Improvements and Applications of the Image-Based Distance Measuring System

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Abstract: - The paper presents practical improvements on the Image-Based Distance Measuring System, achieving the capability of 3-dimensional measurement of distant objects. The configuration of the proposed measurement is very simple, consisting of only a single CCD camera and two laser projectors formed in parallel. Because of the disposition of the laser projectors and the CCD camera, two laser-projected spots will appear on the same scan line of CCD images. Based on an established relationship between pixel counts and photographing distance, 3-D measurement and area information of distant objects can be obtained by using only one scan line in the image frame.

Key-Words: - IBDMS (Image-Based Distance Measuring System), Distance Measurement, Area Measurement, CCD camera, laser projector.

1 Introduction

There are generally two types of non-contact methods in measuring distance: image-based and non-image-based approaches. Non-image-based techniques include ultrasonic reflection [1]-[3] and laser reflection [4]-[6] methods. Because these two methods use the theory of reflection, object reflectivity plays an import role. If the reflection surface is undesired, the measuring system generally performs poorly or not at all. On the other hand, image-based measuring systems based on pattern recognition or image analysis [7]-[9] techniques generally demand huge amount of storage capacity and high-speed microprocessors, which inevitably imposes a critical constraint for practical applications. To overcome the problems and difficulties encountered by the existing techniques, an image-based measuring system without complex calculation entitled IBDMS (Image-Based Distance Measuring System) is presented in this paper.

The configuration of the proposed IBDMS is very simple, consisting of only a single CCD camera and two laser projectors formed in parallel besides the camera. Because of the disposition of the laser projectors and optical origin of the CCD camera which form a straight line, two laser-projected spots will appear on the same scan line in a CCD image. As a result, processing of a single scan line, rather than the whole image, is only required to identify the projected spots in the CCD image. Complex computation of video signals of the whole image via either pattern recognition or image analysis methods is therefore circumvented. Based on a derived relationship between the distance and pixel counts between the projected spots on a CCD image, 3-D information in measuring distant objects can be obtained via the proposed system. Previous researches [15] in measuring distance and area, though worked to some extents, did not consider the intrinsic parameters of a particular camera. As a result, larger measurement errors are expected. To solve these problems, this paper shows how these intrinsic parameters of cameras can be determined. Furthermore, a new method in measuring area is presented under the proposed framework in this paper, relaxing the constraints of explicit knowledge of the boundaries of the area under measurement.

The paper is organized as follows. Section 2 reviews the IBDMS we proposed before. Section 3 describes the improvements over existing measuring systems and how 3-dimensional measurement can be performed. Determination of the optical origin of CCD cameras is illustrated in Section 4. Experiment results are demonstrated in Section 5. Conclusions are drawn in Section 6.

2 Review of the IBDMS methods

This section reviews two distance measuring techniques. The traditional triangular measuring method [11]-[13] is shown in the first part, followed by the parallel measuring method of the IBDMS [14], [15].

2.1 The Triangular measuring method

Figure 1 shows the triangular measuring method, in which D_{max} and H_{max} are the maximal horizontal distance and maximal photographing distance, respectively. By a triangular formula, we have the relationship:

$$\frac{D_K}{D_{max}} = \frac{H_K}{H_{max}} \quad (1)$$

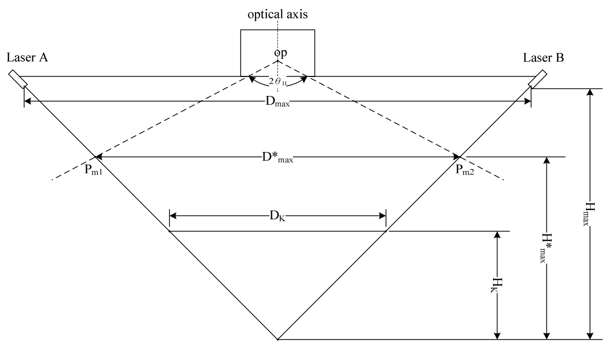

Fig. 1 Schematic diagram illustrating the triangular measuring method.

Because every CCD camera has a limited view angle $2\theta_H$ as shown in Fig. 1, the effective measuring range therefore lies between two dotted lines. Attempts in measuring objects lying in the invalid range between H^*_{max} and H_{max} will result in fatal errors, because the projected spots will not appear on the image captured by the camera. Therefore, both maximal photographing distance (H_{max}) and maximal horizontal distance (D_{max}) must be suitably adjusted as H^*_{max} and D^*_{max} to prevent from lying in the ineffective zone outside the dotted lines. As a result, (1) has to be modified as follows:

$$\frac{D_K}{D^*_{max}} = \frac{H_K}{H^*_{max}} \quad (2)$$

Although redefining measuring range solves the problems of invalid measuring range, it is still difficult to make these two laser beams projected onto an identical position, which is extremely inconvenient for practical applications. That is why the parallel measuring method is proposed to remove the constraints on the triangular measuring method.

2.2 The Parallel measuring method

The parallel measuring method presents a new architecture which is easier for deployment. Based on the triangular formula, the parallel measuring method has a relationship as follows:

$$H_K = \frac{H_D \times D_K}{D_{min}} - H_D \quad (3)$$

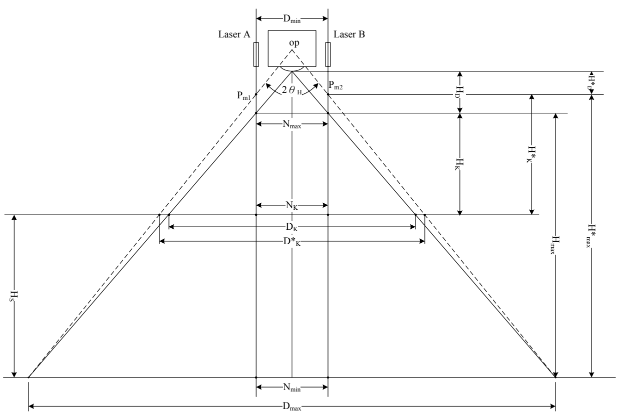

Fig. 2 Schematic diagram illustrating the parallel measuring method.

Previous researches have measuring inaccuracy caused by the invalid measuring area between H^*_{max} and H_{max} because the intrinsic parameters, view angle, and optical origin of the camera are not considered during the measurement. With the view angle of $2\theta_H$ in Fig. 2, the valid range for measurement is the area between two dotted lines as shown in Fig. 2. As a result, (3) can be modified as follows:

$$H^*_K = \frac{H^*_D \times D^*_K}{D_{min}} - H^*_D \quad (4)$$

Although the parallel measuring method has achieved a more satisfactory measuring performance in comparison to the triangular measuring method, there are still rooms for improvements by taking account of the optical origin of the camera and H^{*}_{D} so as to obtain more accurate measuring results. In this paper, we have improved the IBDMS for a lower error rate and easier implement by using any cameras.

3 Three-dimensional measurements via IBDMS

Fig. 3 shows the disposition of the two laser projectors, Laser A and Laser B, on both sides of the CCD camera, so that the optical axis of the camera is in parallel with the laser beams projected. No matter how the measuring system is rotated, the video signal of the projected spots, P_a and P_b, will appear on the $1/2N_v(\max)$ scan line, indicated as I_a and I_b in Figs. 4 and 5, respectively. Because of this disposition, relative positions between the projected spots and optical axis remain the same. That is, I_a and I_b always appear on the $1/2N_v(\max)$ scan line besides the image center, SC, irrelevant to the photographing distances.

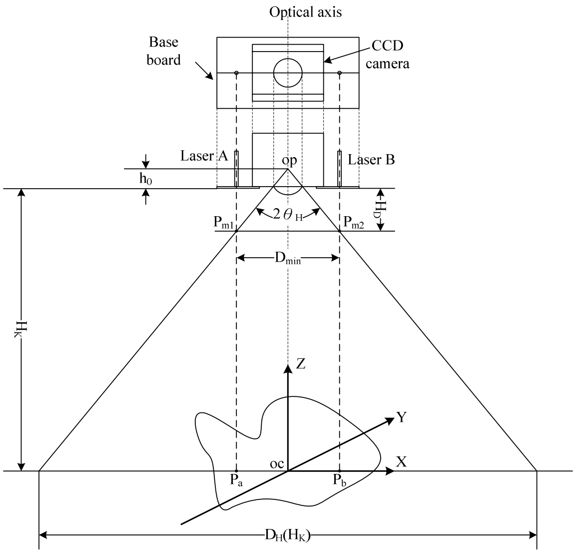

Fig. 3 Improvements on the parallel measuring method.

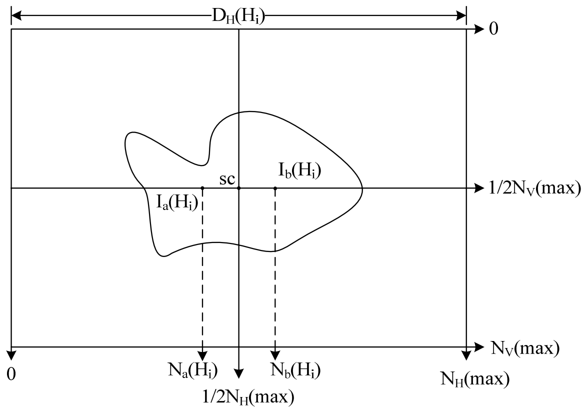

Fig. 4 Image at photographing distance H_i.

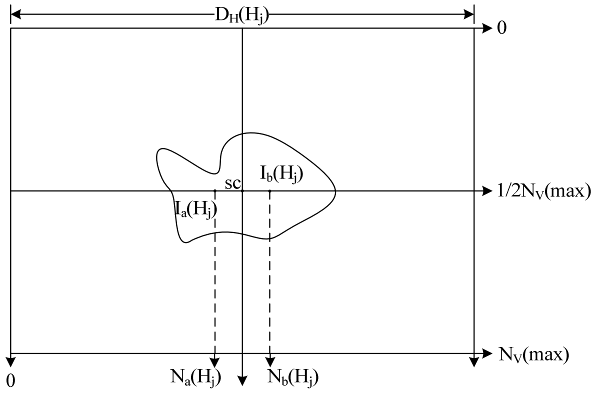

Fig. 5 Image at photographing distance H_j.

The $1/2N_v(\max)$ scan line can be regarded as the data source for measuring distance. A suitable threshold value can be easily determined based on brightness and color [13]-[15] for identifying the projected spots in the image. Detailed descriptions of the identification process can be referred to [13]-[15], and will not be re-iterated here. Note that pixels between spots $I_a(H_i)$ and $I_b(H_i)$ are $N_b(H_i)$-$N_a(H_i)$ at photographing distance H_i, and pixels between spots $I_a(H_j)$ and $I_b(H_j)$ are $N_b(H_j)$-$N_a(H_j)$ at distance H_j. As demonstrated in our previous work [13]-[15], there is a direct proportion relationship between the scanning time and horizontal distance. For distances H_i and H_j with view angle $2\theta_H$, the maximal horizontal distances $D_H(H_i)$ and $D_H(H_j)$ can be respectively expressed as:

$$D_H(H_i) = \frac{N_H(\max)}{N_b(H_i) - N_a(H_i)} \times D\min$$
$$D_H(H_j) = \frac{N_H(\max)}{N_b(H_j) - N_a(H_j)} \times D\min \qquad (5)$$

Also, the maximal horizontal distance can be found for any photographing distance. As long as $D_H(H_K)$ is found in Fig. 3, H_K can be obtained as follows:

$$H_K = \frac{1}{2} D_H(H_K) \times \cot\theta_H - h_0 \qquad (6)$$
$$= \frac{1}{2}\frac{N_H(\max)}{N_b(H_K) - N_a(H_K)} \times D\min \times \cot\theta_H - h_0$$

The parameters $\cot\theta_H$ and h_0 in (6) are intrinsic parameters depending on the camera used in the measuring system. How these parameters are determined for any brands of cameras will be shown in next section. After all parameters, θ_H and θ_V, are defined in Fig. 6, H_K can be obtained as follows:

$$H_K = \frac{1}{2} D_V(H_K) \times \cot\theta_v - h_0 \qquad (7)$$

The maxima vertical distance can be derived from (7) as long as H_K is determined via (6) as:

$$D_V(H_k) = 2(H_K + h_0) \times \cot\theta_V \qquad (8)$$

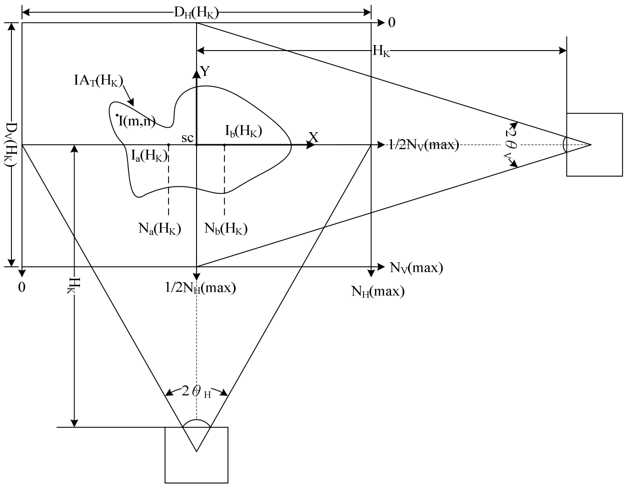

Fig. 6 Measurement of the maximal vertical distance $D_V(H_K)$.

From the preceding discussion, we have shown that horizontal distance (X direction), photographing distance (Z direction), and vertical distance (Y direction) can be determined via (5), (6), and (8), respectively, achieving 3-dimensional measurement for distant objects via the proposed approach.

4 Determination of the optical origin for CCD cameras

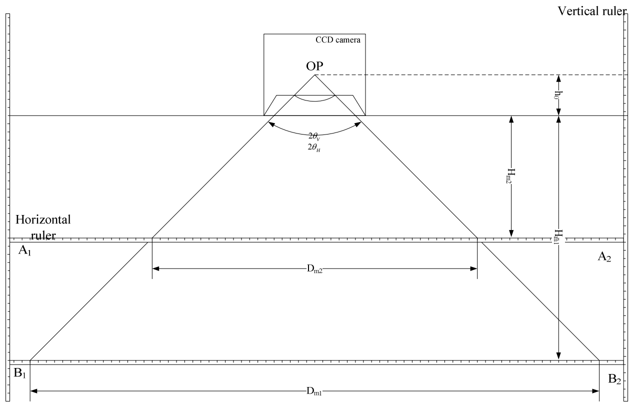

Fig. 7 Mechanism for obtaining an accurate h_0 for a CCD camera.

To construct a measuring system suitable for all kinds of CCD cameras, the distance h_0 between the optical origin (op) and the front end of the camera needs to be established. With reference to Fig. (7), when the horizontal ruler is positioned at (A_1 , A_2) and (B_1 , B_2), the distances between the front end of the CCD camera and (A_1 , A_2) and (B_1 , B_2) are H_{m2} and Hm_1, respectively. By a triangular relationship, we have:

$$h_0 = \frac{H_{m1} \times D_{m2} - H_{m2} \times D_{m1}}{D_{m1} - D_{m2}} \qquad (9)$$

$$\cot\theta_H = \frac{2(H_{m1} - H_{m2})}{D_{m1} - D_{m2}} \qquad (10)$$

When the camera is rotated 90°, $\cot\theta_V$ can be obtained with the above-mentioned procedures. With the calibration procedures in Fig. 7, we can obtain all information for $\cot\theta_H$, $\cot\theta_V$, and h_0.

5 Unconstrained area measuring

In the previous research [15] in measuring area, an area frame needed to be used for limiting the maximal area during the measurement. With the use of (5) and (8), maximal horizontal distance $D_H(H_K)$ and maximal vertical distance $D_V(H_K)$ can be calculated. Given the view angles $2\theta_H$ and $2\theta_V$ at the photographing distance H_K , the maximal area is:

$$A\max(H_K) = D_H(H_K) \times D_V(H_K) \qquad (11)$$

As a result, the area under measurement $A_T(H_K)$ can be calculated based on the pixel counts in the whole image. As shown in Fig. 6, $IA_T(H_K)$ is the area to be measured. I(m,n) stands for pixels in the image. To measure the area $IA_T(H_K)$, we need to calculate the total pixels $NA_T(H_K)$ residing in the area $IA_T(H_K)$:

$$NA_T(H_K) = \sum_{m=1}^{N_V(\max)} \sum_{n=1}^{N_H(\max)} I(m,n) \qquad (12)$$

, where $I(m,n)=1$ if $I(m,n) \in IA_T(H_K)$, otherwise $I(m,n)=0$. Therefore, the area to be measured can be obtained:

$$A_T(H_K) = \frac{D_H(H_K) \times D_V(H_K)}{N_V(\max) \times N_H(\max)} \times NA_T(H_K) \qquad (13)$$

Note that the area measurement method in the proposed approach has nothing to do with the maximal area allowed or photographing distance, and is therefore an unconstrained area measurement technique.

6 Experiment results

In this section, we present experimental results to demonstrate the effectiveness of the proposed IBDMS shown in Fig. 3.

6.1. Preparations for the experiments:

CCD camera adopted: PANASONIC Lumix DMC-FZ30.

Distance between Laser A and Laser B: (D_{min}) = 20 cm.

Camera resolution: $N_H(\max)$= 3264 pixels, $N_V(\max)$= 2448 pixels.

Intrinsic parameters: $\cot\theta_H$ = 2.11 , $\cot\theta_V$ = 2.81 , h_0 = 1.121 cm

6.2 Experiment results:

Table 1 Results of distance measurement

Photographing distance H_K	Measured distance H^*_K	Error %
500	502.22	0.44
450	450.69	0.15
400	401.04	0.26
350	349.79	-0.06
300	300.81	0.27
250	251.38	0.55
200	200.78	0.39
150	151.23	0.83

Table 2 Results of area measurement

Photographing distance H_K	Actual area $A_T(H_K)$ (cm^2)	Measured area $A^*_T(H_K)$ (cm^2)	Error %
500	9690	9723.34	0.34
450	9690	9678.443	-0.12
400	9690	9655.359	-0.36
350	9690	9587.733	-1.06
300	9690	9576.935	-1.17
250	9690	9529.522	-1.66
200	9690	9402.808	-2.96
150	9690	9224.321	-4.81

In comparison to the previous researches [13]-[15] , the proposed method has significantly improved the measuring accuracy as demonstrated in Tables 1 and 2 of this paper.

7 Conclusion

This research significantly improves the existing image-based measuring methods, including the triangular measuring and parallel measuring methods. To reduce measuring error, a calibration mechanism for identifying the intrinsic parameters of cameras has been proposed so that any kinds of cameras can be adopted in the proposed approach. As demonstrated in the paper, measuring accuracy via the proposed approach is significantly improved. As far as area measurement is concerned, the constraints of prior knowledge on the maximal area required in existing approaches have been removed. Because the merits of the proposed approach, shooting distance and area information of distant objects can be obtained for only one shot, which has achieved the objective of non-contact measurement without complex calculations.

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