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Three Dimensional Measurement Based on Image Shift and Its Applications in Object Inspection

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Abstract: -A novel three-dimensional measurement method is proposed in this paper based on images shifted to a preset position. The proposed measuring system with a simple architecture can be easily established with very low installation costs as long as two images shifted by a certain window frame can be obtained. To show the effectiveness of the proposed approach, an object inspection system for use in a production line based on the measuring method is demonstrated in this paper, where a single CCD camera is used to capture images with the help of two position sensors to obtain non-contact 3-dimensional measurements for objects on a conveyer. Because a single scan line of images is only used for calculating the measurements including distance from the object and length and width of the object under inspection, the proposed measuring method has demonstrated itself as an efficient yet cost-effective method in achieving the objectives of sorting or screening defects of objects. Simulation results show that average measurement errors generally lie within a satisfactory range of 1.38%.

Key-Words: - Measurement, 3-D measurement, distance measuring, CCD camera, images, pixels, non-contact measurement, online detection, Inspection, Conveyer.

1 Introduction

Quality control is one of the most critical and resource-consuming tasks in the highly competitive automation industry. Visual inspection by human operators has problems of low inspection rate and poor accuracy. Because of the problems of costs and inconsistent inspection results, automatic optical inspection techniques are therefore widely used in the manufacturing industry over the past years to improve the inspection accuracy and efficiency. However, most of the existing optical inspection techniques were based on machine vision, where whole image processing and identification are required. As a result, high-performance digital processing systems with large storage capacity are inevitable to obtain desired inspection results. Inspired by the success of distance measurement via image-based methods, a low-cost non-contact inspection method using a CCD camera mounted above a conveyer is proposed in this paper to overcome these problems.

Traditional distance measuring methods can be roughly divided into contact or non-contact approaches. Contact type measuring tools are mainly scaled rulers or tape measures. Generally, non-contact distance measuring systems were based on reflection, such as laser distance measuring [1]-[2] and ultrasonic distance measuring [3]-[4]. Unfortunately, measuring results via these two methods will be affected and even nullified if the reflection plane is not desired. Also, these two methods can only measure distance in a single direction and are not capable of measuring distance in 3D space. In addition, physical images of objects cannot be obtained during the measurement.

Another image-based distance measuring method [5]-[9] proposed by the authors can measure distance in 3D space with the use of additional 2 laser projectors. However, there will be a problem of having to install two laser beams precisely formed in parallel from the projectors and same distance from CCD cameras (digital video cameras) required Therefore, this paper proposes a new image distance measuring method which allows distance measurement in 3D space by shift CCD camera horizontally in such a way that the optical axis of the CCD camera moves horizontally for equal distance.

The proposed approach has a distinguished feature in the use of only a horizontal scan line from within a CCD image. Based on information revealed in the single scan line of images taken at various distances, dimension of objects can be measured. The proposed approach differs from distance measuring by image graphic recognition or image signal analysis [10]-[13], requiring only very simple calculations. The framework of this paper is as follows. Section 2 illustrates the principle of the image shift measuring method. Section 3 illustrates the realization of distance measuring in 3D space. Section 4 illustrates the inspection method to automatically determine the size of objects on a conveyer. Section 5 illustrates how to set up the structure for measuring parameters of CCD cameras. Thus any make of digital CCD camera can be used for measuring distance via the proposed approach. Section 6 shows the experiment results to prove the correctness and practicability of the method proposed in this paper. The final section draws the conclusion of this paper.

2 Principle of the image shift measuring method

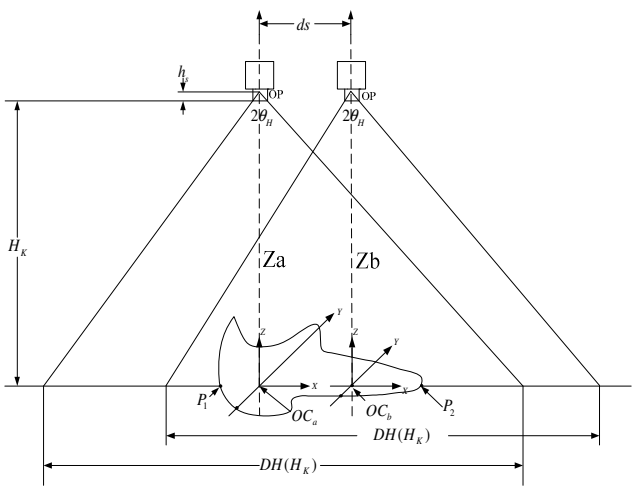

Fig. 1 Image horizontal shifted distance measuring.

Fig. 1 shows a distance H_K between the CCD camera and any plane to be measured. O_P in the figure is the location of the optical origin of the CCD camera, which has a distance of h_s from the front of the CCD camera. $2\theta_H$ is defined as the CCD camera horizontal field of view. h_s and $2\theta_H$ are two measuring parameters used in this paper, which will be introduced in details in section 5. Before the CCD camera moves horizontally, we capture an image, where OC_a is the point projected from the optical axis in the CCD horizontal scanning line. After capturing the image, the CCD camera horizontally moves a distance of d_s, where OC_b is the point projected from the optical axis in the CCD horizontal scanning line. These two points will be center points of the two CCD image as illustrated in Figs. 2 and 3.

The CCD camera has a horizontal resolution of NH_{MAX} pixels and a vertical resolution of NV_{MAX} pixels, respectively. I_{1a}, I_{2a} and I_{1b}, I_{2b} are the image projection points of P_1 and P_2 are the two dots in the boundary of the measured plane in Fig.1 before and after horizontal shifted. $NH(1a)-NH(1b)$ 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 take averages to reduce errors. Then, number of pixels in between SC_a and SC_b are represented as $N(SC_a, SC_b)$:

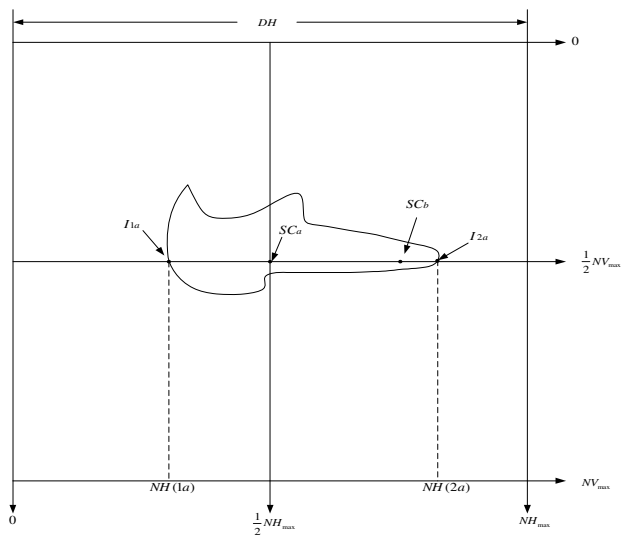

Fig. 2 Corresponding OC_a image graphic before shifted.

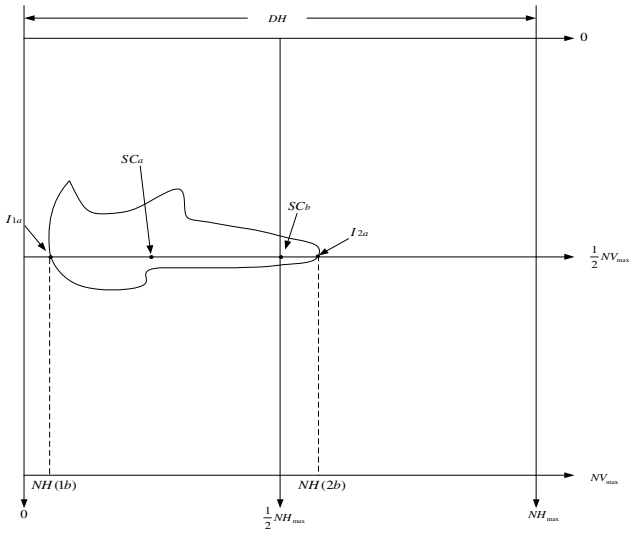

Fig. 3 Corresponding OC_b image graphic after shifted.

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

The corresponding points of SC_a and SC_b are OC_a and OC_b while the real distance ds between two parallel optical axis Z_a and Z_b before and after displacement. Hence, the corresponding real length DH to the CCD horizontal maximum display can be represented as:

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

It has been proved by previous studies that horizontal scanning time is in proportion to horizontal distance. As to the CCD camera, the number of pixels it occupies is in proportion to the horizontal distance.

3 Realization of distance measuring in three dimensional space

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

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

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

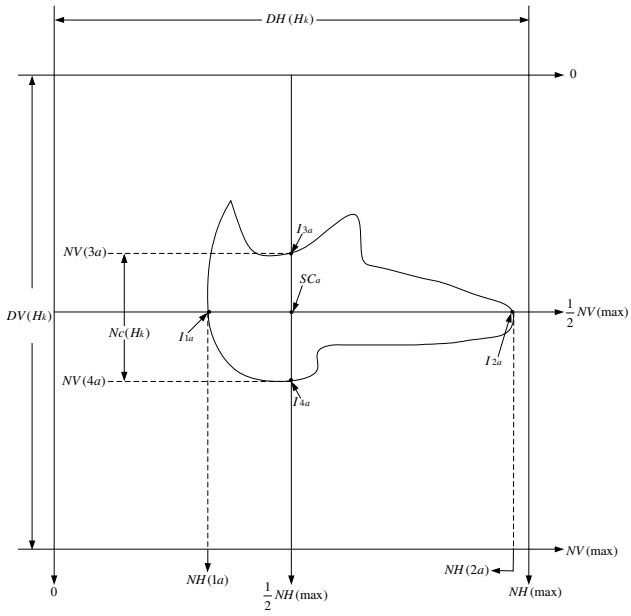

Fig. 4 Any direction distance measuring.

If we know CCD horizontal maximum length DH form calibration procedure, the maximum vertical length 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 5. From the aforementioned analysis, we can learn clearly that measuring of all distances originate from a horizontal scanning line. 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 H_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:

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

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

At different shooting distances H_K, we can get

different $N(SC_a, SC_b)$ to deduct the measuring values of real world distances.

The calculation of $N(SC_a, SC_b)$ is practically a problem of automatic search of corresponding points before and after image shift. Existing methods to solve this problem include area-based [15]-[16] and feature-based [17]-[18] approaches, which are inevitably involved large mathematical manipulations. In this paper, we only need to consider the centered horizontal scan line for these two images, where pixels of a specific window are used to calculate the Sum of Absolute Differences (SAD) for determining $N(SC_a, SC_b)$ and SAD is defined as:

$$SAD = \sum_{(u,v)\in w} \left| I_1(u,v) - I_2(u+x,v) \right| \tag{9}$$

Note that I_1 stands for the gray level of RGB values for a particular pixel on the horizontal scan line, I_2 stands for the gray level of RGB values for a particular pixel on the horizontal scan line after shifting x pixels, respectively. Window size can be suitably adjusted based on the size of the object under inspection or the purpose of the inspection. As far as automatic production line is concerned, we need to know the positions P_1, P_2, P_3, P_4 to calculate the length and width of the objects under inspection via Eq. (7) and (8). To solve this problem, the color of the conveyer can be designed in significant difference with the objects under inspection.

As a result, the boundary between the object under inspection and the conveyer can be easily differentiated via chrominance filters to identify the positions of P_1, P_2 及 P_3, P_4. Because significant difference lies in the boundary between the conveyer and the object under inspection, a certain window on the centered horizontal/vertical scan line of images can be selected. Pixels with particular colors are then processed via a difference operation to determine the position with maximal values, i.e., positions P_1, P_2, P_3, P_4 on the boundary of the object under inspection.

4. Automatic inspection of objects on conveyer

We now apply the proposed three-dimensional measurement to a practical application of object inspection for a production line, where two laser position sensors are installed besides the conveyer and a CCD camera is mounted above the conveyer as shown in Fig. 5

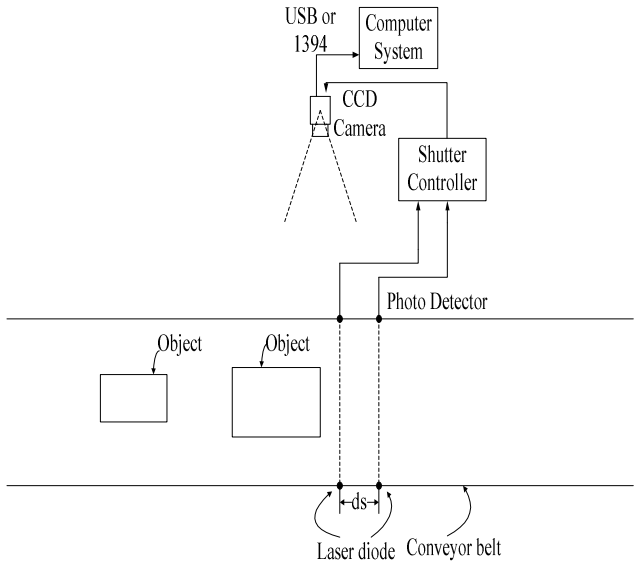

Fig. 5 Schematic diagram showing automatic size detection of objects on a conveyer.

With reference to Fig. 5, the CCD camera can be installed above the conveyer at a designated altitude. If objects under inspection are smaller, the CCD camera can be lowered in altitude; if objects under inspection are larger, the CCD camera can then be lifted higher in altitude. This is to allow a suitable size of the objects in images for further processing. To avoid the laser transmitters and detectors being affected by external noises and disturbance, shielding covering the laser devices can be adopted. As a result, the laser detectors receive signals only from the transmitters and optical axis can be accurately aligned.

When the object is moved by the conveyer and detected by the first photo detector, the shutter controller is enabled for taking the first image frame. As long as object is detected by the second photo detector, the shutter controller is enabled again for taking the second image frame. These two images reveal exactly the same implication as the CCD camera being shifted by ds. Thus, the distance between the object and the CCD camera can be obtained bia Eq. (4), and dimension of the object can be obtained via Eqs. (7) and (8). Based on the measurements obtained via the proposed approach, we can sort the objects or locate defect items with little effort.

5 Measuring parameters setup

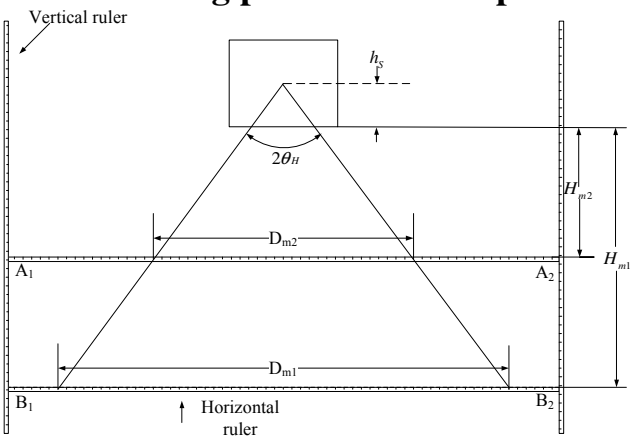

Fig.6 Structure to set up measuring parameters.

$\cot\theta_H$, 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.6 for all makes of CCD cameras (digital video cameras) to work out individual measuring parameters: $\cot\theta_H$ and hs. Therefore, any make of CCD 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:

$$\frac{h_s + H_{m2}}{D_{m2}} = \frac{h_s + H_{m1}}{D_{m1}} \tag{10}$$

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

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

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 CCD camera vertical and horizontal resolutions. The measuring parameters of any make of digital video camera (CCD camera) can be obtained by the structure designed by us to overcome the differences. Hence, any make of digital video camera (CCD camera) can measure the shooting distance according to the relationship in Eq. (3).

6 Experiment results

6.1 Experiment setup

In this paper, we will use a digital camera to simulate a high-resolution ccd video camera. Experimental details we have to establish the measuring system are as follows:

Digital camera: PANASONIC Lumix DMC-LX1, with maximum horizontal and vertical pixel value:

$NH(\max) = 3248$ pixels.

$NV(\max) = 2160$ pixels.

Intrinsic parameters of the digital camera:

$\cot\theta_H = 1.782$

$hs = 0.5$ cm

$K_P = 0.991$

Fig. 7 shows simulation results of on-line size inspection of objects in different sizes. The upper figure in Fig. 7 shows the image taken by the CCD camera when the objects are detected by the first photo detector, while the lower figure shows the image taken by the CCD camera when the second detector is activated by the object advancement by the conveyer.

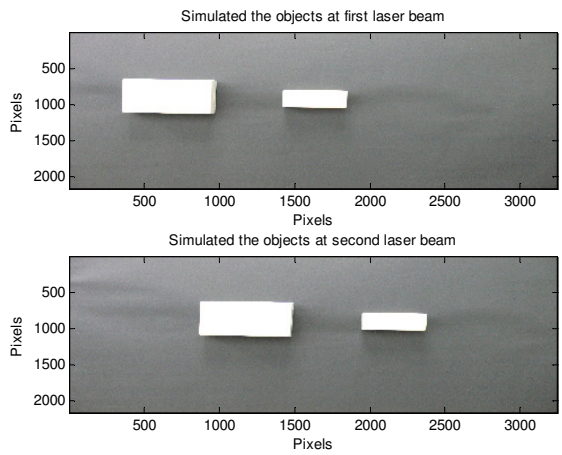

Fig. 7 Simulation results of on-line size inspection.

Thus, we do not have to process the whole image frame. Processing of the gray levels of RGB values for pixels from within a particular window on a horizontal or vertical scan line passing through the center of images is only required.

Fig. 8 shows the gray levels of the central horizontal scan line of the ccd images in Fig. 7, where a salient difference of background colors on the horizontal boundaries of the object and the conveyer can be easily observed. A simple difference method can be adopted to determine points P_1 and P_2. Similarly, we can determine points P_3 and P_4 based on the vertical boundaries of the object. As a result, dimension of the object under inspection can be obtained via Eqs. (7) and (8).

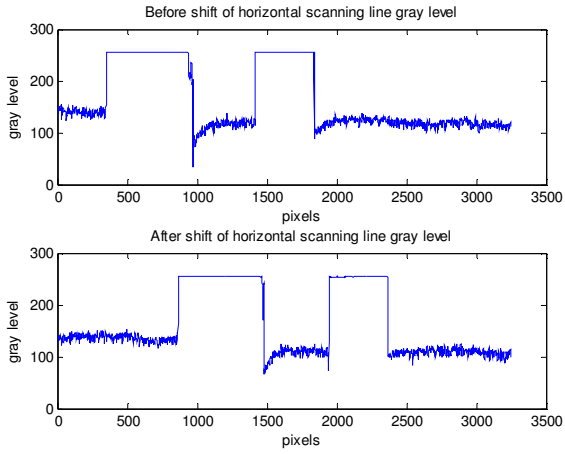

Fig. 8 Gray levels of the central horizontal scan line of the ccd images in Fig. 7.

As far as the corresponding points before and after image shift is concerned, we use a window of 1000 pixels for calculating the sum of absolute differences (SAD) so as to determine the shifted pixel number.

Fig. 9 shows the sum of absolute differences of 1000 pixels between the corresponding points on the horizontal scan line of images taken due to the enabling of the two photo detectors. The pixels number shifted between these two images based on minimal SAD can be easily identified. This suffices to demonstrate that the proposed approach is a simple, yet responsive non-contact method for determining the length of objects under inspection. Similar derivation via the proposed approach can be used to determine the width of objects, and will not re-illiterate here.

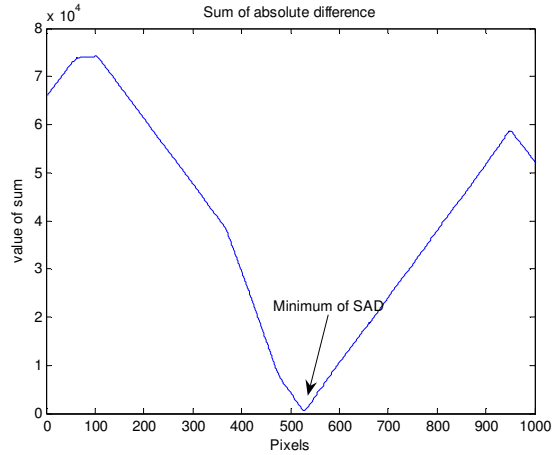

Fig. 9 Diagram depicting on-line inspection via image shift.

6.2 Measuring records

From the above analysis, we may first improve the performance revealed in previous studies [5]-[9]. Fig. 10 is simulation result of the 3D space distance measurement. In this experiment where horizontal displacement $ds = 30$ cm, the mean absolute percentage error of the depth distance measuring errors is 0.93% as shown in Table 1. The horizontal line $\overline{P_1P_2}$ mean absolute percentage error is 1.38%. The vertical line $\overline{P_3P_4}$ mean absolute percentage error is 1.32%. The results have improved the performance of the prior research with an error of 8%.

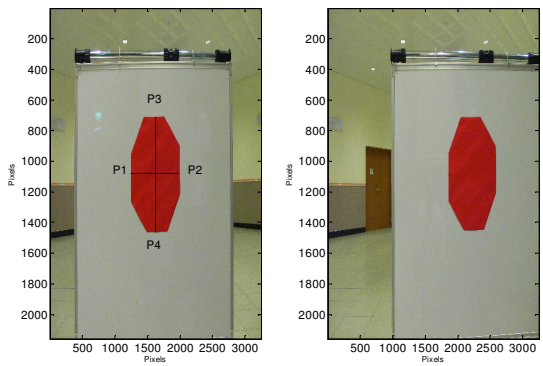

Fig. 10 Simulated 3D space distance measurement.

Based on the proposed approach, the objective of automatic object inspection for practical applications in production lines can be achieved. Simple yet responsive inspection of objects can be obtained for use wither in automatic sorting or size matching based on the dimension measured via the proposed approach.

Table 1
Measurement at various depth distances for horizontal distance

Actual distance	H_K^*	Percentage error
100	100.90	0.9%
150	149.24	-0.51%
200	202.36	1.18%
250	254.98	1.99%
300	300.80	0.27%
350	347.30	-0.77%
400	401.93	0.48%
450	462.44	2.76%
500	493.24	-1.35%
550	551.53	0.28%
600	592.11	-1.31%
650	648.60	-0.22%
700	694.54	-0.78%
750	753.94	0.53%
800	794.76	-0.66%
Mean Absolute Percentage Error	0.93%	

Units: cm

H_K^* : measured depth distance

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

Actual distance	$\overline{P_1P_2}$	Percentage error	$\overline{P_3P_4}$	Percentage error
100	36.24	0.67%	35.77	-0.64%
150	36.05	0.14%	36.81	2.25%
200	36.93	2.58%	36.94	2.61%
250	37.41	3.92%	37.33	3.69%
300	37.14	3.17%	36.60	1.67%
350	36.07	0.19%	35.74	-0.72%
400	36.71	1.97%	36.51	1.42%
450	37.10	3.06%	37.08	3%
500	35.86	-0.39%	35.87	-0.36%
550	36.60	1.67%	36.27	0.75%
600	36.081	0.23%	35.95	-0.14%
650	36.44	1.22%	36.11	0.31%
700	35.95	-0.14%	35.62	-1.06%
750	36.20	0.56%	36.39	1.08%
800	36.27	0.75%	35.94	-0.17%
Mean Absolute Percentage Error	1.38%		1.32%	

Units: cm

$\overline{P_1P_2}$ =36cm

$\overline{P_3P_4}$ =36cm

Experiment results have demonstrated that the proposed approach is reliable, efficient, and responsive for obtaining satisfactory results with very low costs, satisfying the needs for a quality inspection and sorting of objects. Note that the method is applicable only to measure objects with a plane perpendicular to the optical axis of the CCD camera. For oblique plane, the proposed method is not applicable. Fortunately, this situation is un-unusual in a practical production line. Furthermore, the proposed approach can be easily extended to measure area based a well known binarization techniques.

7 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 (CCD camera) system software without need to increase any hardware, can the function of measuring distance in 3D space be achieved.

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