

PERFORMANCE EVALUATION FOR VISION COORDINATE MEASURING MACHINES

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INTRODUCTION

Non-contact vision (or video) type coordinate measuring machines (VCMM) have been used in the manufacturing industries for more than two decades. Common applications range from early efforts in two dimensional (2D) measurement of printed circuit boards to current three dimensional (3D) measurements of precision fuel system components. Despite the great growth in this market, very few attempts have been made to develop a method for VCMM's performance evaluation. The goal of this study is to investigate the correlation between error sources and measurement uncertainty and facilitate the development of a new VCMM evaluation methodology.

A common vision system in the VCMM includes a charge coupled device (CCD) camera, lens, and illumination lighting. With a vision system, images of a mechanical component are captured and then analyzed by image processing tools against inspection tolerances. For those features that can not be covered in a single field of view (FOV), the stage must move during the measurement. Therefore, the measurement uncertainty of a VCMM measurement will rely on the stage error, vision system error, image processing error, part surface/edge dullness, fixture error, sampling error, and environmental error. To evaluate a VCMM's performance, we will consider error sources unique to each measurement device: the stage, vision system, image processing and analysis. Though other error sources may be important in practical applications, they should be minimized to facilitate a standard evaluation technique.

In this study we intend to focus on the issues that will aid the users and purchasers when evaluating generalized claims regarding the VCMM's accuracy. Therefore, we evaluate the repeatability, optical focusing, reproducibility, and measurement bias, which are directly results from the stage error, vision system error, and image processing and analysis error. In addition we also investigate the sensitivity of the vision system to the geometric profiles of various measurants.

EXPERIMENTAL SETUP AND SAMPLING STRATEGY

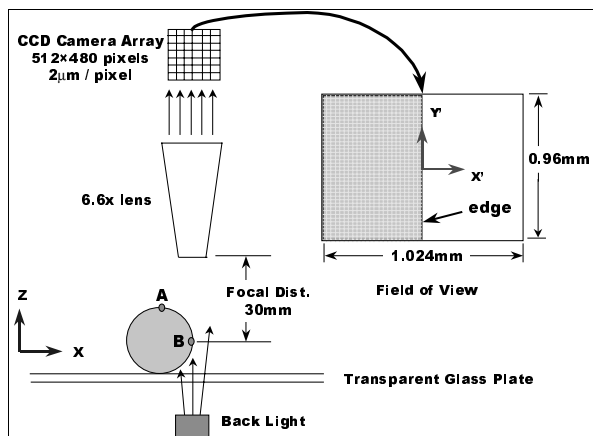







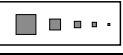

Figure 1 The optical parameters for the VCMM used in this study.

Environmental error and part form and surface finish error were minimized through the experimental design such as performing measurements in temperature controlled laboratory ($20 \pm 0.25^\circ\text{C}$), vibration isolation floor, class 10,000 clean room, air circulation 300 cycles/hour, and using artifacts as the measurants. The VCMM used in this study has a work volume of $200 \times 200 \times 150\text{mm}$ in X, Y, and Z directions respectively. The VCMM optical parameters can be found in Figure 1. The stage travel speed is set at 200mm/sec , and glass scales with resolution of $0.5\mu\text{m}$ are attached on stage to provide stage travel reading. Only the backlight illumination system is used in this study, though there are other illumination types available. The backlight

illumination was chosen based on most VCMM manufacture's recommendation when measuring 3D artifacts as listed in Table 1.

The artifacts used in the performance evaluation are tabulated in Table 1. The gage pins are lying on the stage so that their diameters are calculated by measuring the distance between two edge lines. Sixty equally spaced points are taken along the circular edges. Thirty equally spaced points are taken along the linear edges.

Table 1 Artifacts used in this study

Geometry	Artifacts	Feature measured	Size (mm)	Certified uncertainty
	Gage bore	ID	2,11 25,40	0.125µm
	Gage sphere	OD	4,8 16,24	0.125µm
	Gage pin	OD	5,8 15, 25	0.125µm
	Gage block	Length	25,50 100	0.125µm
	Chromed scale	Length	25,50 75,10	0.25µm
	Chromed block	Length	13	0.25µm
	Chromed hole	ID	6.35	0.25µm

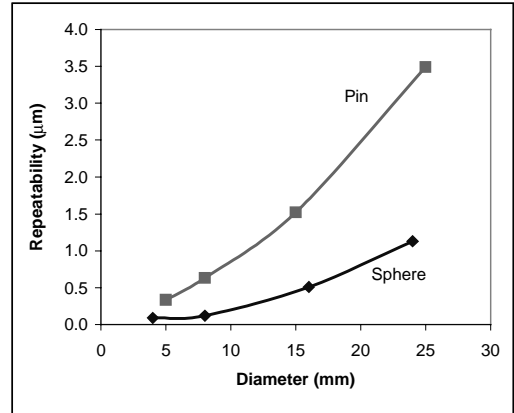


Figure 2 Measurement repeatability for gage pins and spheres by using the edge-focusing tool.

REPEATABILITY

Reference to ANSI/ASME B89.1.12M [1], this test is designed to check only the non-repeatable, i.e., random error at a particular position in the work zone. The definition for our repeatability test is two standards deviation (2σ) of the size variation determined by ten successive measurements under the same condition (same artifact, location, sampling, and fitting strategy.) The edge-focusing tool was used to determine the best contrast edge during each of the ten repeat measurements. All the artifacts listed in Table 1 are tested, and the results show that all the artifacts, except gage pins and spheres, have repeatability within 0.25µm. In the chromed artifacts the repeatability was within 0.16µm. For the pins and spheres, as shown in Figure 2, the bigger the diameter, the worse the repeatability. We will have further discussion of this phenomenon in next section.

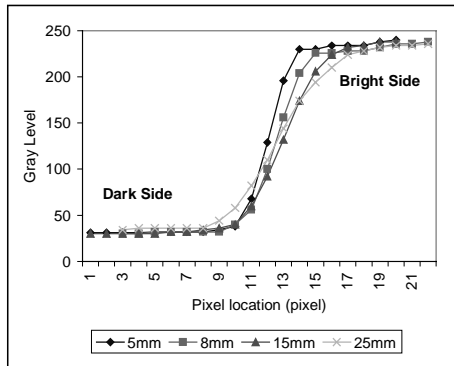


Figure 3 The gray level variation at the edge transition area for gage pins.

FOCUSING

Due to optical diffraction, it is observed that the smaller the diameter of the pin or sphere, the sharper and clearer the captured image edge. To illustrate the dullness of the image edge, the corresponding image gray level variation and gradient at the edge transition area are shown in Figures 3 and 4. Because of this dullness in the edge transition area for large diameter pin or sphere, the focusing-tool can not obtain a repeatable best contrast position. Consequently, we observed the greater repeatability deviation in larger diameter pins and spheres. Extraordinarily, better repeatability and accuracy are obtained by using the surface-focusing tool to obtain focused point on the top surface of the pin or sphere in the Z direction (point A shown in Figure 1), then replacing the edge-focus tool

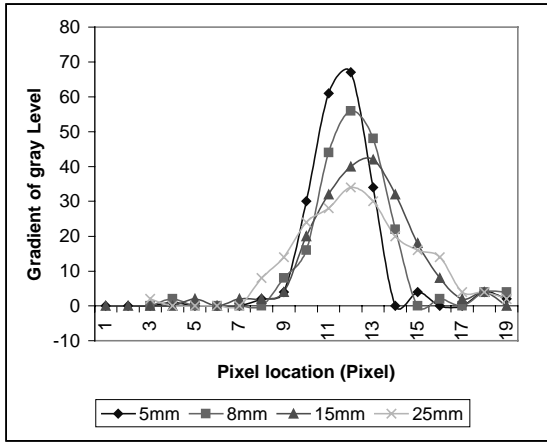


Figure 4 The gray level gradient at the edge transition area.

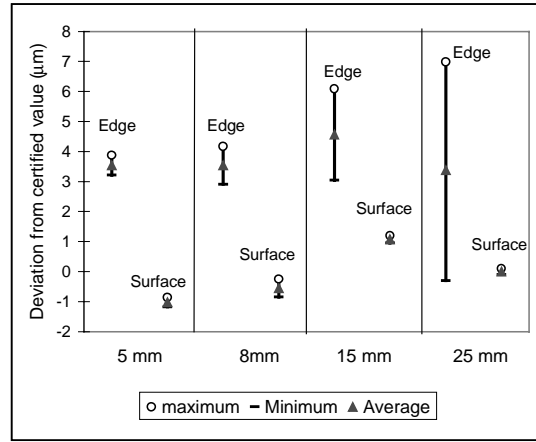


Figure 5 The measurement repeatability for gage pins by using different focusing tool.

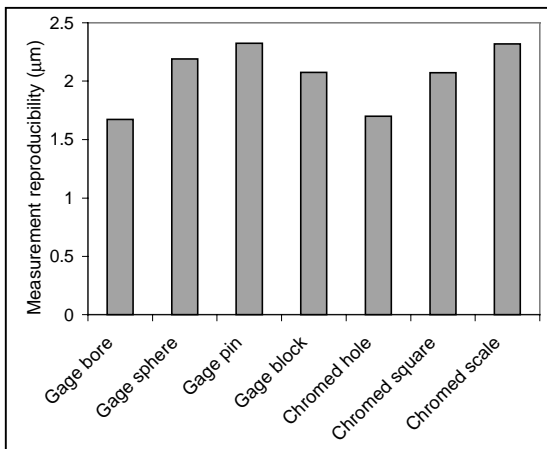


Figure 6 The measurement variation range in each geometric category between five different locations.

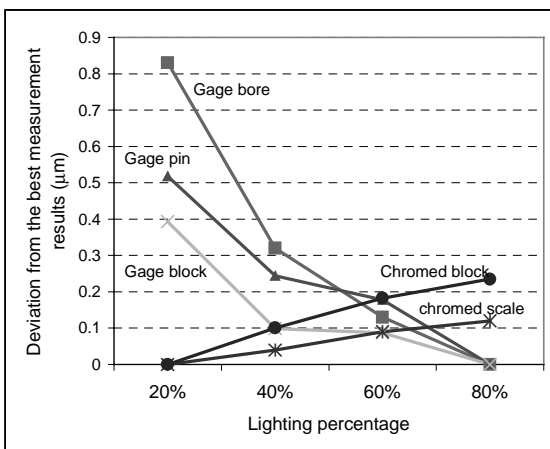


Figure 7 The measurement deviation from the best value illumination percentage.

by dropping a distance of the nominal radius of the pin in the Z direction (to point B in Figure 1). The improvements are shown in Figure 5. Using the same edge finding technique for pins and spheres in other working areas, the same level of measurement difference is observed.

REPRODUCIBILITY

In this test, we are trying to investigate the measurement variation between different working areas for the same artifact under the same testing conditions. According to the Germany VDI/VDE standard [2], the working area is divided into four quartered zones plus the central zone of the stage. To minimize the focusing error, the surface-focus tool was used in the gage pin and sphere tests. For the other artifacts, the edge-focus tool was adopted. In each of the test, the size is determined by the average of ten successive measurements. For the same artifact, comparing the five measurement values, the range of the deviation is the measurement reproducibility. In each geometric category, we selected the worst reproducibility value and plotted these in the Figure 6.

LIGHTING

The VCMM used in this test allows user to mechanically set the lighting power percentage to illuminate the measurants in a measurement procedure, such that the CCD camera can “see” the image of the measurants. In this study different values of lighting power percentage are used to investigate the lighting. Figure 7 only shows the light effect on bore (25mm), pin (15mm), block (100mm),

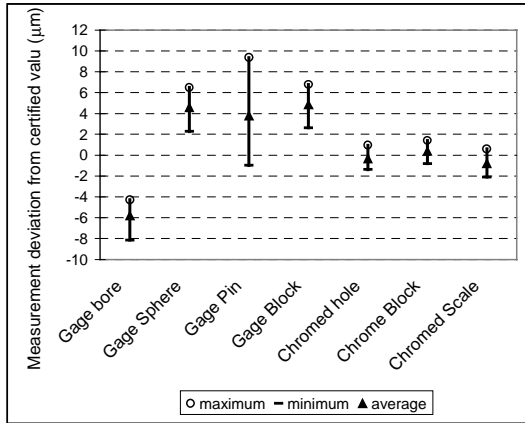


Figure 8 The measurement bias and variation range associated with different geometric artifacts.

and the chromed artifacts. However in the other 3D artifacts, the stronger light intensity still results better measurement accuracy. In contrast, for 2D chromed artifacts we observed the weaker light intensity produced better measurement results.

MEASUREMENT BIAS

In previous sections, we only compare the variation range but not include the variation from the certified value. Whenever the edge focus tool is used, comparing the measurement results with the certified values, no matter the geometry and size, significant systematic error is observed in the 3D components. Figure 8 shows the average measurement errors for different geometry artifacts. The associated deviation with the measurement bias are the effects from sizes, lighting, focusing repeatability, stage calibration, and the unidentified error factors.

CONCLUSION

It is found that the image focusing is a major factor of the measurement uncertainty for 3D components in our testing machine. By using the top focus (or surface focus) approach the experimenters obtained more accurate and repeatable results than using the edge focus approach. Experiments show that the illumination intensity is a relatively minor factor in the measurement uncertainty, compared to the focusing and stage errors. It also is observed that systematic errors of oversized and undersized occurred in the outer diameter and inner diameter measurements respectively. By knowing the correlation between the measurement uncertainty and error sources, one can design a procedure to assess the most critical error factors in the performance evaluation. Thus, a VCMM machine performance evaluation procedure can be established for initial purchasing acceptance and periodical performance assurance.

REFERENCE

1. ANSI/ASME B89.1.12M (1990), "Methods for Performance Evaluation of Coordinate Measuring Machines," ASME, New York, NY, 1990.
2. German standard VDI/VDE 2617 Part 6, "Accuracy of Coordinate Measurement Machines, Coordinate Measuring Machines with Optical Probes-Basics."