Investigation on Comparability of Surface- and Material Dependent Measurements in Multi-Sensor Coordinate Measuring Machines

M. Vogel, M. Rosenberger, G. Linß, S.C.N. Töpfer

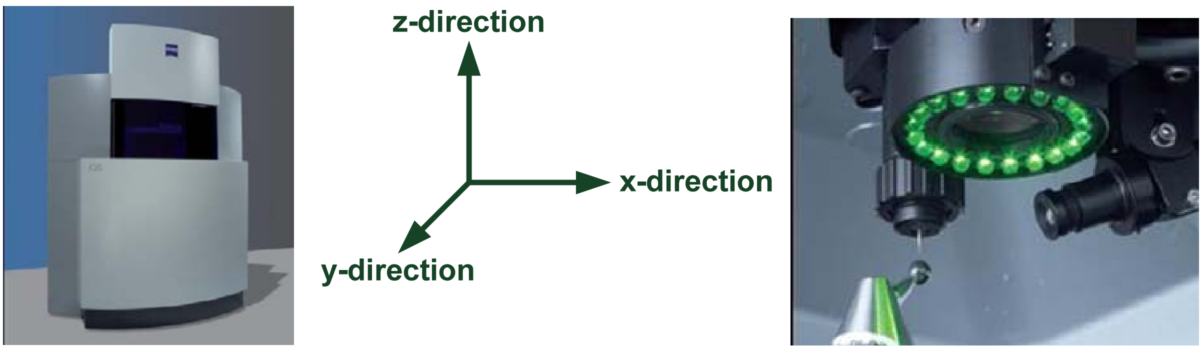
Technische Universität Ilmenau, Ilmenau, Germany,
Email: Michael.Vogel@tu-ilmenau.de

Abstract. *Multi-sensor coordinate measuring machines (MS-CMM) offer new possibilities for probing work pieces. The advantage of these sensor systems lies in the different working principles of its individual sensors. Tactile and non tactile sensors are often combined in such a sensor system. Most non tactile sensors deployed are using optical principles to acquire the measuring points. The quality of these points depends besides various factors significantly on the surface characteristics of the sample. Typically different measurement results are attained for different work piece material and surface characteristics. Consequently, there exists a characteristic displacement between a tactilely and optically measured surface point. This paper describes an experiment exploring this displacement between the point detection of a touch probe and an optical CCD matrix sensor.*
Furthermore the issue of the displacement stability in relation to the material properties is discussed.

Keywords: sensor displacement, tactile point detection, optical point detection, 3D coordinate measurement techniques, focus based height measurements with CCD matrix sensors;

1. Introduction

The coordinate measurement technique is a very important technology for quality assurance in wide ranges of industrial quality assurance applications. The measuring range spreads from few metres up to few nanometres [1]. The range of different samples demands tactile and non tactile sensors. Tactile sensors utilise the direct contact to the surface of the measuring object. During the measuring process only one point without moving the positioning stage can be sampled. Furthermore there are samples like thin membranes which can not be sampled with a tactile sensor, because the measuring object would be destroyed.



Deployed multi-sensor coordinate measuring machine (on the left), the orientation of the machine coordinate system (in the middle), probing sensors of the MS-CMM (on the right) [1]

In that case an optical sampling method is to be preferred. Choosing an optical matrix sensor for this task has the advantage getting more measuring points without moving the positioning stage. Additionally there is no contact to the sample surface. Thus, it is advantageous to combine these two measuring principles in relation to the intended measuring task. There are many applications in industry which require multi-sensor capabilities. One of the most discussed topics is the objectivity of optical measurements in comparison to tactile measurements. In our experiment the results of tactile point detection are compared to optical point detection. The focus in this paper lies on the deviation in the z-coordinate of the detected points in dependence of surface and material properties [Fig.1]. In the following discussions the coordinates are oriented as shown in Fig.1.

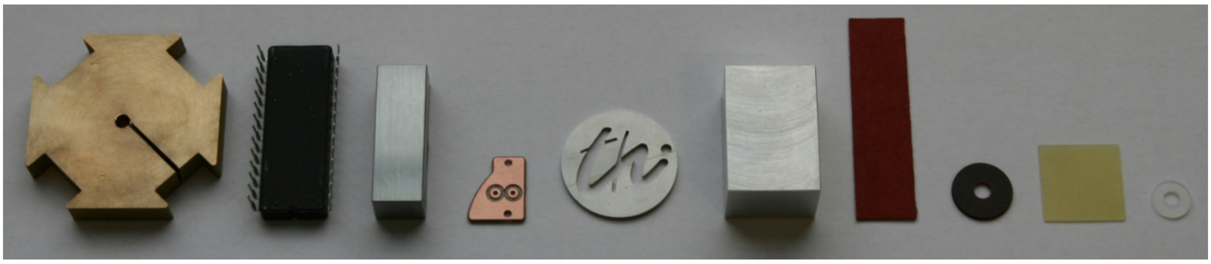
Demands for optical measurements with optical matrix sensors in comparison with tactile measurements

In cases of optical point detection and objectivity in optical measurements a wide range of influencing factors must be considered. In [2], [3], [4], [5] the most influencing factors for optical measurements were described. In summary it is necessary to follow the hints regarding illumination and focus criteria. For our experiments always the same focus criterion was used. Furthermore a comparable illumination was established by controlling the gray scale diagrams for each measuring object individually. Beside this, the same light source was used, id est bright field top light illumination.

2. Subject and Methods

Measuring objects and experimental setup

The experiment was done with a 3D coordinate measurement machine F25. It is a machine from the Carl Zeiss Company. This machine is equipped with a tactile sensor and a CCD camera with different magnifications. The measuring volume is 130x130x100 mm³ with a length measuring deviation of 0,25+l/666 µm (MPE in comparison to DIN EN ISO 10360-2 (MPE_p = 0,3 µm)) [1].



1 2 3 4 5 6 7 8 9 10

The measuring objects for the experiment (from left to right: first six metallic materials; last four non-metallic materials)

For the experiment the tactile sensor with a probing sphere diameter of 120 µm was used. The sensitivity of the tactile probe is configurable and had a value of 0,6 mN during the tests. For the optical measurements the optical sensor ViScan was used. During the experiment the magnification was 10.0 and the illumination wavelength 532 nm. Both sensors were probing the sample from above (in negative z-direction). For the analysis the measuring software Calypso was used. For the experiment ten different material samples were chosen, six types of metal and four types of non metal material [Fig. 2.]. The focus hereby lies to get information about typical surfaces in industrial measuring applications. The manufacturing process differs from laser beam cutting, electric discharge machine, and turning centre up to injection moulding machines. So a wide band of characteristic surface properties were tested. The surface properties are characterized in [6]. Especially the bidirectional reflectance distribution function (BRDF) describes the interaction of light source with the material surface. It shows the difficulty of optical conditions in case of measuring on a surface structure [7],[8],[9]. Recent works are using the Cook-Torrance BRDF model [10] in order to model specular reflection [11]. Additionally to the height measurements with the coordinate measurement machine, roughness-measurements were done.

Sensor calibration method

Both sensors were calibrated on an ultra precise sphere. Furthermore the optical sensor was calibrated under the test rules of the VDI 2617 part 6. At first the operator had to measure four points with the tactile sensor. After that the sphere is scanned automatically collecting many measuring points. The same procedure on the same sphere had to be done with the optical sensor. The middle point coordinates of the sphere were stored in the machine. After that a software algorithm inside the machine software can correct the displacement between the two sensors. During the calibration process also a material and surface depending offset occurs.

Measuring process chain

Every sample was touched ten times with the tactile sensor at three different points. The identical three points were focused with the video optical sensor. As focus criterion the area probing criterion was used. Considering the optical transfer characteristics of the tested materials the illumination had to be adjusted to keep a constant grey level. The grey level amounted to 160±10 (increments), (camera resolution 8 bit).

The measured values for the coordinate “z” (height) of both measurements were compared. The average displacement between both measuring sensors and the standard deviation are given in Tab.1 . The table shows the results of one detected point of these measurements.

Tab. 1. Measurement results at different materials

Nr.	material	R_z	R_a	touch probe		optical probe		average value Δz (mm)	$б_z$ (mm)
				average value z (mm)	$б_z$ (mm)	average value z (mm)	$б_z$ (mm)		
1	CuZn	10,7	2,2	-1,822269	0,000153	-1,974719	0,000457	0,152450	0,000535
2	Al203	3,8	0,7	-0,000337	0,000027	-0,148015	0,000272	0,147678	0,000284
3	hardened steel (DIN 861)	3,5	0,6	0,001737	0,000033	-0,142271	0,000216	0,144008	0,000205
4	Cu	1,8	0,3	-0,155648	0,000032	-0,299356	0,000485	0,143708	0,000490
5	CrNi	1,0	0,1	-0,137287	0,000013	-0,280664	0,000405	0,143377	0,000405
6	Al	0,7	0,2	0,000529	0,000007	-0,142545	0,000555	0,143074	0,000552
7	PET (red)	10,2	2,0	-0,584480	0,000026	-0,732391	0,000345	0,147911	0,000351
8	PET (brown)	2,0	0,3	-0,187274	0,000041	-0,334853	0,000491	0,147578	0,000498
9	FR4 synthetic resin	2,3	0,5	-0,636396	0,000010	-0,783443	0,000869	0,147047	0,000866
10	PET (transparent)	0,8	0,1	-0,378031	0,000272	-0,520717	0,001399	0,142687	0,001387

Afterwards the roughness measurements were done. Therefore the samples were also proofed ten times. The results of the roughness measurements are given in Tab.1 with R_a and R_z.

3. Results and Discussion

Table 1 contains the measurements with the touch probe. It shows the stability and the precision of the machine. Mostly the standard deviation lies under 153 nm for tactile and 1.44µm for optical probing. The offset between the optical and tactile measurement depends on the material, the material surface and the calibration process. A look at the standard deviation on a combined optical-tactile measurement shows for metal surfaces a maximum value of 552nm. This is corresponding to a high degree of stability. It shows the possibility to correct these offset values. For the non metal samples the standard deviations are up to factor six higher.

Overall the measurements showing a material and surface characteristics related deviation during the point detection in the z-coordinate. The roughness measurements reveal the dependencies on the surface roughness and the error behavior. A high roughness value leads to greater deviations in the height measurements. It is the predominant influence for the tactile measurements (compare columns 3 and 4 with column 6). As for optically probed points this is not true (column 8). Roughness has a significant influence but it is not the only one. One other important factor for optical measurements is the type of reflection on the surface. For optical probing it is a great difference whether diffuse or specular reflection is the predominant component of the observed reflection image. For metal surfaces specular reflection may be the most predominant reflection component depending on the observation angle, the illumination angle and on the local surface structure. Using the Cook Torrance model describing a surface with a microfacet model specular reflection can be well modeled. Additionally a higher surface roughness results in a more efficient light trapping and absorption. Thus, a lower brightness is observed. At measuring objects 7 to 10 diffuse reflection is predominant. Measuring object 10 is a special case for it is transparent. Considering the tactile results on measuring object 10 it poses the interesting question which influence leads to the high value of the standard deviation σ_z? Whether it is an outlier or not shall be investigated in future experiments.

4. Conclusions

The experiment shows to what extent an optical measurement depends on the optical surface characteristics of the sample.

Our future research will deal with these effects using tactile sensors with different probing ball diameter and different optical magnifications. Furthermore a cross-validation with results acquired with direct mounted sensors is interesting and shall be done. Additionally the separation of different surface roughness and different optical surface properties has to be done. This research will provide a new quality and stability of measurement results of multi-sensor measurements.

Furthermore the trend in mechanical engineering techniques goes to Computer Aided Designs (CAD). During the construction process, during the production process and also during the measurement process CAD data are available. Therefore a lot of additional information is given. It can be used for automated inspection planning. So the material and the processing parameters are known. With this knowledge and the results of our ongoing research a new quality in measurements can be achieved.

Acknowledgements

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