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THE NEW HYBRID METHOD FOR FAST AND PRECISION MEASUREMENT

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Abstract. In this article a new concept of a hybrid measurement method will be presented. The hybrid method is developed for fast and precise measurement especially for the automotive industry. It combines the high-speed of optical methods with the high-accuracy of CMMs measurement. A laboratory prototype of the system is described. Furthermore we present preliminary work on assessment of measurement uncertainty of the hybrid system based on the comparison of the results with CMM measurements.
Keywords: Hybrid System, Optical System, CMM, Uncertainty

1. INTRODUCTION

The dimensional inspection of a car body is one of the most important measuring operations in the process of car production. Traditional tactile probe and data-gathering technology is often too slow to support automotive industries requirements for timely process-control applications. Consequently, manufacturers are continually looking for more effective measurement techniques [1]. High speed measurement can be realized by the use of optical methods. However their accuracy is still too low to meet industrial requirements. Moreover there are no metrological standards for the assessment of their measurement uncertainty. The new method should introduce faster measurement speed as well as high accuracy.

2. THE CONCEPT OF HYBRID SYSTEM

Our idea is to combine the best features of two techniques; the accuracy of CMMs and the speed of full-field optical methods [2,3].

We propose the following steps of measurement (see figure 1). The unified coordinate system is created according to existing metrological strategies used in CMMs. The next step is to transform relative coordinate systems (from optical measurement) to absolute ones (CMM). After this operation the examined object is measured by a fast optical system. As a result we get 3D clouds of points. Further automatic or semi-automatic analysis of the measurement results can take place. The cloud of points is imported into the segmentation algorithm. At first, the local neighbourhood for each point is calculated. The local neighbourhood consists for points whose distance is less then the given threshold. The threshold is determined for each cloud individually based on the clouds' density. Now the calculation of features can take place. A best fitting plane is fitted for each points' neighbourhood. Local curvature is defined by the Gaussian weighting distance of each point from the plane of its neighbourhood. By comparing the local curvature and the normal of best fitting planes of adjacent points the algorithm groups them together. The values of the features in these groups are either constant or change in a particular way.

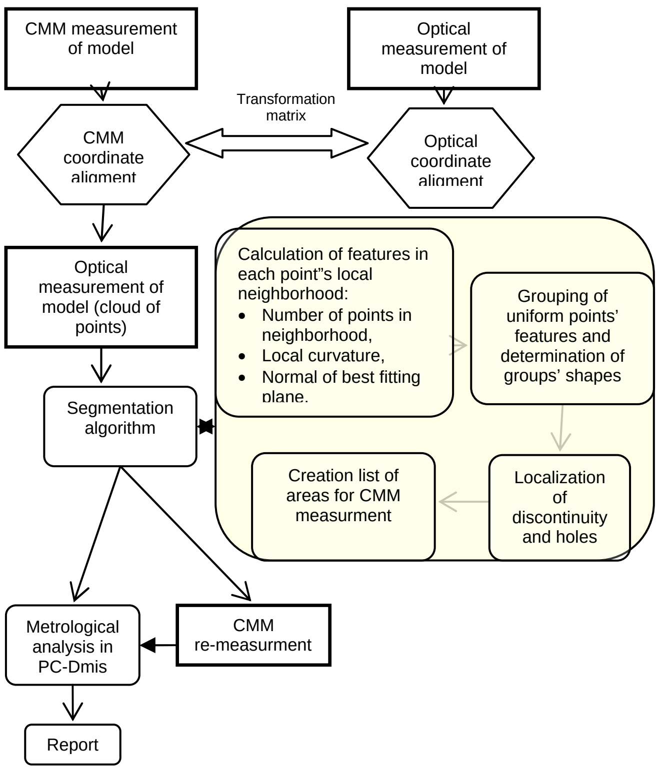

Fig. 1. Scheme of hybrid measurement process

All of these groups are then fitted to shapes like planes, spheres, cylinders and cones. The best fitting shape for each group is determined. At this stage we are able specify if the grouping proceeded correctly. Merging of groups belonging to the same surface can take place. All of the groups that we are not able to univocally assign to a specific surface are marked as free form. At last the localization of discontinued areas and areas with holes takes place. These areas can be located by finding the edges in the cloud. Points suspected of being edge points are usually the ones with relatively few points in their neighbourhood. These areas are pointed out to be re-measured by the CMM machine. When these two measurements are completed, a virtual 3D characterization of object is created. Final metrological analysis is performed in classical, certified metrological software.

3. CALIBRATION PROCESS

The most popular method of calibrating optical systems is based on simultaneous measurement of a known, geometrically characterized, calibration 3D-model. We also propose to use this model for further calculations and for establishing relations between optical coordinate systems and CMM ones.

3.1. Description of the ball–plate model calibration process

For the calibration of the system a special ball-plate model has been designed. It is well geometrically characterized and can be measured by both contact and non-contact optical, full-field, phase methods. The model is shown on figure 2. It is made out of a ceramic glass plate 500x500mm. Its average linear thermal expansion factor is $(0,0\pm0,3)*10^{6}\,K^{-1}$. A number of well diffused balls hale been attached to the plate. They are 25mm in diameter and their shape error is under 0,05µm. The nominal distance between their centers is 90mm.

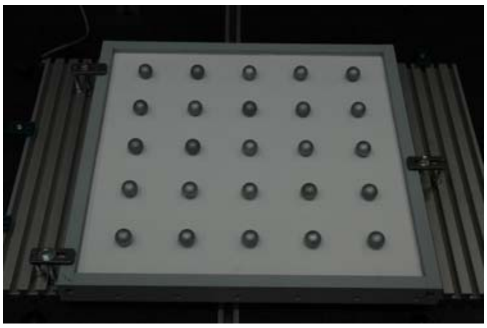

Fig. 2. Photograph of the ball – plate model

The Leitz PMM12106 Coordinate measuring machine has been chosen for the calibration process with the QUINDOS program. The machine is located in the Coordinate Measurement Laboratory at the Cracow University of Technology. It fulfills all the requirements formulated by the PTB for accredited laboratories used for machine calibration.

The uncertainty of the measurement of the machine equals U=0,8 ± L/400 [µm]. To eliminate systematical errors of the machine we use the **swing round** method. These errors are associated with the deformation of its kinematical structure. The plate is measured in four different positions in the sequence shown below (fig.2,3,4).

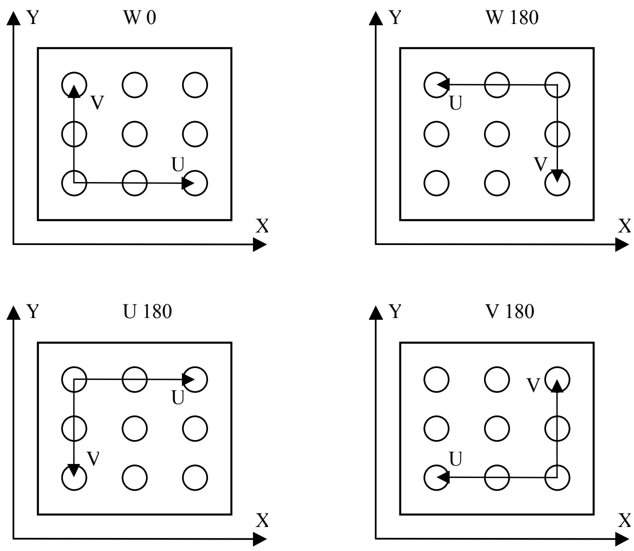

Fig.2. Positions of the calibration model during the calibration process. X, Y – axes of the CMM, U, V – axes of the plate [4]

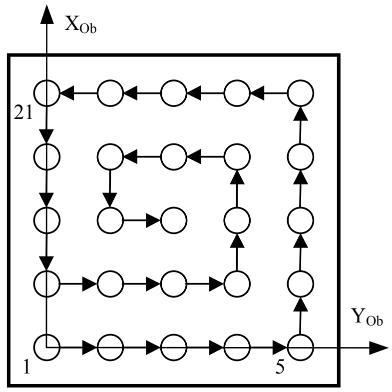

Fig 3. Measurement sequence of the calibration model[4]

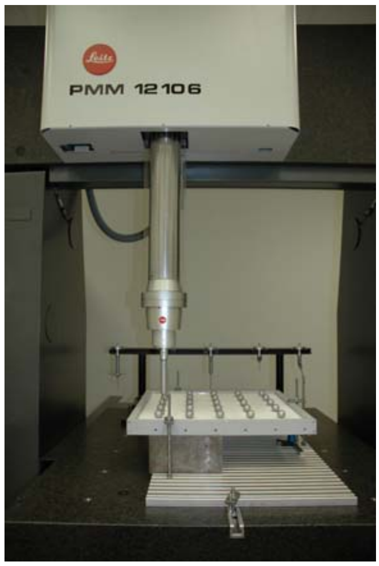

Fig. 4. The ball-plate model during the calibration process

3.2. *Calibration process of optical system*

On the base of known 3D-model analysis (the coordinates of the centers of the spheres) the parameters of the calibration matrix for the optical system are estimated. Next the model of the plate is measured by an optical scanner. This process takes place many times, with the model situated in different positions perpendicularly to the scanning axis in the entire measurement volume. This way the coordinates x,y,z are appointed for the measurement volume. During the calibration process, the calibration model has to fill the entire field of view of the camera. The calibration process is performed once and it is valid until any geometrical or optical changes are made. Further 3D-models can be measured by the optical method and the transformation matrix from the optical to the CMM coordinate spaces can be calculated

4. LABORATORY PROTOTYPE

To prove correctness of the hybrid measurement concept a laboratory prototype had been constructed.

The 3DMADMAC system has been chosen to be used as the optical measurement system. Its calibrated volume is $0.5x0.5x0.3m^3$ (see figure 5). It is based on the structured light measurement technique with digital sinusoidal fringe and Gray code projection. 3DMADMAC consists of a digital projector (Digital Light Processing unit) and a detector (CCD or CMOS camera) [5]. It realizes absolute 3D measurements. The measurement process is performed in two steps: phase measurement and scaling of the phase values to real (x,y,z) Cartesian coordinates. Scaling is realized by establishing a calibration matrix which represents 3D phase distribution in real measurement volume. The measurement result is in the form of a cloud of (x,y,z) points.

Fig. 5. 3DMADMAC optical measurement system

As the contact system the Global Clima machine from DEA equipped with a PC-DMIS program has been proposed (see figure 6). Based on the product data its measurement uncertainty is U =1,7 + L/333 [µm]. It is equipped with Renishaw TP 200 measuring head. The measurement range for each axis is: x = 700, y = 1000, z = 700 [mm]

Fig. 6. CMM Global Clima

Some algorithms aren't yet fully optimized and automated. However initial results seem to be very promising for further work on the development of the hybrid system.

5. UNCERTAINTY MEASURMENT MODEL

The form of reporting the result of the measurement should consist of the estimate y of the measurand and the associated expanded uncertainty U [6]. The uncertainty characterizes the dispersion of the values that can be attributed to the measurand [7].

There are two fundamental methods of uncertainty assessment:

A *Type A* evaluation of standard uncertainty may be based on any valid statistical method for treating data. In example calculating the standard deviation of the mean of a series of independent observations, and carrying out an analysis of variance in order to identify and quantify random effects in certain kinds of measurements.

Type B evaluation of standard uncertainty is usually based on scientific judgment using all the relevant information available, which may include

- previous measurement data,
- experience with, or general knowledge of, the behavior and property of relevant materials and instruments,
- manufacturer's specifications,
- data provided in calibration and other reports, and
- uncertainties assigned to reference data taken from handbooks [8].

The statement of uncertainty is usually based on the comparisons with standards traceable to the national units (SI units). As already mention the main drawbacks of optical methods are associated with the lack of a world-wide industrial standard for their calibration and assessment of their measurement uncertainty [9].

The determination of the accuracy of the hybrid method is based on the measurement of a series of known reference models (see figure7). Their metrological characteristics are known based on the measurement using s reference WMP PMM12106 CMM from Leitz (increased accuracy).

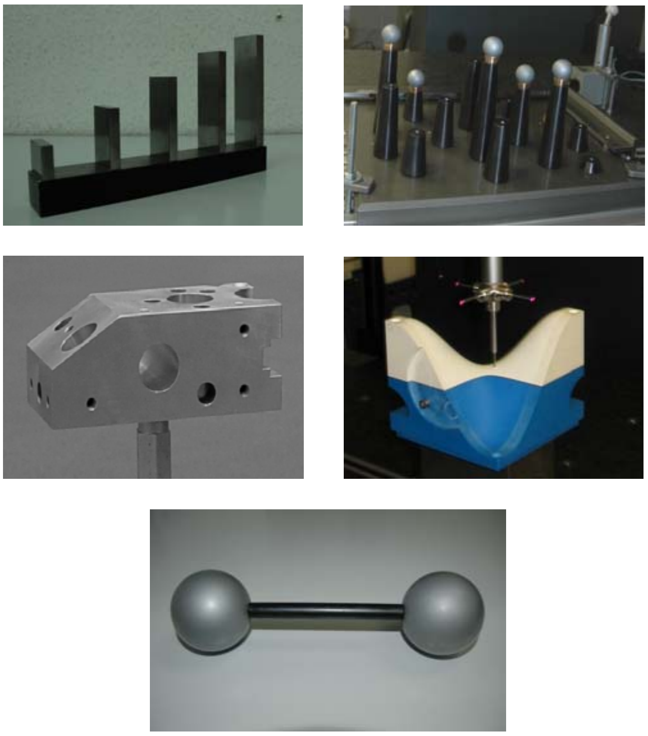

Fig. 7 Examples of reference models

The procedure of determining particular measurement uncertainty components (accuracy model) of the hybrid system incorporates the use of both methods noted above (A and B) is listed below.

Accuracy of appointing the coordinate system

Two factors influence the uncertainty of the appointment of the coordinate system. These are repeatability and the geometrical errors of the CMM:

$$u_{ukl} = \sqrt{u^2{}_{rep} + u^2{}_{geo}} \quad (1)$$

To define this uncertainty the object has to be measured from four different angles. The $u_{rep\ i}$ u_{geo} can be calculated from the following formulas:

$$u_{rep} = \frac{1}{\sqrt{n_1}} \sqrt{\frac{1}{n_2} * \sum_{j=1}^{n_2} ({}^{j}S)^2} \quad (2)$$

$$u_{geo} = \frac{1}{\sqrt{n_2}} \sqrt{\frac{1}{(n_2 - 1)} * \sum_{j=1}^{n2} ({}^{j}y - \bar{y})^2 - \frac{u^2{}_{rep}}{n_1}} \quad (3)$$

$${}^{j}S = \sqrt{\frac{1}{(n_1 - 1)} \sum_{i=1}^{n_1} \left({}^{ij}y - \frac{1}{n_1} * \sum_{i=1}^{n_1} {}^{ij}y \right)^2}$$

$$\bar{y} = \frac{1}{n_1 * n2} * \sum_{j=1}^{n_2} \sum_{i=1}^{n_1} {}^{ij}y$$

where:
u_{rep}- uncertainty of repeatability of the CMM
u_{geo}- uncertainty of geometrical errors of the CMM
${}^{j}S$- standard deviation of the *j-th* position
$\bar{y}$ - average value of all measurements
${}^{ij}y$- value of the result of the *i-th* cycle of the *j-th* position
n_1- number of cycles, n_2- number of positions
i – cycle index, *j*- position index

Uncertainty of length measurement

The Uncertainty of length measurement incorporates the measurement of objects of known length. The known length of the model is compared with the results of the measurement of the machine we are verifying. As a result we get the error of the measuring machine. This uncertainty is described by the following formula:

$$u_{dl} = A_{dl} + k_{dl} * L \quad (4)$$

where:
A_{dl} - constant of the trait of the variation of errors not related to the measured distance (including the errors of the contact system)
k_{dl}- coefficient of the trait of the variation of errors related to the measured distance
L- measured length

Uncertainty of the measurement of the objects' temperature

For the measurement of the objects' temperature the following formula is used:

$$u_{temp} = L \cdot \sqrt{u^2{}_{Tcal} * \alpha^2 + \left(u_\alpha (T - 20^o C)\right)^2} \quad (5)$$

where:
u_{temp} – uncertainty due of temperature change
u_{Tcal} – standard uncertainty of the thermometer
u_α– uncertainty of the thermal expansion factor
α – thermal expansion factor
T – temperature of the object during measurement

Uncertainty of the calibration model and the reference models

The value of uncertainty of the calibration model and the reference models are based on the measurement using a reference PMM machine. The formula is adequate for the machine and takes into account the measurement conditions and the strategy used.

$$u_w = A_w + k_w * L \tag{6}$$

where:
A_w - constant
k_w – uncertainty coefficient dependent on length
L - length

Uncertainty caused by the reflectiveness of the measured object

To determine the uncertainty of the measurement depending on the reflectiveness of the object we measure k different objects with different reflectiveness values. To calculate the uncertainty we use the following formula:

$$u_r = \frac{1}{\sqrt{n}} \sqrt{\frac{1}{k} \sum_{i=1}^{k} {}^jS^2} \tag{7}$$

$${}^jS = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(y_{ij} - \frac{1}{n} \sum_{i=1}^{n} y_{ij} \right)^2}$$

where:
u_r- uncertainty due to reflection
${}^jS_r$- standard deviation of the j object
y_{ij}- value of the result of the *i-th* measurement of the *j-th* object
n-number of measurements, *k*- number of objects
i – measuremnt index
j- object index

Finally the individual uncertainties are combined to give an overall figure:

$$U = 2 \cdot \sqrt{u_{ukl}^2 + u_{dl}^2 + u_w^2 + u_{temp}^2 + u_r^2} \tag{8}$$

6. CONCLUSIONS

We propose the new concept of a hybrid contact and no-contact measurement method. It responds to the need of improving existing measurement techniques. The laboratory prototype was build to verify the correctness of the concept. Additionally, uncertainty sources discussion of the hybrid measuring method are presented. We expect that we will be able to achieve measurement uncertainties around 0.01mm.

In future we will be working on:.

- implementation and testing calibration and coordinates systems unification processes, by using pate-ball model,
- development of automatic algorithms for numerical (cloud of point segmentation, transforming of co-ordinate systems) and hardware tasks,
- assessment of uncertainty of measurement realized by hybrid system,
- creation of a full functional system that could be incorporated in a car production line.

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