cm as an example. For a total pixel number of 2,000, the maximum horizontal distance that can be measured is (2000÷2)×10 cm =100 m. This means the proposed method can be used for measuring large areas without any problems. In what follows, we'll explain the principles and methods to measure an area. Next, we'll explain the effect of laser dispersion phenomenon, which can be easily dealt with or simply ignored without causing significant measuring errors based on solutions provided in this paper.

III. SOLUTIONS TO LASER DISPERSION PHENOMENON

When shooting at different distances, the laser beam dispersion phenomenon will cause the area of the projected points to be different. For a longer shooting distance, the area of the projected points will become larger because of the dispersion phenomenon, but the size of the projected spot in the image will become smaller. That means the image size of the projected points doesn't really vary in CCD images. We can eliminate the measurement error caused by the dispersion phenomenon by performing a positive differential edge processing when calculating the pixel number between the two projected points.

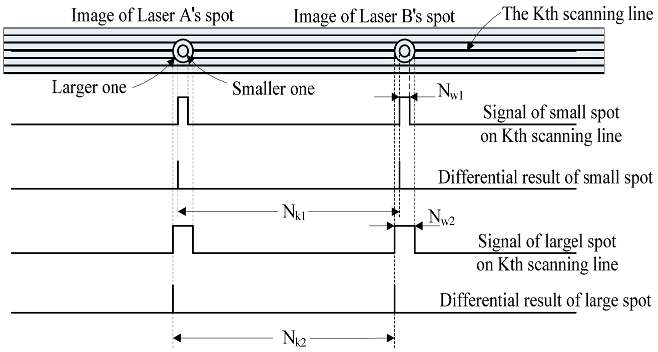

Fig. 2 Diagram illustrating the dispersion phenomenon

Fig. 2 shows the diagram illustrating the dispersion phenomenon, in which large and small circles respectively represent different images created by projected points with different sizes. Note that we've already secured the two laser projectors on the same base, and we've configured these projectors to project parallel laser beams. In this case, the images of these projected points in the CCD frame will appear on the same horizontal scanning line (the K_{th} scan line according to Fig. 2), disregarding the change of angles of going up or down by the two laser beams. Because the projected points are much brighter than the background, we can easily identify the location of the projected points based on the amplitude of the intensity of the red signal. By differentiating the intensity of the red signal, we can obtain the position of the left edge of images of the projected points. By using this solution, the pixel value $N_r(h_i)$ on the scanning line will be the same, no matter the size of the area formed by the projected points is. The results will remain the same even if we try to find out the value using the $(K+1)_{th}$ or $(K-1)_{th}$ scanning lines. From above discussions, we can see that the dispersion phenomenon does not affect the measurement results of this system.

IV. AREA MEASUREMENT VIA THE PROPOSED METHOD

Fig. 3 shows the proposed configuration for area measurement. On the board used to secure the laser projector, there are 10 holes ($H_1 \sim H_6$ and $V_1 \sim V_4$) so that we can install the laser projector on the board for projecting parallel laser beams. The angle of laser projection can be changed using a stepping motor reduction gear set. On the basis where the CCD camera is fixed at a location, the laser beams will produce two projected points onto different locations according to different angles used for each projection. Two different projected points are therefore produced in images each time when the change of projection angle occurs. By overlapping the projected points in the CCD image after every projection angle change, we have the results shown in Fig. 4. The CCD image doesn't change at all. What is illustrated in this figure is that different images of the projected spots due to different angles are produced and placed on the same CCD image.

Because we use stepping motor to change the laser beam projection in equiangular rotation, the parallel distance formed by the points is always the width of (d_r), since the two lasers beams are parallel. However, distances in the vertical direction are not identical as shown in Fig. 4. Connecting all the different projected points forming horizontal lines for intersecting with the exterior of the area to be measured, we obtain the horizontal distance $D_T(h_i)$ to be measured. After we define the exterior of the area to be measured with cursors, we can get the pixel value $N_T(h_i)$ of the horizontal distance $D_T(h_i)$ of all the horizontal connections of the images from testing the exterior intersecting points of the image to be measured. By (2), we can obtain the measured value of the horizontal distance $D_T(h_i)$. After all the horizontal distances have been determined, we are able to calculate the area to be measured as an entity formed by many rectangular slices. The total area of A_T can be obtained as:

$$\begin{aligned} \mathrm{A}_T &= \sum_{i=1}^{n} D_T(hi) \times H_T(hi) \\ &= \sum_{i=1}^{N} \frac{N_T(hi)}{Nr(hi)} \times dr \times H_T(hi) \end{aligned} \tag{3}$$

Examining the area in Fig. 4, we can see that a portion of the shadowed area marked in light black on both sides of the rectangles are the measurement error of that area. Because we have the values for $D_T(h_i)$, $D_T(h_i+1)$, and so on, for each horizontal distance, we can use the average value of the two neighboring upper and lower horizontal distance measuring values as the horizontal distance while measuring, which will reduce the error while measuring the area. Thus, we modify (3) and change it into (4) as

$$\begin{aligned} A_T &= \sum_{j=1}^{N} \frac{D_T(hj) + D_T(hj+1)}{2} \times H_T(hj) \\ &= \sum_{j=1}^{N} \frac{1}{2}\left(\frac{N_T(hj)}{Nr(hj)} + \frac{N_T(hj+1)}{Nr(hj+1)} \right) \times dr \times H_T(hj) \end{aligned} \tag{4}$$

Now, only the vertical distance $H_T(h_i)$ is not available. To find out the value of $H_T(h_i)$, we first derive the size of $H_T(h_i)$ based on the neighboring CCD image's vertical or horizontal pixels being equidistant. Another method is to use the parallel laser beams provided by (V_1 and V_2) or (V_3 and V_4) in Fig. 3 to determine $H_T(h_i)$.

V. DISTANCE TRANSFORMATION BY PARALLEL LINES

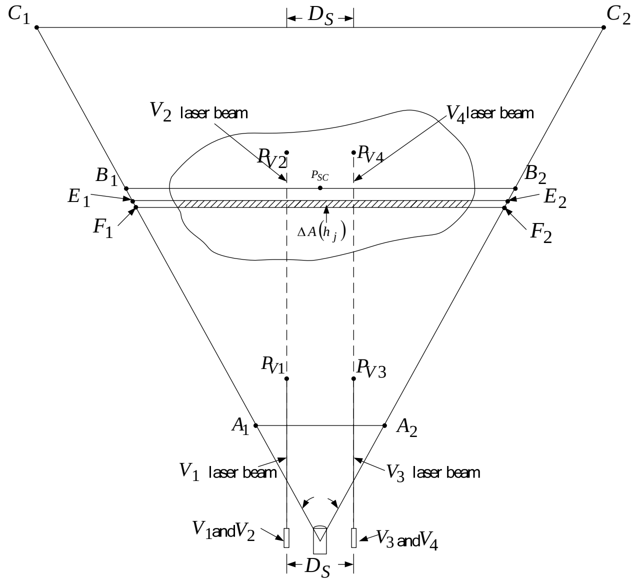

Fig. 5 Actual state of area measuring

When only the four vertical projection laser diodes V_1, V_2, V_3 and V_4 are working, we can only get four projected spots P_{V1}, P_{V2}, P_{V3} and P_{V4} on object plane. Connect P_{V1} and P_{V2} to get line $\overline{P_{V1}P_{V2}}$, connect P_{V3} and P_{V4} to get line $\overline{P_{V3}P_{V4}}$. Line $\overline{P_{V1}P_{V2}}$ and line $\overline{P_{V3}P_{V4}}$ will be in parallel, and the distance between these two lines D_S will never be changed, no matter what the angle between laser beams and the object is, as shown in Fig. 5.

Fig. 6, I_{V1}, I_{V2}, I_{V3} and I_{V4} are the images of the projected spots P_{V1}, P_{V2}, P_{V3} and P_{V4}. I_{SC} is the image of screen center point P_{SC}.

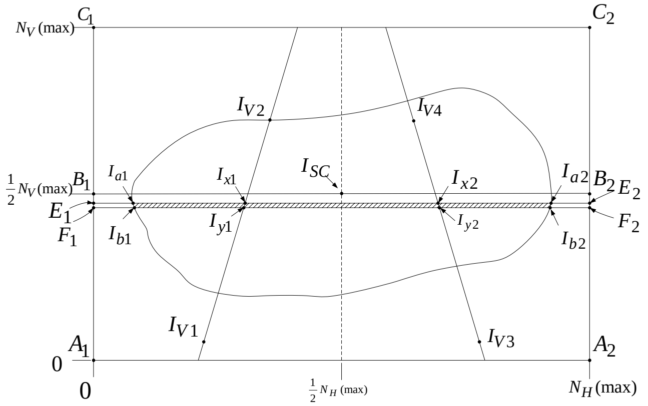

Fig. 6 The image which is shot by camera in Fig. 5

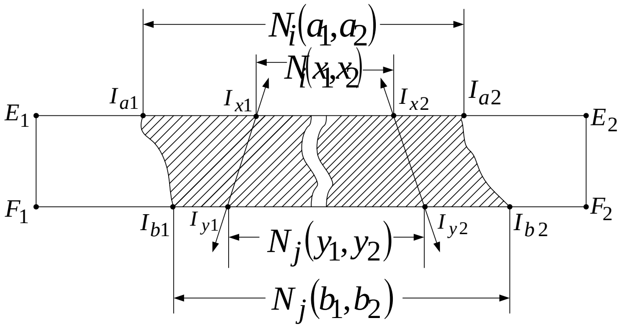

Fig. 7 Zoom in the shadow part in Fig. 6

The distance $D_i(a_1,a_2)$ corresponding to $N_i(a_1,a_2)$ is

$$D_i(a_1,a_2)=\frac{N_i(a_1,a_2)}{N_i(x_1,x_2)}\times D_S \tag{5}$$

The distance $D_j(b_1,b_2)$ corresponding to $N_j(b_1,b_2)$ is

$$D_j(b_1,b_2)=\frac{N_j(b_1,b_2)}{N_j(y_1,y_2)}\times D_S \tag{6}$$

when $N_i(x_1,x_2)=N_j(y_1,y_2)$, we can use the (4) to calculate the area, but when $N_i(x_1,x_2)\neq N_j(y_1,y_2)$, the height $H_T(h_j)$ should be modified to (7), then we can use (9) to calculate the area.

$$H_T(h_j)=\left|\frac{1}{2}\left[\frac{N_H(\max)}{N_i(x_1,x_2)}-\frac{N_H(\max)}{Nj(y_1,y_2)}\right]\times D_S\times\cot\theta_H\right| \tag{7}$$

$$\Delta A(h_j)=\frac{1}{2}\left(D_i(a_1,a_2+D_j(b_1,b_2)\right)\times H_T(h_j) \tag{8}$$

$$A_T=\sum_{j=1}^{N_V(\max)}\frac{1}{2}\left(D_i(a_1,a_2+D_j(b_1,b_2)\right)\times H_T(h_j) \tag{9}$$

$*i=j+1$

VI. EXPERIMENT AND MEASUREMENT RESULTS

Fig. 8 Photograph of area measurement the condition is as follows

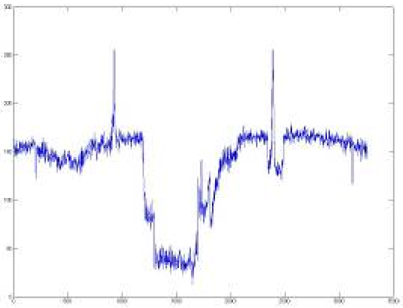

Fig. 9 The video signal of I_{V2} and I_{V4}

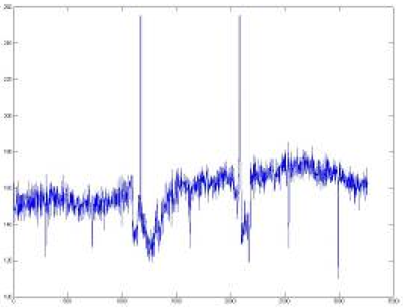

Fig. 10 The video signal of I_{V1} and I_{V3}

Fig. 11 Photograph of area measurement, the condition is as follows Shooting angle=45°

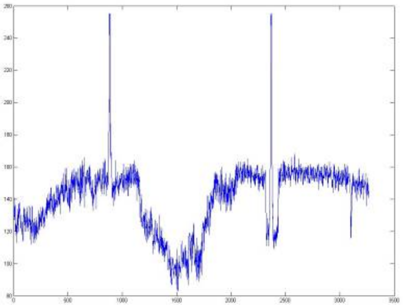

Fig. 12 The video signal of I_{V2} and I_{V4}

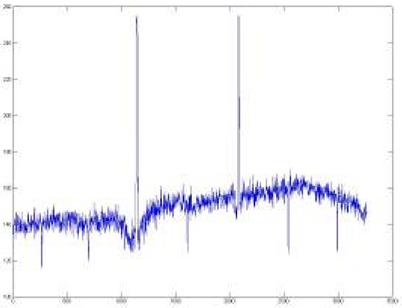

Fig. 13 The video signal of I_{V1} and I_{V3}

The angle between camera and object is unknown in general, the validity of the area measurement method in this paper for different shooting angle is verified by the analysis of all above, and the experiment results in Table 3 and 4.

VII. CONCLUSION

The Area measurement method discussed in this paper is an improvement based experiences accumulated from previous studies. With the use of this method, the measuring errors are very small because the CCD cameras adopted nowadays generally have a resolution of more than 6M pixels, which allow images formed with each horizontal scanning line of over 2000 pixels. Because of the use of the stepping motors to slow down the speed by moving the reduction gear set, we are able to make slices on the area to be measured with very short distance between slices. As a result, very high accuracy in the area measurement can be achieved via the proposed method.

To avoid the laser dispersion phenomenon, a positive differential edge processing is performed to eliminate the measurement error caused by this phenomenon. Because the laser beams are always parallel to each other, the distance of the projected points in the images always remains the same. Therefore, the results of the vertical, diagonal, and horizontal shots are almost completely equal.

From the experiment results demonstrated, the method revealed in this paper can be used to significantly improve the accuracy of outdoor area measuring while recording images at the same time.

REFERENCES

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

[2] 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.

[3] J. Ureña, M. Mazo, J. J. García, Á Hernández, and E. Bueno, "Correlation detector based on a FPGA for ultrasonic sensors," *Microprocess. Microsyst.,* vol. 23, pp.25-33 1999..

[4] B. Culshaw, G. Pierce, and P. Jun, "Non-contact measurement of the mechanical properties of materials using an all-optical technique," *IEEE Sensors J.,* vol. 3, no. 1, pp.62-70, Feb. 2003.

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

[6] 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.

[7] M.-C.Lu, W.-Y. Wang, and H.-H. Lan, "Image-based height measuring system for Liquid or particles in tanks," in *Proc. IEEE Int. Conf. Networking, Sensing and Control,* vol. 1, pp.24-29, 2004.M. Young, *The Techincal Writers Handbook.* Mill Valley, CA: University Science, 1989.

[8] M.-C.Lu, W.-Y.Wang, and C.-Y.Chu, "Optical-Based Distance Measuring system (ODMS)," *The Eighth International Conference on Automation Technology,* pp.282-283, 2005.

[9] T.-H. Wang, M.-C. Lu, C.-C. Hsu and W.-Y. Wang, "A Method of Distance Measurement by Digital Camera "*Proceeding of 2006 ACAS Automatic Control Conference* ,St. John's University, TAMSUI, Taiwan, Nov. 10-11, 2003.

[10] C.-C. Chen, M.-C. Lu, T.-H. Wang, W.-Y. Wang, Y.-Y. Lu, "Area Measurement System Using a Single Camera" *Proceeding of 2006 CACS Automatic Control Conference*, St. John's University, TAMSUI, Taiwan, Nov.10-11, 2006.

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

[12] C.-C. Chen, M.-C. Lu, W.-Y. Wang, C.-T. Chuang, "The Mere diverter and its application," *ROC patent of invention, No. M2279875, 2005.*

Table 3 The results derive from (9). Shooting angle=30°

Shooting distance (cm)	250	350	450	550	650	750
Measured distance (cm)	246.4	347.7	449.9	554.6	660.32	764.94
Error (%)	1.43	0.65	0.01	0.83	1.58	1.99
Area measuring (cm^2)	7026.9	7257.5	7011.5	7069.8	6990.9	7041.41

Error (%)	1.46	-1.77	1.67	0.85	1.96	1.25

Table 4 The results derive from (9). Shooting angle=45°

Shooting distance (cm)	250	350	450	550	650	750
Measured distance (cm)	255.3	352	451.6	551.3	654.5	761.6
Error (%)	2.13	0.58	0.36	0.23	0.69	1.55
Area measuring (cm^2)	7086.4	7128.8	7031.5	7034.7	7010.7	7134.2
Error (%)	0.62	0.03	1.39	1.35	1.68	-0.04