

PARAMETRIC METHOD FOR ESTIMATION OF THE UNCERTAINTY OF MULTI- SENSOR COORDINATE MEASUREMENT WITH THE USE OF INTELLIGENT MATRIX

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Abstract – The paper presents the parametric method for estimation of the uncertainty of multi-sensor coordinate measurement, based on the use of intelligent matrix, built for elements from basic geometry to these of complex shapes for which the uncertainty were calculated with the use of various methods. Multi-position, substitution and recently developed OPTI-U methods were used. In future also the virtual machine will be used. Important is an attempt to cross-validation of used methods.

Keywords: measurement uncertainty, multi-sensor coordinate measuring systems

1. MEASUREMENT UNCERTAINTY

Uncertainty of coordinate measurement is an important and constantly developed issue. From a technical point of view to consider the measurement result as a useful it has to be specified together with the uncertainty of its obtaining. Accordingly to recently performed works connected with evaluation of the uncertainty of coordinate measurement it may be concluded that this is a hard and problematic task, especially in industrial practice [1-12]. One of the most difficult tasks is the estimation of the uncertainty of multi-sensor measurement, especially the non-contact one with the use of laser probe heads.

The article describes a new, developed in the Laboratory of Coordinate Metrology at Cracow University of Technology (LCM CUT) method based on the use of surface and contours models, for which the measurement uncertainty are determined, to allow later estimation of the uncertainty of real contours by the use of parametrisation. From each contours models and surfaces, created for both the basic shape elements and also more and more complex ones (as required) selection matrix is built. In the LCM CUT has been planned a cycle of studies for developing the experimental matrix, which will allow the rapid estimation of the uncertainty of measured contour in conditions of multi-sensor measurement. It is important to include the problem of measurement uncertainty estimation for particular tasks performed with the use of various sensors and various methods and their later cross-validation.

Parametrization of obtained results by including factors such as the sensor selection, geometries of measured element, the required measurement accuracy, MPE - the maximum permissible error of the machine, external conditions - mainly temperature, number of operators and also the measurement strategy. The development of so constructed matrix requires a number of advanced researches, in the initial phase an account of limited number of factors to verify the set concept were planned.

2. INTELLIGENT SELECTION MATRIX

2.1. The concept of standards designing

In order to enable the development of the matrix in the Laboratory of Coordinate Metrology was created the concept of using standards made with use of Fused Deposition Modeling (FDM) technology from a group of rapid prototyping methods. The example of such standard is shown in Fig. 1. It enables to produce dedicated standards and creating a broad base of models, significantly reducing the time and cost of production. The printer on which standards are printed is a project of the Laboratory of Coordinate Metrology. It has a working volume of 500×500×500 [mm] and moving bridge structure. Standards made in FDM technology, according to authors allow the verification of set concept and they are the base for its further development.

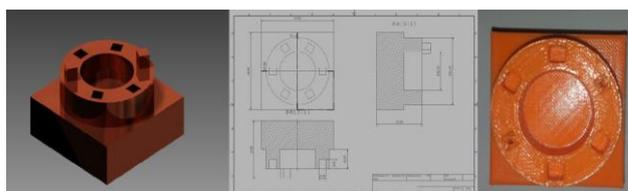


Fig. 1. Standard made in FDM technology.

2.2. Methods for the estimation of measurement uncertainty

In researches are actually used three methods for uncertainty estimation. They are multi-position method, comparative method and the method developed in the LCM – OPTI-U (Optical Uncertainty).

OPTI-U method is used for estimating the uncertainty of optical coordinate measurements. The particular components (1) included in this method had been partly used in multi-position method and in methods known in the metrology as R&R [13].

$$U = |E_L| + |E_D| + |E_{PR}| + |E_S| + k\sqrt{(u_{AV})^2 + (u_{EV})^2 + (u_{CAL})^2 + (u_{CTE})^2} \quad (1)$$

where: E_L — component of error of length measurement, mm, E_{Dext} — component of average error for external diameter measurement, mm, E_{Dint} — component of average error for internal diameter measurement, mm, E_{Dfla} — component of average error for flat surface, mm, E_{PR} — component of used software, mm, E_S — component of matching of „points clouds”, mm, u_{AV} — uncertainty component depended on machine operator, mm, u_{EV} — uncertainty component depended on gauge, mm, u_{CAL} — uncertainty component depended on calibration value, mm, u_{CTE} — uncertainty component depended on calibration temperature, mm.

Multi-position method [14,15,16] is a connection of the use of non-calibrated measurement object with frequently repeat measurement strategy. During an estimation of the uncertainty with the use of multi-position method a number of factors is included (2).

$$U = |E_L| + |E_D| + k\sqrt{(u_{rep})^2 + (u_{geo})^2 + (u_{corrL})^2 + (u_D)^2 + (u_{temp})^2} \quad (2)$$

where: k — extension factor depended on effective degrees of freedom, u_{rep} — standard uncertainty component depended on CMM repeatability, mm, u_{geo} — standard uncertainty component depended on CMM geometrical errors, mm, u_{corrL} — correction uncertainty, included in length measurement of the standard, mm, u_D — standard uncertainty of difference of errors between internal and external standard measurements, mm, u_{temp} — standard uncertainty depended on temperature of measured object, standard and environment, mm.

The third used method is a comparative method [14] which consists in the performance and development of results of measurements carried out on the calibrated standard of the shape and size, which is close to the measured object. In its formula (3) less in comparison to the previous methods factors are included.

$$U = k\sqrt{(u_c)^2 + (u_p)^2 + (u_w)^2 + (u_b)^2} \quad (3)$$

where: u_c — uncertainty component depended on standard, mm, u_p — uncertainty component depended on used procedure, mm, u_w — uncertainty component depended

on measured object, mm, u_b — uncertainty component depended on systematic error, mm.

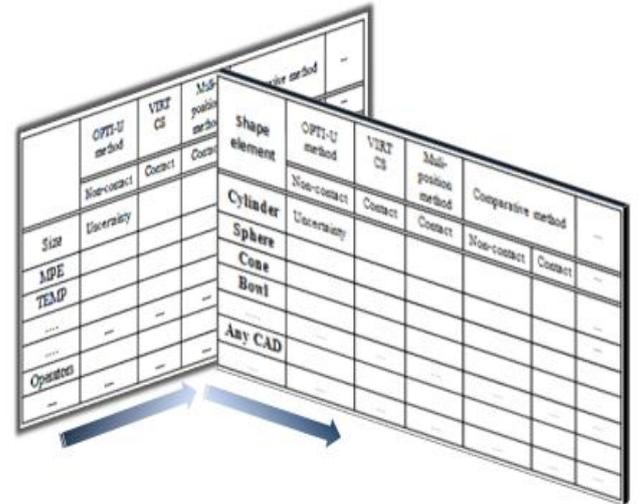
Summary of certain features of presented method are shown in Table 1.

Table 1. Certain features of method for estimation of the uncertainty.

| Method / feature | OPTI-U method | Multi-position method | Comparative method | VIRTUAL Coordinate System |
|---|---|---|---|---------------------------|
| Number of the element measurements repetitions in certain position | 6 | 3 | 10 | x |
| Number of the standard measurements repetitions in certain position | 3 | 3 | 10 | x |
| Number of positions | 3 | 4 | 1 | x |
| The element and the standard orientation in the measuring volume |  |  |  | Consistent with the task |

2.3. The concept of Intelligent Selection Matrix

The matrix (Fig.2) is developing to allow an estimation of the uncertainty of realized task by the use of data collected in the matrix of intelligent selection and also to allow an estimation for task for which there is no strict information.



$$\begin{bmatrix}
 x_{11} & x_{12} & \dots & x_{1m} \\
 x_{21} & x_{22} & \dots & x_{2m} \\
 \vdots & \vdots & \ddots & \vdots \\
 x_{n1} & x_{n2} & \dots & x_{nm}
 \end{bmatrix}
 \cdot
 \begin{bmatrix}
 y_{11} & y_{12} & \dots & y_{1r} \\
 y_{21} & y_{22} & \dots & y_{2r} \\
 \vdots & \vdots & \ddots & \vdots \\
 y_{m1} & y_{m2} & \dots & y_{mr}
 \end{bmatrix}
 =
 \begin{bmatrix}
 \sum_{s=1}^m x_{1s} y_{s1} & \sum_{s=1}^m x_{1s} y_{s2} & \dots & \sum_{s=1}^m x_{1s} y_{sr} \\
 \sum_{s=1}^m x_{2s} y_{s1} & \sum_{s=1}^m x_{2s} y_{s2} & \dots & \sum_{s=1}^m x_{2s} y_{sr} \\
 \vdots & \vdots & \ddots & \vdots \\
 \sum_{s=1}^m x_{ns} y_{s1} & \sum_{s=1}^m x_{ns} y_{s2} & \dots & \sum_{s=1}^m x_{ns} y_{sr}
 \end{bmatrix}$$

Fig. 2. Project of the matrix of intelligent selection of the uncertainty estimation method for measurements of basic geometry elements, where: x, y – certain factors

The matrix is constructed due to the measurement of basic geometry elements or those which can be compared to geometric elements such as sphere, plane, cylinder and so on, and also for calculated uncertainties for more complex tasks or for these realized under different conditions, or with different sizes under various MPE for certain sensors, strategies, or for certain operators – what is important for systems operating in manual or automatic system (e.g. CMM or AACMM). An important goal is the methodology for determining the optimal method for estimating the uncertainty for given tasks if there are alternative methods and their validations.

Estimated uncertainty of the measurement U_o (4) through the use of the Intelligent Selection Matrix is calculated as a weighted mean value from the uncertainties that had been calculated before for a given machine and for a given measuring task U_b [17] which meet the similarity condition with actually performed measuring task (Fig. 3). This generally means that for calculations they are only used uncertainties determined for analogous measuring tasks performed with the use of analogous measuring machines to actually performed one.

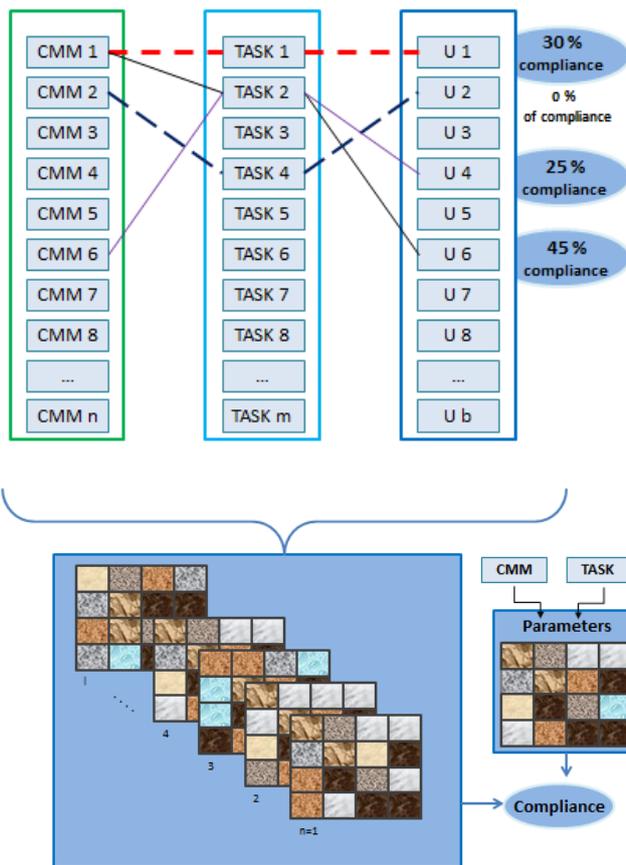


Fig. 3. Comparison between parameters of coordinate measuring machines and measuring tasks from previous measurements with those of actually performed one [17,18]

$$U_o = \frac{Z_1 * U_{b,1} + Z_2 * U_{b,2} + \dots + Z_i * U_{b,i}}{Z_1 + Z_2 + \dots + Z_i} \quad (4)$$

where: U_o — estimated uncertainty, mm, Z — the degree of compliance, U_b — uncertainties calculated before for given machine and for given measuring task, mm.

The degree of compliance Z is calculated in accordance to the following formula (5) [17]:

$$Z_i = \frac{Z_{CMM} + Z_{MT}}{P_{max}} \quad (5)$$

where: Z_{CMM} — the degree of compliance of Coordinate Measuring Machines, Z_{MT} — the degree of compliance of measuring tasks, P_{max} — the maximum number of points given for the identical systems and identical measuring tasks. Every uncertainty U_b is calculated in accordance to procedures used by given laboratory (6). Parameters which are not considered for given measuring task in the formula for uncertainty calculation have the value zero ($\alpha=0$). On the other hand for those which are considered $\alpha=1$.

$$U_b = \alpha |E_i| + k \sqrt{\alpha(u_1)^2 + \alpha(u_2)^2 + \dots + \alpha(u_i)^2} \quad (6)$$

where: α — occurrence factor, E_i — component of error, mm, k — extension factor depended on effective degrees of freedom, u_i — uncertainty component, mm.

For Intelligent Selection Matrix constructed to estimate the uncertainty of optical measurements, in order to perform the comparison of machines and measuring tasks so to calculate the degree of compliance of Coordinate Measuring Machines Z_{CMM} , and the degree of compliance of measuring tasks Z_{MT} the number of parameters is taken into account. All comparing information must be presented in the way enabling this comparison to be done clearly. Due to the significant differences both in machine constructions as well in measuring methods the comparison is preceded by the necessity of choosing the right type of machine (including the type of measuring probe head). The Intelligent Selection Matrix generally has a modular construction, allowing the user to expand it by importing information about given measuring task carried out with the use of given coordinate measuring system. That makes it useful and possible to adapt in every laboratory or factory.

3. CONCLUSIONS

The task of developing the Intelligent Selection Matrix to estimate the uncertainty of multi-sensor measurements is a promising project that has been pre-verified for chosen elements of varied geometry created with FDM method. Measurements carried out for both the basic geometry elements and these of more complex shape allow to build the intelligent matrix for selection and estimation of measurement uncertainty, especially for multi-sensor measurements. A new OPTI-U method dedicated to optical

measurements is also important here. More over works on the selection of an optimal method for uncertainty estimation for certain tasks through they mutual validation seem to be the right direction of works dedicated to creation an uncertainty matrix for given measurement tasks. The Intelligent Selection Matrixes can be built in two ways: as a developed ones including changeable accuracy of sensors or as a mono-sensor ones for a particular measurement system. Information collection during particular systems operation can take place automatically, based on the developed software supervising the collection of measurement results including as well the calculated uncertainty of measurements. For aproximate estimation of the uncertainty of non-specialized tasks it is proposed the use of a method based on artificial neural networks, which had been already used in LCM CUT when developing one of virtual CMM version [19-23]. The presented concept seems to be especially useful in industrial conditions where the necessity of an estimating of the measurements uncertainty is an important problem even for very experienced operators.

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