Random and Systematic Errors Correction of Micron-sized Machine Vision Measurement System

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***Abstract*—The machine vision measurement system was established to measure 2D sizes of parts. The 5 Megapixels CCD sensors, bi-telecentric lenses, telecentric back illumination and image acquisition modes were chosen to establish hardware part, according to the requirement of views and precision. The software system was developed to extract the edge of the part from the digital image and transform it to a polynomial curve. The optimal estimation of expected value and the measured value was calculated based on contour tangential continuity, to eliminate the effects of random error. The gauge block set was set on the four quadrants of the visual field, and their edges were extracted. Distortion correction and system calibration was done combining with the distortion model. The actual size of each pixel is 4.584μm after using subdivision, Kalman filter, distortion correction and calibration. Tests and analyses show that the measurement precise is ±3μm class.**

Keywords-machine vision; pixel sub-division; tangential continuity; distortion correction; calibration.

I. INTRODUCTION

Machine vision systems are continuously deployed in different application fields, especially in measurement system.[1] Shape and dimensional inspection is used to check the geometric parameters of a product to ensure that they lie within the required tolerances. This can be used during the production process but also after a produce has been in use for some time to ensure that the product still meets the requirement despite wear and tear.[2] But the research on micron-sized machine vision measurement system is little, because of random errors and camera optical distortion. The micron vision measurement system was established, and the methods of random and systematic errors correction were studied in this paper.

II. HARDWARE PART OF MEASUREMENT SYSTEM

Aaccording to the requirement of views and precision, the views is 35mm×30mm. The object is set on the defined position, and is illuminated by a telecentric back illumination. The device driver of the camera-computer interface assembles the image in the memory of the computer. The camera-computer interface is Ethernet, which is a standard interface. The machine vision software inspects the objects and return an evaluation of the objects. The result of the evaluation is communicated to a controller. This communication is performed by digital input/output (I/O) interfaces. Main parts of hardware are camera, lenses, and illumination.

Main parameters of the camera (basler piA2400-17gm) are as follows. Resolution: 5 Megapixels (2448×2050), Chip: Sony ICX625, Size of target: 2/3" (W=8.8mm, H=6.6mm), pixel dimensions: 3.45μm×3.45μm.

Main parameters of the bi-telecentric lenses are as follows. telecentricity: <0.08 deg, distortion: <0.08%.

In order to eliminate the impact of the reflections, the system uses the telecentric back illumination (470nm blue LED), which produces very sharp edges.

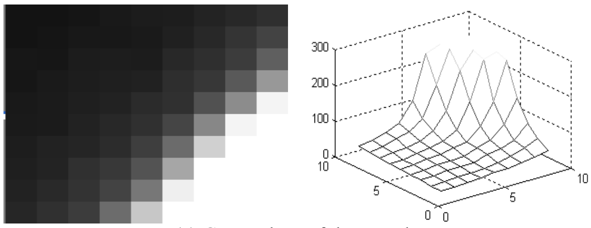
III. SUB-DIVISION CALCULATION OF EDGE PIXELS

The aim of the machine vision is to extract useful information from an image, such as edge, profile, color, and shape. High-precision image measurement is essentially accurate positioning information, such as the edge. Edges are areas in the image in which the gray values change significantly. There are many methods of edge extraction and subpixel algorithms. These algorithms has advantages and disadvantages considering precise, multiplicity, calculation and sensitivity to noise and other aspects [3-6]. Bilinear interpolation algorithm was improved to subpixel locate.

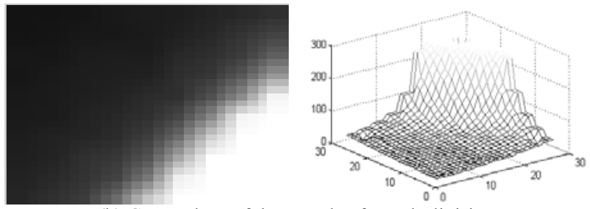
The output pixel value of bilinear interpolation is the average of the 2 × 2 neighborhood of sampling points in the input image, according to the gray values of the four pixels around this pixel in the horizontal and vertical direction interpolation. $g(m,n)$, $g(m+1,n)$, $g(m,n+1)$ and $g(m+1,n+1)$ is the grayscale values of the adjacent pixels, set $0<h<1, 0<j<1$, then the bilinear interpolation formula is:

$$G(m+h,n+j)=(1-h)(1-j)g(m,n)+h(1-j)g(m+1,n)$$
$$+(1-h)jg(m,n+1)+hjg(m+1,n+1) \quad (1)$$

According to the Eq.1, the sum of the 4 coefficients is 1. When broken one pixel down to three pixels, the coefficients are four-ninths, two-ninths, two-ninths, one-ninth, respectively. According to the weights of the four inputs to outputs, an amendment is amended to the coefficients, namely, 0.34, 0.25, 0.25, 0.16. Fig.1(b) shows the gray values of the sample image (Fig.1(a)) after three-segment sub-division.



(a) Gray values of the sample

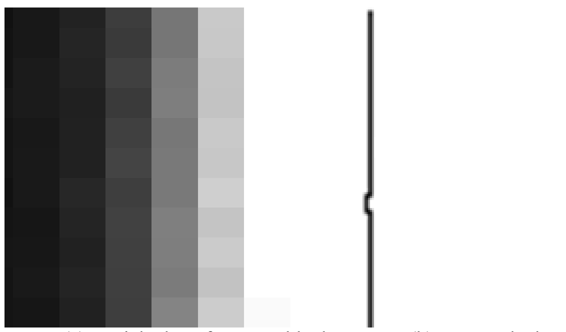


(b) Gray values of the sample after sub-division

Figure 1. Pixel sub-division using improved bilinear interpolation algorithm

IV. RANDOM ERRORS CORRECTION BY KALMAN FILTERING

There is random error in the edge extracted by previous step. The partial edge of a gauge block image shown in fig.2 (a) is a straight line. The extracted edge is shown in fig. 2 (b). The gray value of the sixth pixel of the first column on the right is 44, and the gray value of the upper and lower pixel is 58 and 64. Since most of the edge detection algorithm is gradient algorithm, so that such random errors makes straight line becomes a poly line.



(a) partial edge of a gauge block (b) extracted edge

Figure 2. Random errors

Kalman filtering is used to make the root mean square error between the desired output and the actual output of the linear system to a minimum. Kalman filtering utilization dynamic information of targets, to remove the effects of noise, and get a good estimate of the target location. so the result is close to the true value of the estimate as accurately as possible.

The actual size of each pixel represents about 13.5μm. The edge burr and roil is more than five pixel.This feature of the edge is defined as the tangential continuity. In determining the edges using the Kalman filter algorithm, more than 10 gradient values were used to calculate the tangential direction, as the desired direction of the contour edges. If there is less than five partial pixels (approximately 70μm) deviates from the desired direction, it should be disposed as random error.

V. DISTORTION CORRECTION AND CALIBRATION

There are tilt distortion between Lens and object, optical aberrations system errors in machine vision measurement system. The relative calibration techniques is used.

Gauge block (2mm) set was set on the four quadrants of the view field. One side of the block was aligned with the axes of the measurement system. These edges were extracted. The distortion correction and calibration system were done based on distortion model. The image of gauge block set is shown in fig.3. Fig.4 shows the barrel distortion of the gauge block edges. In the center of the field within a radius range of 500 pixels, the distortion values within 0.3 pixel. The edge of the image (a radius greater than1000 pixels), the distortion is 0.7 pixels.

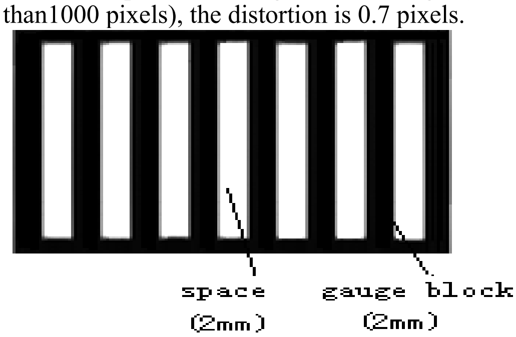


Figure 3. Gauge blocks set

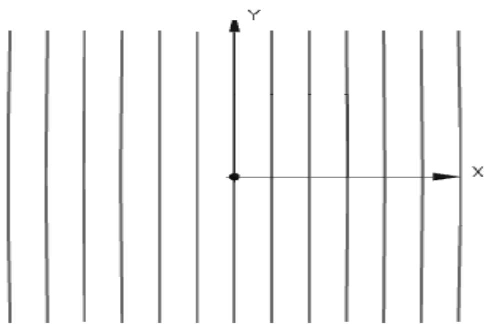


Figure 4. Barrel distortion of gauge block edges

There are there optical distortion: radial distortion, centrifugal distortion, and thin prism distortion. The radial distortion is mainly, and polynomial model is shown in Eq.2.

$$\begin{cases} x_0 = x_1 \sum_{i=1}^{n} k_i r_1^{i-1} \\ y_0 = y_1 \sum_{i=1}^{n} k_i r_1^{i-1} \end{cases} \tag{2}$$

Where the subscript 1 presents coordinates of images, and the subscript 0 presents that after the distortion correction.

$$r_1 = \sqrt{x_1^2 + y_1^2},$$

k_i- the polynomial coefficients,

n - generally 3-5.

k_1 = 1.12, k_2 = 6.58E-6, k_3 = 8.69E-09. After distortion correction, the position and straightness error is 0.21 pixels and 0.13pixels.

VI. EXAMPLES AND ANALYSIS

A middle and small module gear (m=2, z=30, gear precision grade=4) is taken as an example. By the technology introduced in this paper, gear image is pre-processed by digital image processing. Then gear tooth profile is obtained, and center of gear is located. The mathematic module from gear tooth profile deviation chart measurement is established. The profile deviation can be measured and classified. The gear tooth profile is shown in fig.5, and the measured profile deviation is 4μm.

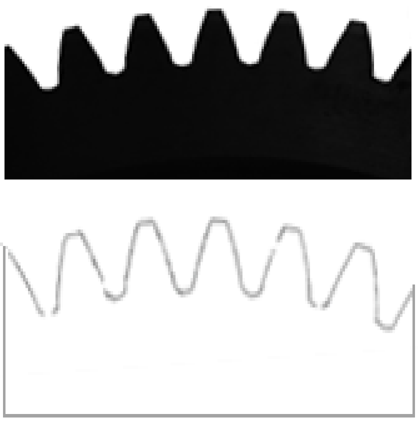


Figure 5. Gear tooth profile

VII. CONCLUSIONS

The untouched micron-sized measurement system based on machine vision and image processing was established to measure 2D sizes of parts automatically. The 5 Megapixels CCD sensors, bi-telecentric lenses, telecentric back illumination and image acquisition modes were chosen to establish hardware part, according to the requirement of views and precision. The bilinear interpolation algorithm was improved and pixels were subdivided by using it. The software system was developed to extract the edge of the part from the digital image and transform it to a polynomial. There are random error and systematic error on the edge. The optimal estimation of expected value and the measured value was calculated based on contour tangential continuity, to eliminate the effects of random error. The gauge block set was set on the four quadrants of the visual field as the calibration target. The actual size of each pixel is 4.584μm after using subdivision, Kalman filter, distortion correction and calibration. The position and straightness error is 0.21 pixels and 0.13pixels.

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