Optical Measurement of Short hollow cylinder in Three-Dimensions

Chin-Tun Chuang, Cheng-Chuan Chen, Ming-Chi Lu, Shyang-Lih Chang, and Chih-Hung Chuang

***Abstract*—**The measuring parts of short hollow cylinder are inner diameter, height and thickness. And the general equipment being used are all kinds of Vernier Calipers which all belong to the contact measuring. In this paper, Image-Based Distance Measuring System (IBDMS) is proposed for measuring the dimensions of short hollow cylinders with only one exposure. Because of a rise-down platform for camera positioning control device developed in this paper, the aforementioned measuring method can reduce expenses and processing time. As a result, maximal image contour of an unknown short hollow cylinder picture can be obtained so as to achieve measuring results with highest resolution at each time. The measurement system not only increases the accuracy of the measuring results but also makes contributions for technicians or technical staffs to get accurate measuring results on unknown short hollow cylinders.

***KeyWords*—**circular plate of light transparent, gray scales concentric circle, short hollow cylinder.

I. Introduction

MOST technicians or technical staffs usually use Vernier Calipers [1]-[2] for short hollow cylinder's dimension measuring. However, it takes three times physical contact measuring to get the inner diameter, height and thickness. Still, there is some short hollow cylinder's dimension measuring instruments still in use. Papers published of related researches mostly brought up the result that only measure a single function.

It does not get the inner diameter, thickness and height of an unknown short hollow cylinder in one measuring. Even if there are many image type of quantity measuring system for an unknown short hollow cylinder's dimension[3]-[4], they are almost 2D plane measuring and complete the test on inner diameter under the fixed measurement system (CCD camera).

Other non-contact measuring gauges such as ultrasonic waves and laser beams can be used for this measurement purpose. However, they are claimed not being very user friendly [5]-[6]. Although ultrasonic waves and laser beams measuring gauges measured the distance between the sample and the measuring table, it needs twice measuring for the height of short hollow cylinder. And it is difficult to use accurate laser beams measuring gauge for inner diameter and thickness measuring of short hollow cylinder. There using PSD(Position Sensing Device) or LVDT(Linear Voltage Differential Transformer) for measuring accurate distance [7]-[8]. Its contact-type function for distance measuring can also apply to measure the short hollow cylinder's dimension. But these measuring systems made up PSD or LVDT have to do the measuring step for three times same as Vernier Calipers.

As mentioned earlier, the goal of this research is to design a measuring method that allows us to do the measurement of the short hollow cylinder's dimension without any physical contact at one shot. We use the diameter of the circular plate of light transparent on the measuring table act as standard rule. In the capture digital image will get three different diameters of gray scales concentric circle image contour region cause of an unknown short hollow cylinder on measuring table. Calculated the total pixels of each round image contour region and get three different diameters. Following the simple formula derivatives the inner diameter, thickness and height, respectively. When adjusted the distance between CCD camera place position and top of an unknown short hollow cylinder on the period of measuring. It will get high resolution of measuring cause of the suitable image contour region of an unknown short hollow cylinder.

The second section will explain the theory of distance measurement and platform can be done in one shot. We continue to elaborate on the parameter of measuring formula in the third section. In the fourth section, we will prove theory illustration of short hollow cylinder's dimensions measuring. Section five will justify calculation process with an experiment and followed is the conclusion.

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II. THEORY OF MEASUREMENT BETWEENMEASURING TABLE AND DISTANCE OF TWO LEVELS

The schematic diagram of measuring table is shown as Fig. 1. It is installed the high intensity LED lights below the ground glass. It would show conspicuous gray scales in the image contour picture because of the mean value brightness from the high intensity LED lights.

In figure 1, h_0 is the height of the optic position, D_S is the diameter of the circular plate of light transparent and $2\theta_H$ denotes the width viewed from horizontal angle of CCD camera. The distance of capture level H_K can be changed by adjusting the knob.

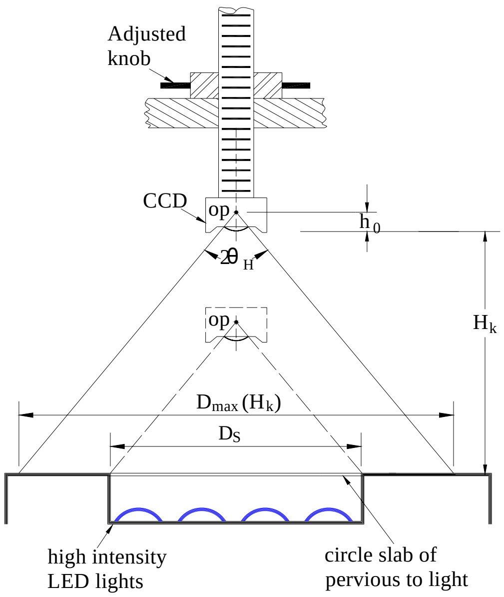

Fig.1 Schematic diagram of measuring table

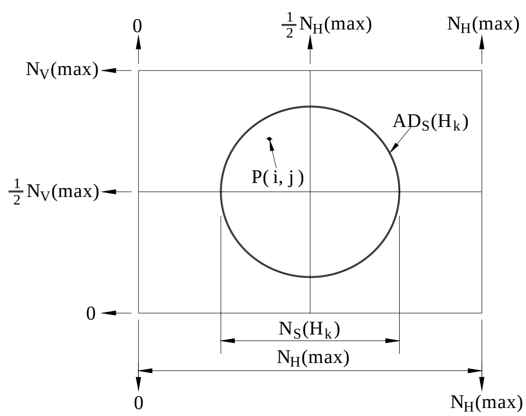

Fig.2 Schematic image diagram of measuring table from the top

Figure 2 shows the image contour region of measuring table from the top. When $P(i,j) \in AD_S$ then $P(i,j)=1$, otherwise $P(i,j)=0$. We shall express it as

$$NAD_S\left(H_k\right)=\sum_{i=1}^{N_V(\max)}\sum_{j=1}^{N_H(\max)} p(i,j) \tag{1}$$

AD_S denotes the area of the round image contour region of the circular plate of light transparent. The total pixels, $NAD_S(H_K)$, would count the pixels based on $AD_S(H_K)$. Then

$$N_S(H_k)=2\times\sqrt{\frac{NAD_S(H_k)}{\pi}} \tag{2}$$

When we calculated the diameter of circular image contour from formula (2), known from the previous research[9]-[13], the distance of horizontal is a positive proportion to the value of pixels on the $\frac{1}{2}N_V(\max)$ horizontal scanning line. Then under the captured level, H_K, and the horizontal view from the angle $2\theta_H$ of CCD camera gives

$$D_{\max}(H_k)=\frac{N_H(\max)}{N_S(H_k)}\times D_S \tag{3}$$

$$\begin{aligned} H_k &= \frac{1}{2}D_{\max}(H_k)\times\cot\theta_H - h_0 \\ &= \frac{1}{2}\frac{N_H\left(\max\right)}{N_S\left(H_k\right)}\times D_S\times\cot\theta_H - h_0 \end{aligned} \tag{4}$$

From formulae (3) and (4), it proved that we can measure the horizontal and vertical distances [12]-[13] at any height and width of the sensor by only one CCD camera on IBDMS (Image-Based Distance Measuring System). The measurement parameters of this measuring table system $\cot\theta_H$ and h_0 in formula (4) would be derived in the following section.

III. MEASUREMENT PARAMETERS $\cot\theta_H$ AND h_0

The position of CCD camera can be placed at the height H_{m1} and H_{m2}, we will be able to get $N_S(H_{m1})$ and $N_S(H_{m2})$ by H_{m1} and H_{m2}, respectively. We can rewrite the formula (4) as

$$H_{m1}=\frac{1}{2}\frac{N_H\left(\max\right)}{N_S\left(H_{m1}\right)}\times D_S\times\cot\theta_H - h_0 \tag{5}$$

$$H_{m2}=\frac{1}{2}\frac{N_H\left(\max\right)}{N_S\left(H_{m2}\right)}\times D_S\times\cot\theta_H - h_0 \tag{6}$$

After finding the magnitudes $\cot\theta_H$ and h_0 from formulae (5) and (6),

$$\begin{aligned} \cot\theta_H &= \frac{H_{m1}-H_{m2}}{\frac{1}{2}\left[\frac{N_H\left(\max\right)}{N_S\left(H_{m1}\right)}-\frac{N_H\left(\max\right)}{N_S\left(H_{m2}\right)}\right]\times D_S} \\ &= \frac{2\left(H_{m1}-H_{m2}\right)}{N_H\left(\max\right)\times D_S}\times\frac{N_S\left(H_{m2}\right)-N_S\left(H_{m1}\right)}{N_S\left(H_{m1}\right)\times N_S\left(H_{m2}\right)} \end{aligned} \tag{7}$$

$$h_0=\frac{H_{m1}\times N_S\left(H_{m1}\right)-H_{m2}\times N_S\left(H_{m2}\right)}{N_S\left(H_{m2}\right)-N_S\left(H_{m1}\right)} \tag{8}$$

IV. MEASUREMENT OF SHORT HOLLOW CYLINDER'S DIMENSION

In figure 4, W_D, W_T and W_H denote the inner diameter, the thickness, and the height respectively. H_{K1} is the height from the measuring table of the CCD camera. H_{K2} is the distance between the top of the short hollow cylinder and the position of CCD camera. Knowing the distance of H_{K1} and H_{K2}, the height of short hollow cylinder W_H may be written in the form $W_H = H_{K1} - H_{K2}$

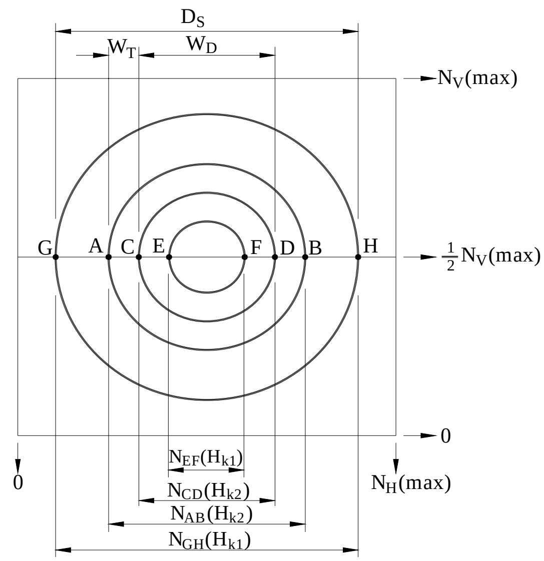

Fig.4 Operation of short hollow cylinder's dimension measuring

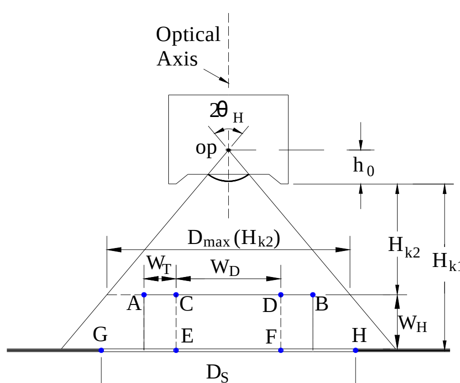

Fig.5 Illustration of short hollow cylinder's dimensions measuring theory

In Fig. 5, $\overline{GH}$ represents the diameter of the round image contour region formed by the circular plate of light transparent, with the captured distance, H_{K1}. $\overline{EF}$ is the diameter of the round image contour region formed by the bottom of short hollow cylinder. $\overline{AB}$ is the diameter of round image contour region formed by the outer diameter of short hollow cylinder, with captured distance, H_{K2}. $\overline{CD}$ is the diameter of round image contour region formed by the inner diameter of short hollow cylinder. We then count the pixels in each round image contour region and calculate the diameter of each circle from formula (2). From the previous research[13], the short hollow cylinder will form two round image contour region in different size because of its height. Then the inner diameter W_D will be equal to $\overline{EF}$, which is the diameter of the round image contour region shown in Fig. 5.

$$W_D = \frac{N_{EF}(H_{k1})}{N_{GH}(H_{k1})} \times D_S \tag{9}$$

If the diameter on the top and the bottom of short hollow cylinder is the same, then the maximal horizontal distance, $D_{\max}(H_{K2})$, pictured at the distance H_{K2} can be shown as:

$$D_{\max}(H_{k2}) = \frac{N_H(\max)}{N_{CD}(H_{k2})} \times W_D \tag{10}$$

Once we get the value of H_{K2} from formula (4), the height, W_H, of an unknown short hollow cylinder can be shown as:

$$W_H = \frac{1}{2}\left[\frac{N_H(\max)}{N_{GH}(H_{k1})} \times D_S - \frac{N_H(\max)}{N_{CD}(H_{k2})} \times W_D\right] \times \cot\theta_H \tag{11}$$

Subtracting the inner diameter from the external diameter, we obtain the thickness, W_T, shown as

$$W_T = \frac{N_{AB}(H_{k2})}{N_{CD}(H_{k2})} \times W_D - W_D$$
$$= \left[\frac{N_{AB}(H_{k2})}{N_{CD}(H_{k2})} - 1\right] \times \frac{N_{EF}(H_{k1})}{N_{GH}(H_{k1})} \times D_S \tag{12}$$

So, as long as we counted the total pixels of each round image contour region from formulas (1) and (2), and calculated the diameter of each round image contour region, we can know the value of inner diameter from formula (9), the value of height from formula (11), the value of thickness from formula (12). Thus, we realize the measurement of the inner diameter, the height and the thickness of an unknown short hollow cylinder's dimension without any physical contact by only one round image contour regions.

V. VERTICAL ADJUSTMENT OF MEASUREMENT SYSTEM

Because of a rise-down platform for camera positioning control device developed in this paper, maximal image contour of an unknown short hollow cylinder picture can be obtained so as to achieve measuring results with the highest resolution at each time. However, it may have an imperceptible slant of digital camera caused by changing the shooting distance. Thus, it gives a dubitable error of measuring data from the image captured non-vertically. We then provide the solution to the aforementioned problem in this paper. There are normal circle and standard square shown as Fig.6. Normal circle is for measuring the inner diameter, height and thickness of short hollow cylinder. Standard square is for vertical adjusting to the measurement system.

When an imperceptible slant of digital camera caused by changing the shooting distance and the image isn't captured from vertical shooting, it will have bigger error of measuring data from an image captured non-vertically. It can be assumed to be a symmetry situation when center the object lens of camera and consider the nun-linear lose of the camera. When the image is vertically captured, $ND_{H1} = ND_{H2}$, $ND_{V1} = ND_{V2}$. In the case that both front and rear are slanted, $ND_{H1} \neq ND_{H2}$. In the case that the left and the right sides are slanted, $ND_{V1} \neq ND_{V2}$.

In this paper, we take 0.2% of maximum horizontal pixels of the image $N_H(\max)$ and maximum vertical pixels of the image $N_V(\max)$ for vertical adjustment of measurement system.

$$ND_{H1} - ND_{H2} \leq \frac{2}{1000} N_H(\max) \tag{13}$$

$$ND_{V1} - ND_{V2} \leq \frac{2}{1000} N_V(\max) \tag{14}$$

Details of the results measured before vertical adjustment shown as in Table 1, Table 2 and Table 3. Details of the results measured after vertical adjustment shown as in Table 4, Table 5 and Table 6. Compared with the results of before and after vertical adjustment, the simple measuring method proposed in this paper does make the error of measurement much fewer.

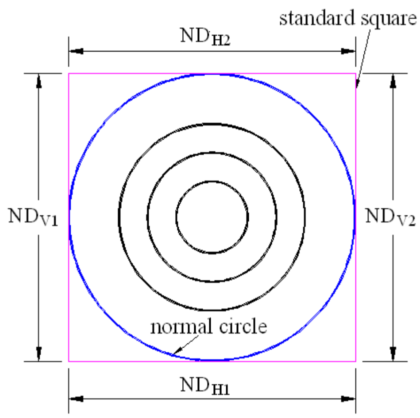

Fig.6 Schematic image diagram of normal circle and standard square

VI. Experiment and Measurement

(1) The digital camera used is PANASONIC Electric Industrial Co., Ltd. Lumix DMC-FZ30 Type.

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

(3) The diameter of the circular plate of light transparent is 60 mm.

(4) Measurement parameters suggested by measurement frame h_0 = 11.21 mm, $\cot\theta_H$ = 2.11 .

Proved from the table1 to table 6, the method brought up in this paper is practical. And the aim of this paper is to develop a rise-down platform of camera positioning control device. In the future, though, the improvement in the accuracy of measurement depends on a more perfect distinction in gray, it will reduce expenses and processing time during the measurement.

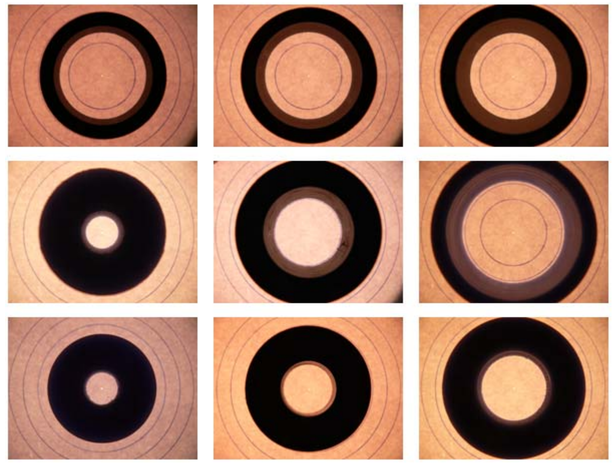

Fig. 7 Images of short hollow cylinder

VII. Conclusion

As demonstrated in this paper, the proposed approach is capable of measuring dimension of short hollow cylinder without physical contact based on 2D round image contour region from a single CCD camera. Measurement of inner diameter, height, and thickness of the short hollow cylinder can be obtained via the proposed approach using only a single CCD camera for 3D gauged dimension of 2D round image contour region. In the future, we will improve the measurement accuracy and design a reliable rise-down platform for projecting beams of light. The methodology proposed in this article has revealed the potential to allow height and perimeter measuring for irregular objects. It is hoped that the measuring system proposed in this paper will make contributions for the mechanical fabrication industry.

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Table 1 Gauged height with same inner diameter and thickness before vertical adjustment

Size of Sample / Result	W_D= 27 W_T= 4 W_H= 8		W_D= 27 W_T= 4 W_H= 12		W_D= 27 W_T= 4 W_H= 16	
$N_{GH}(H_{K1})$	3170.00		3170.00		3170.00	
		Error		Error		Error
W_D^*	28.326	4.911%	28.328	4.919%	28.341	4.967%
W_T^*	3.953	-1.175%	3.952	-1.200%	4.062	1.550%
W_H^*	7.915	-1.063%	11.864	-1.133%	16.271	1.694%

$N_{GH}(H_{K1})$: Horizontal pixels of the circular plate of light transparent.

Table 2 Gauged thickness with same height before vertical adjustment

Size of Sample / Result	W_D= 10 W_T= 10 W_H= 16		W_D= 21 W_T= 7 W_H=16		W_D= 32 W_T= 4 W_H= 16	
$N_{GH}(H_{K1})$	3170.00		3170.00		3170.00	
		Error		Error		Error
W_D^*	10.498	4.980%	22.046	4.981%	33.057	3.303%
W_T^*	10.119	1.190%	6.928	-1.029%	3.952	-1.200%
W_H^*	16.185	1.156%	16.172	1.075%	16.188	1.175%

Table 3 Gauged inner diameter with same thickness and height before vertical adjustment

Size of Sample / Result	W_D= 10 W_T= 10 W_H= 8		W_D= 15 W_T= 10 W_H= 8		W_D= 20 W_T= 10 W_H= 8	
$N_{GH}(H_{K1})$	3170.00		3170.00		3170.00	
		Error		Error		Error
W_D^*	10.492	4.920%	15.740	4.933%	20.967	4.835%
W_T^*	10.112	1.120%	10.102	1.020%	10.129	1.290%
W_H^*	8.097	1.212%	8.104	1.300%	8.099	1.238%

Table 4 Gauged height with same inner diameter and thickness after vertical adjustment

Size of Sample / Result	W_D= 27 W_T= 4 W_H= 8		W_D= 27 W_T= 4 W_H= 12		W_D= 27 W_T= 4 W_H= 16	
$N_{GH}(H_{K1})$	3159.45		3165.53		3161.41	
		Error		Error		Error
W_D^*	27.262	0.970%	27.266	0.985%	27.226	0.837%
W_T^*	3.957	-1.075%	3.964	-0.900%	4.048	1.200%
W_H^*	7.941	-0.738%	11.932	-0.567%	16.132	0.825%

Table 5 Gauged thickness with same height after vertical adjustment

Size of Sample / Result	W_D= 10 W_T= 10 W_H= 16		W_D= 21 W_T= 7 W_H=16		W_D= 32 W_T= 4 W_H= 16	
$N_{GH}(H_{K1})$	3167.97		3162.34		3149.52	
		Error		Error		Error
W_D^*	10.109	1.090%	21.188	0.895%	32.293	0.916%
W_T^*	10.106	1.060%	6.932	-0.971%	3.960	-1.000%
W_H^*	16.158	0.988%	16.170	1.063%	16.159	0.994%

Table 6 Gauged inner diameter with same thickness and height after vertical adjustment

Size of Sample / Result	W_D= 10 W_T= 10 W_H= 8		W_D= 15 W_T= 10 W_H= 8		W_D= 20 W_T= 10 W_H= 8	
$N_{GH}(H_{K1})$	3161.87		3160.54		3154.44	
		Error		Error		Error
W_D^*	10.092	0.920%	15.143	0.953%	20.211	1.055%
W_T^*	10.109	1.090%	10.094	0.940%	10.098	0.988%
W_H^*	8.082	1.025%	8.087	1.088%	8.082	1.025%