Three dimensional distance measurement based on single digital camera

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Abstract: - This paper proposes a 3D space distance measuring method to accomplish non-contact 3D space distance measuring by using a digital camera or digital video camera. The measuring principle of the proposed method in this paper is to learn the present camera shooting distance and the horizontal or vertical distance between the given points according to the number of pixels of the image in horizontal motion corresponding to the moving digital video camera or digital camera. The measuring structure proposed in this paper does not employ image graphic recognition or image signal analysis method to accomplish distance measuring, therefore, high-speed micro-computer and Digital Signal Processor are not used. All the distance measuring data come from a single horizontal scanning line. Only by modifying the system software of the digital video cameras (digital cameras), all makes of digital video cameras or digital cameras can have the feature of measuring 3D space distance.

Key-Words: - 3D space, distance measuring, digital camera, non-contact measurement

1 Introduction

Distance measuring can be roughly divided into contact or non-contact types. Contact type measuring tools are mainly scaled rulers or tape measures. The common non-contact distance measuring principles are almost reflective, such as laser distance measuring [1]-[2] and ultrasonic distance measuring [3]-[4]. The measuring results of these two methods will be affected and even be nullified by the fact whether the reflecting plane is good or not. These two methods can only measure distance in a single direction and are not capable of measuring distance in 3D space. In addition, real image records of the spots measured cannot be obtained.

Our team proposed another image distance measuring method [5]-[9], which can measure distance in 3D space with additional 2 laser projectors requested. There will be a problem of having to install two laser beams precisely formed in parallel from the projectors and same distance from digital cameras (digital video cameras) required Therefore, this paper proposes a new image distance measuring method which making any person able to do distance measuring in 3D space by shift digital camera horizontally, the optical axis of the digital camera moves horizontally for equal distance. Hence, the image projected on the digital camera display moves the same distance accordingly. With respect to plane in parallel to the distance to be measured and the digital camera, we can designate a given pixel in the horizontal scanning line and measure its moving distance in the horizontal scanning line before and after the image horizontal motion. Namely, measuring the displacement of a given pixel in the same parallel line can work out the distance between any points on the plane to be measured, i.e. the depth in between the plane to be measured and the digital camera. The feature of the method proposed in this paper is that we can only use the image data of a single horizontal scanning line to work out the change of pixels number from the given point to the display center for measuring distance in 3D space.

It differs from distance measuring by image graphic recognition or image signal analysis [10]-[13]. The framework of this paper is: section 2 illustrates the principle of image horizontal motion distance measuring method; section 3 illustrates how to realize the feature of measuring distance in 3D space. Section 4 illustrates how to set up the structure of measuring parameters to find out parameters requested when measuring for makes of digital cameras), thus any make of digital video camera (digital camera) can have the feature of measuring distance. Section 4 lists the real measuring records to prove the correctness and practicability of the method proposed in this paper. The final section is the conclusion of this paper.

2 Principle of image horizontal motion distance measuring method

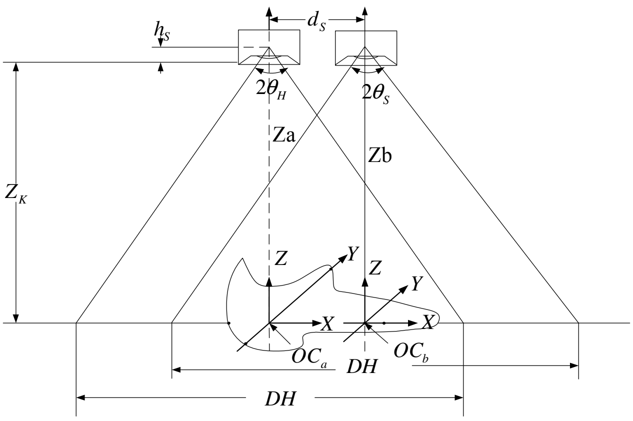

Fig.1 Image horizontal shifted distance measuring

Fig.1 represents the distance Z_K between the digital camera and any plane to be measured. O_P in the graphic is the location of the digital camera optical origin, which is at a distance of h_s with the front of the digital camera. $2\theta_H$ is defined as the digital camera horizontal field of view. h_s and $2\theta_H$ as two parameters used in this paper will be illustrated in detail in section 4. Before the digital camera moving horizontally, we captured an image, the Optical axis, projected in the CCD horizontal scanning line OC_a; after capturing the image, the distance of the digital camera moving horizontally d_s, the Optical axis, projected in the CCD horizontal scanning line OC_b. And these two points will be center points of the two graphics of digital camera CCD image as illustrated in Figs.2 and Figs.3.

The digital camera has a horizontal resolution of $NH_{\max}$ pixels and a vertical resolution of $NV_{\max}$ pixels. I_{1a} , I_{2a} And I_{2a} , I_{2a} are the image projection points of P_1 and P_2 in Fig.1 before and after horizontal motion. We took the horizontal scanning line (1/2 of the image vertical axis) as the horizontal reference benchmark axis. To increase measuring accuracy, we designated P_1 and P_2 as the given ends. Then, $NH(1a)-NH(1b)$ and $NH(2a)-NH(2b)$ will be the numbers of the pixels of projected P_1 and P_2 displacement after shifted. To increase measuring accuracy, we took averages to reduce errors. Then, number of pixels in

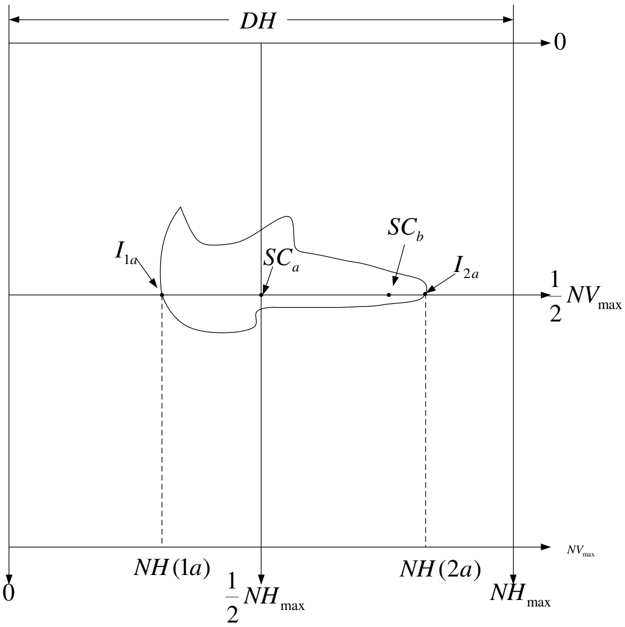

Fig.2 Corresponding OC_a image graphic brfore shifted

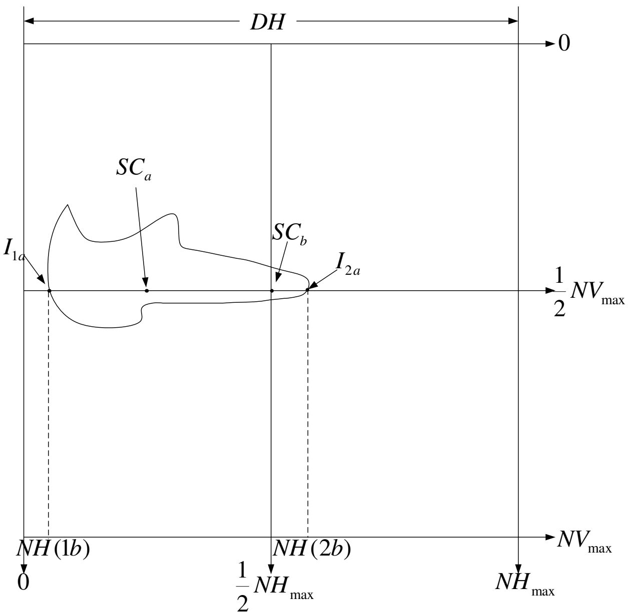

Fig.3 Corresponding OC_b image graphic after shifted

between SC_a and SC_b are represented as $N(SC_a, SC_b)$:

$$N(SC_a,SC_b)=\frac{1}{2}[NH(1a)-NH(1b)+NH(2a)-NH(2b)] \quad (1)$$

The corresponding points of SC_a and SC_b are OC_a and OC_b while the real distance between OC_a and OC_b is the distance (ds) between two parallel lines Z_a and Z_b (optical axis before and after displacement), which occupies a pixel as $N(SC_a, SC_b)$. Hence, the corresponding real distance

DH to the horizontal maximum display can be represented as:

$$DH = \frac{NH_{\max}}{N(SC_a, SC_b)} \times d_s \quad (2)$$

It have been proved by previous studies that horizontal scanning time is in proportion to horizontal distance, therefore Eq.(2) is correct. As to the digital camera, the number of pixels it occupies is in proportion to the horizontal distance.

3 Realization of distance measuring in 3D space

According to trigonometric principles, the relationship of measuring depth Z_K, the maximum horizontal distance DH, $\cot\theta_H$ and hs in Fig.1 as follows:

$$Z_K = \frac{1}{2} \times DH \times \cot\theta_H - hs \quad (3)$$

$$Z_K = \frac{1}{2} \frac{NH}{N(SC_a, SC_b)} \times ds \times \cot\theta_H - hs \quad (4)$$

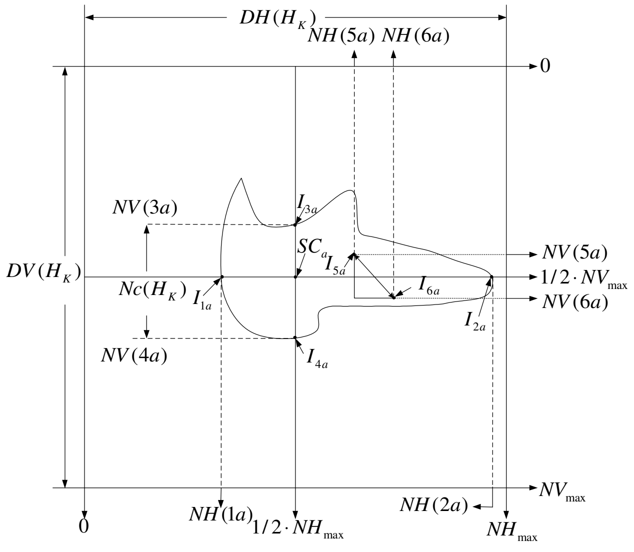

Fig.4 Any dirction distance measuring

If we know CCD horizontal maximum distance DH form calibration procedure, regardless of sloping status, the maximum vertical distance DV in parallel to CCD plane can be represented as :

$$DV = K_V \times DH \quad (5)$$

$$K_P = \frac{DV / NV_{\max}}{DH / NH_{\max}} = K_V \frac{NH_{\max}}{NV_{\max}} \quad (6)$$

K_v in Eq.(5) is the ratio constant of the image horizontal axis and vertical axis. K_P is of each pixel to the real world image horizontal/vertical image projection ratio, which can be obtained from the parameter setting process in section 4. From the aforementioned analysis, we can learn clearly that measuring of all distances originate from the horizontal scanning line of the $1/2 \cdot NV_{\max}$. Only by learning $N(SC_a, SC_b)$, can we measure the distance in X axis DH, the distance in Y axis DV and the distance in Z direction Z_K, therefore realizing distance measuring in 3D. Therefore, we can take SC_a or SC_b as the image of the display center to learn the distance between any two points. Fig.4 represents the image when SC_a is the image of the display center. The real world distance can be measured by corresponding pixels of various points as illustrated below:

$$\overline{P_1P_2} = (\frac{ds}{N(SC_a, SC_b)}) \times [NH(2a) - NH(1a)] \quad (7)$$

$$\overline{P_3P_4} = (\frac{ds}{N(SC_a, SC_b)}) \times K_P \times [NH(4a) - NH(3a)] \quad (8)$$

$$\overline{P_5P_6} = (\frac{ds}{N(SC_a, SC_b)}) \times K_2$$

$$K_2 = \sqrt{[K_P \cdot (NV(6a) - NV(5a))]^2 + [NH(6a) - NH(5a)]^2} \quad (9)$$

At different shooting distances Z_K, we can get different $N(SC_a, SC_b)$ to deduct the measuring values of real world distances.

4 Measuring parameters setup

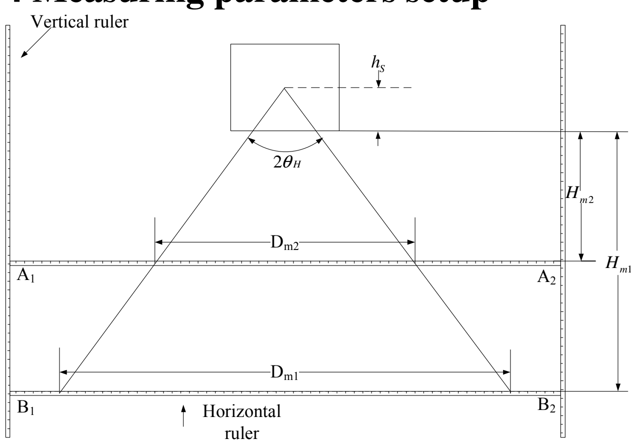

Fig.5 Structure to set up measuring parameters

$\cot\theta_H$, hs employed in Eq. (3), i.e. K_V are the measuring parameters used in this paper. We designed a structure as illustrated in Fig.5 for all makes of digital cameras (digital video cameras) to work out individual measuring parameters: $\cot\theta_H$ and hs. Therefore, any make of digital camera can accomplish distance measuring in 3D space by the method proposed in this paper.

When placing horizontal ruler at A_1 and A_2, we can learn its height is H_{m2} and the corresponding distance displayed is D_{m2}. Then, moving the horizontal ruler to B_1 and B_2, the height is H_{m1} and the corresponding horizontal distance is D_{m1}. We can learn from the analogical triangle principle that:

$$\frac{hs + Hm2}{Dm2} = \frac{hs + Hm1}{Dm1} \tag{10}$$

$$h_s = \frac{H_{m1}D_{m2} - H_{m2}D_{m1}}{D_{m1} - D_{m2}} \tag{11}$$

$$\cot\theta_H = \frac{2(H_{m1} - H_{m2})}{D_{m1} - D_{m2}} \tag{12}$$

As to vertical parameters K_V, K_P, we only to record CCD vertical axis real world distance V_{m1}, V_{m2} during the aforementioned different horizontal axis real world distance H_{m1}, H_{m2} to work out K_V, K_P parameters according to Eq. (5)(6) and known digital camera vertical and horizontal resolutions. The measuring parameters of any make of digital video camera (digital camera) can be obtained by the structure designed by us to overcome the differences. Hence, any make of digital video camera (digital camera) can measure the shooting distance according to the relationship in Eq. (3).

5 Experiment E RESULTS

5.1 Experiment plan

In this paper, we establish the measuring system by adopting a PANASONIC Lumix DMC-LX1 digital camera. Maximum horizontal and vertical pixel value

$NH(\max) = 3248$ pixels.

$NV(\max) = 2160$ pixels.

The parameters measured:

$\cot\theta_H = 1.782$

$hs = 0.5$ cm

K_P =0.991

Parallel displacement $ds = 30$ cm.

5.2Measuring records

From the above analysis, we may first improve the methods in previous studies[5]-[9]. Fig.6 is one of the 3D space distance measurement simulation. I n this experiment, the mean absolute Percentage error of the depth distance measuring errors are 0.93% show as table 1. The horizotal line $\overline{P_1P_2}$ mean absolute Percentage errors are 1.38%. The vertical line $\overline{P_3P_4}$ mean absolute Percentage errors are 1.32% and any direction line $\overline{P_5P_6}$ mean absolute Percentage errors are 1.19% show as table 2. The resluts have improved the performance of the prior research 8% errors.

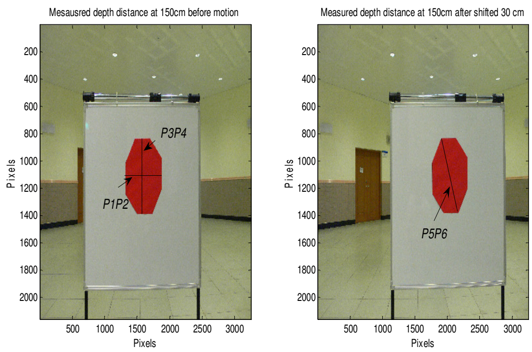

Fig. 6 Simulated 3D space distance measurement

Table 1
Measurement at various depth distances for horizontal distance

Actual distance	ZK*	Percentage error	$\overline{P_1P_2}$	Percentage error
100	100.90	0.9%	36.24	0.67%
150	149.24	-0.51%	36.05	0.14%
200	202.36	1.18%	36.93	2.58%
250	254.98	1.99%	37.41	3.92%
300	300.80	0.27%	37.14	3.17%
350	347.30	-0.77%	36.07	0.19%
400	401.93	0.48%	36.71	1.97%
450	462.44	2.76%	37.10	3.06%
500	493.24	-1.35%	35.86	-0.39%
550	551.53	0.28%	36.60	1.67%
600	592.11	-1.31%	36.081	0.23%
650	648.60	-0.22%	36.44	1.22%
700	694.54	-0.78%	35.95	-0.14%
750	753.94	0.53%	36.20	0.56%
800	794.76	-0.66%	36.27	0.75%
Mean Absolute Percentage Error	0.93%		1.38%	

Units: cm, $\overline{P_1P_2}$ =36cm

ZK*: measured depth distance,

Table 2
Measurement at various depth distances for vertical and any direction distance

Actual distance	$\overline{P_3P_4}$	Percentage error	$\overline{P_5P_6}$	Percentage error
100	35.77	-0.64%	39.65	-0.88%
150	36.81	2.25%	40.1	0.25%
200	36.94	2.61%	40.95	2.38%
250	37.33	3.69%	41.29	3.22%
300	36.60	1.67%	40.50	1.25%
350	35.74	-0.72%	39.75	-0.63%
400	36.51	1.42%	40.69	1.72%
450	37.08	3%	41.50	3.75%
500	35.87	-0.36%	39.73	-0.68%
550	36.27	0.75%	40.46	1.15%
600	35.95	-0.14%	39.78	-0.55%
650	36.11	0.31%	40.25	0.63%
700	35.62	-1.06%	40.06	0.15%
750	36.39	1.08%	40.07	0.18%
800	35.94	-0.17%	40.20	0.5%
Mean Absolute Percentage Error	1.32%		1.19%	

Units: cm, $\overline{P_3P_4}$ =36cm, $\overline{P_5P_6}$ =40cm

6 Conclusion

The image parallel motion 3D space distance measuring system proposed in this paper has creatively improved the distance measuring system. Moreover, the method uses only image data in one single scanning line to work out the change of number of pixels without employing image graphic recognition or image signal analysis methods[12-14]. Only by adding distance-measuring software to the digital video camera (digital camera) system software without need to increase any hardware, can the function of measuring distance in 3D space be achieved.

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