XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22 - 27, 2003, Dubrovnik, Croatia

DATA PROCESSING AND INFORMATION ASSESSMENT IN SCALES MEASUREMENT SIMULATION

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Abstract The paper deals with the data assessment and implementation of scale measurement simulation using computation by PC. The PC simulation was applied to the newly developed method of the raster scales measurement. The metrological functions of the computer simulation are described explaining the new method of circular scales measurement, and the main features of the system are also explained. Computer simulation (CS) system consists of the object of measurement – the circular scale – and the reference measure, scale-reading sensors, the registration of their readings and their processing. The equations of the result evaluation are given, for which the statistical means are used for result evaluation. The diagram of the CS system is presented. The system is developed to fulfil the tasks necessary for engineering and education. The measurement is simulated to assess the metrological properties of the method applied and for educational purposes as well. The interactive mode of measurement is simulated to change the parameters being measured and to use the static and dynamic modes of measurement. The results of measurement are calculated using the equations with large number of unknown parameters, expressing the errors of the scale.

Keywords: data, processing, measurement

1 INTRODUCTION

A wide range of methods for circular scale measurement is known from astronomy and geodesy sciences. Most of them are based on the calibration within full circumference of the angle formed by measuring microscopes which are positioned on the relevant strokes of the scale. There are methods known in general by the names of the scientists who have developed them. They are *Heinrich Bruns,* mathematician *Guido Schreiber,* French physicist and metrology scientist *A. Perard,* Swiss scientist *Heinrich Wielde, Heiwelynk, S. Jelisejev,* etc. [1, 2]. The most often used methods of circular scales measurements are based on comparing them against the reference scale, pulses of rotary encoder or rotary measuring table of high accuracy (for example, Rotary Index Table 1440).

The measurement presented here is simulated to perform a newly developed method of measurement of circular raster scales using three registering devices – sensors. Equations of the result evaluation are given, for which the statistical means are used for result evaluation. The diagram of the CS system is presented. The system is developed to fulfil the tasks necessary for engineering and education.

The measurement is simulated to assess the metrological properties of the method applied and for educational purposes as well. During real engineering measurements the reference scale and scale to be measured are placed on the table of the comparator and photoelectric microscopes are adjusted on the opposite strokes of the circular scale to be measured. The readings from the two pairs of microscopes are input into computer for data processing. For educational tasks the data of the reference measure are stored in the PC memory, and data of "measurement" are input manually at every step of measurement according to program. In both cases the data processing is freely selected according to user's requirements and for the presentation of the results in the desirable form. Systematic error evaluation and uncertainty limits according to the chosen confidence level of the measurement are usually calculated for engineering purposes.

The interactive mode of measurement can be simulated to change the parameters being measured and to use the static and dynamic modes of measurement. The self-calibrating design of measuring instruments for the simplification and accuracy improvement of instruments is described in [3]. Some examples of self-calibrated measurement systems are given. The simulation process can help for explanation and practical aspects of measurement and for checking, for example, the instrument's accuracy parameters and improve them by self-calibration abilities. Theoretical background for the basic algebraic relationships of entropy, relative entropy and mutual information are presented in [4]. The information theory is very relevant for the scales (including raster scales) measurement process as the accurate position practically can be determined only for relatively small number strokes in the scale. A great amount of uncertainty of the scale's accuracy remains. Not only angular or linear position of the strokes in the scale can be determined by the method described in this paper. Some types of scale deformation also can be investigated having prior investigations on the influence of deformation of the strokes under some load applied to the scale. The law of the scale loading must be known and strokes displacement under this load can be determined during the measurement. The investigation presented here has the task to create the means for measurement simulation of the circular scale measurement that could be transferred into the engineering practice. The reasons for the errors are deformation, thermal expansion, etc.; they have not been explored at this stage. The presented method of measurement serves for the investigation of a new measuring method based on the calibration of 180˚ reference angle determined by the same scale and for the evaluation of other statistical characteristics of the process. The results of measurement are calculated using the equations with large number of unknown parameters, expressing the errors of the scale. The information entropy of measurement data is assessed. The main items of the process and the algorithm for solving it are presented.

2. THE MAIN PRINCIPLE OF THE SYSTEM

The angle of 180° of high precision can be set up by means of the circular raster scale to be measured, two opposite microscopes and the axis for the scale rotation [1]. By adjusting the microscopes in the tangential direction, such position can be reached when readings from both microscopes are equal after turning the scale to 0° and 180°. Microscopes 1 and 2 are set for determining the standard angle of measurement. The third microscope is set on the optical axis of one of the strokes of the raster scale. The readings from microscope 1 are designated as a_i , from the second as b_i. and from the third - c_i. Initial readings will be:

$$a_0 = 0;\ \delta\varphi_0 = 0;\ \delta\varphi_n = b_n\ ;\ \delta\varphi_{2n-1} = -\Delta \qquad (1)$$

Further readings give the system of equations:

$$\begin{cases} c_i = dj_i - \frac{1}{2}\left(dj_{i+1} + dj_{n+i+1}\right) + \Delta, \\ \Delta = -dj_{2n-1}, \end{cases} \qquad (2)$$

where i is the strokes' number, i = 0,..., 2n-1;
the total number of the strokes in the scale is $2n$;
dj_i - angular errors of the strokes, and Δ - the error of the set position of the third microscope.

After expanding the system and some arrangements such general expression of the errors is:

$$\begin{cases} dj_i = \frac{1}{2}\left[dj_n + dj_0 - c_{n+i} + c_i - \sum_{j=n}^{n+i-1}(c_j + c_{n+j}) + 2i\Delta\right], \\ dj_{n+i} = c_{n+i} - c_i + dj_i . \end{cases} \qquad (3)$$

An error calculation program has been developed (program PAKLDF). Solving of equations by computerised methods is performed using unknowns changing methods. These main concepts of measurement were chosen as the basis of computer simulation (CS) system development [5].

The main goals of this CS study would be formulated as follows:

i) create CS methods for the functioning process of measurement of physical quantities simulating the instrumental steps performed on the object using a reference measure, their comparison and transfer of measurement information for its evaluation;

ii) simulate the different limits of errors investigation comparing it to the engineering needs and possibilities;

iii) facilitate the performance of measurement including the influence of environmental and intrinsic errors;

iv) investigate the different methods of measurement by the means created;

v) investigate the static and dynamic characteristics of measurement;

vi) use of the CS system for further investigations and educational process expanding intrinsic and external errors influence and mathematics data evaluation means.

As it is defined in some references on measurement theory measurement is a comparison of a physical quantity with some value known as its unit of measurement. Quantity is an attribute of phenomenon, physical body or substance, abstract concept defined by the method of comparison with the standard measure, evaluating it by means of mathematic statistics within the appropriate limits of confidence. An object of measurement can be a single entity, set of entities and systems, relations between the quantities and variations due to their interaction. Personal, instrumental, methodical, environment errors as well as concomitant and non-concomitant errors are bound up with the process. Models of measurement are known as physical and mathematical their simulation, computer simulation means getting wider implementation transferring it to multimedia simulation means. Computers are mostly used to receive information from the measuring instrument, interact with the instrument of measurement, the latter interacting with the object to be measured [6]. Computer evaluates information collected according to method selected and presents it in the form convenient for assessing, transfer and necessary control or correction actions to be taken.

Expression of measurement in general shows the comparison between the value of the object to be measured and its reference value:

$$d_i(x) = d(x)_i - A, \qquad (4)$$

where $d_i(x)$ – numerical value of physical quantity, measurand; A – unit of measure of this physical quantity, a reference measure; $d(x)_i$ – numerical value of measured quantity.

The result of measurement is expressed as

$$X = \bar{x} \pm e, P, \qquad (5)$$

where $\bar{x}$ - mean value of the set of data, developed by evaluating of set of measurands $d_i(x)$;

e - evaluation of mean square value (S) of measurements at the confidence level P.

These main concepts of measurement were chosen as the basis of CS system development (Fig. 1). Process of measurement also can be described as a ratio achieved between two physical quantities unilaterally connected between them, it is, some kind of transformation of unknown value to the other kind of value or the type of its presentation. The scales play especially significant role in the measurement process. The scale of the physical values it is the set of its quantities denoted according to uniformly accepted rules. Because the scales are present in almost all measurement processes and instruments, they play the most important role in the measurement itself. The CS presented here deals with measurement of scales demonstrating it for the measurement of circular scale. Measurement of the linear scale would be easier to organise and demonstrate.

3. SYSTEM REALISATION AND DATA PROCESSING

CS must implement the means of checking the methods of measurement verifying the results achieved and their analysis. The diagram of the main elements of measurement

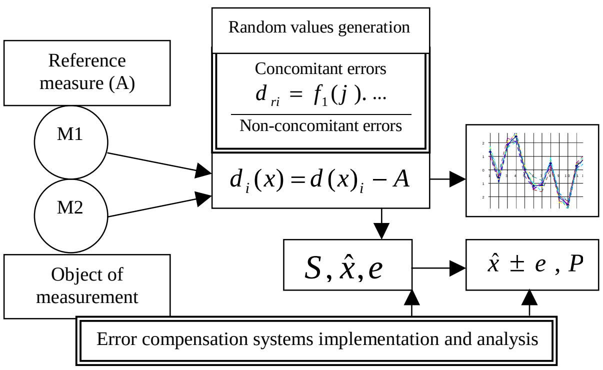

Fig. 1. The main elements included in the CS measurement system

included in the model of CS system is shown in Fig.1. The model consists of the object of measurement and reference measure, scale reading sensors M1 and M2, results collecting, transferring and evaluation system and presentation of the results in the required form. Standard mathematic statistics means are used for result evaluation. For engineering applications the measurement system is designed to have an input signal $F_i(j)$ that could be expressed as general n^{th} order linear ordinary differential equation, and output signal $F_o(j)$, represented by the equation developed from the error of the scale measurement by the CS means.

The first approach for CS system is chosen for circular scale measurement. The PC screen (pixel grid) is used as the reference measure. Measured values are recorded at the top and bottom diameter points of the scale thus imitating measurement microscopes (sensors M1 and M2). The object of measurement - circular scale - has on purpose made errors by displacing the strokes from their true position. There are cases where it may be impossible to solve all systems, as there may not be enough room in the computer memory to accommodate all data at one time. Standard mathematical software packages can be used for these tasks. Using these means, a lower - triangular matrix is created and the final result is obtained from the other identity matrix. Systematic errors and uncertainty of measurement are derived. The interactive changes are demonstrated for the educational purposes. The diagram and the results of systematic and random components of the measurement illustrate the virtual system of measurement versus the real tool as well. The development of CS method was performed in the cases when:

data are input in sequence by an operator,

data are stored in the file importing from it for evaluation,

data are supplied automatically by interface from measurement devices.

The scale is positioned by steps according to top and bottom measuring devices. Positioning goes in the rectangular co-ordinate system according to freely chosen centre. The measurement system (MS) has the instrumental constituents mandatory for the mock-up of the real system. The main performance of the system consists of intermittent and continuous links between the instruments of measurement and statistical software with standard programmes available. Next set of instruments and system performance capabilities are to be introduced according to requirements and of scope of measurement. Some other functional links, such as influence of temperature, etc., are planned to be introduced at the next stage of development. Errors of measurement are generated by random values according to the range predetermined prior to measurement. This function is controlled by push-button "GENERATE". Step by step positioning goes till the end of measurement, i.e., after completing full circle of the scale. The rate of positioning also can be changed, thus investigating dynamic properties of the MS.

Number of strokes in the scale can be predetermined using of top command window. The example shown uses twelve strokes, that is, enough for the demonstrative purposes. It is more convenient to work without displaying the view in the screen when number of strokes is great. The measurement can be performed manually and in the automatic mode. The scale rotation has possibility to move in clockwise and counter-clockwise directions. It can be controlled by arrows under the scale image. View of the measurement scale of the measurement instrument is shown at the centre of the display in enlarged scale. Results are read in the control element group "RESULTS". The results of eighth series of measurement are shown in Fig. 2.

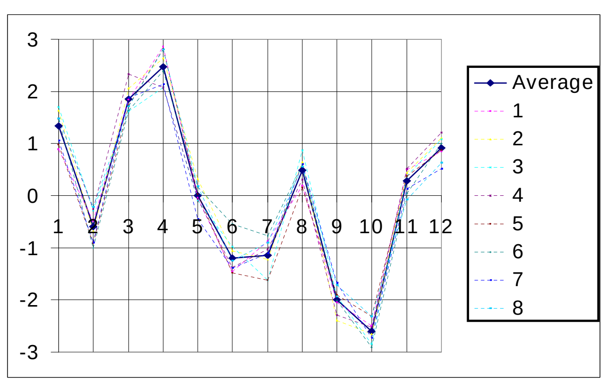

Fig. 2. Diagram of the results of measurement

Example of the results of the series of 64 measurements are stored in memory as demonstration version. The MS program is created by using of “Microsoft Visual Basic” program media.

Example of data evaluation using Mathematica software:

```
var_a = Import[“inputfile_a.txt”, “Number”]
var_b = Import[“inputfile_b.txt”, “Number”]
var_c = Import[“inputfile_c.txt”, “Number”]
n = Floor[Dimensions[var_a] / 2]
Take[var_b, (2n-1)] + Take[var_c, (2n-1)] +
Apply[Plus, Take[var_a, (2n-1)]] - Apply[Plus, Take[var_a,
n]] >> resultsfile.txt
```

First, three numeric variables are formed out of three text files, and a summation coefficient is evaluated dividing the number of elements of one variable and eliminating a fractional part [7]. Next, using *Take* functions appropriate numbers of variable elements ($2n - 1$ or n) are used to evaluate an expression and save the results in a result file. *Take* functions work with individual elements of variables, while *Apply* in conjunction with *Sum* sum up a given number of Variable *a*.

Experimental investigations of the new method for engineering purposes show a good coincidence of the results. The same scale of 150 mm in the diameter having 5400 strokes in the circle was measured using the step of measurement of 3°. The measurements were verified using the Rotary Index Table 1440 of high precision. The overall systematic error of the scale measured by the new method was determined as being 5.2” (seconds of arc), and during the verification on the Index Table, the result was 5.35’. The standard deviation of measurements by the Rotary Index Table 1440 lies between ± 0.15”.

4. CONCLUSIONS

A computer simulation method applied to the new raster scales measurement method is proposed together with data processing and evaluation. Data acquisition and interactive mode of processing permit to implement wide range of metrological and education tasks. Measurement simulation can be used for the development of new instrumentation means for circular scales measurement and development of more efficient practical data assessment structure using mathematic statistics.

Engineering investigations of the new method of circular scales measurement show a good coincidence of the results.

Computer simulation of the circular scales measurement is useful for the educational purposes for demonstrating the principles of measurement and for engineering purposes serving as instrument for measuring process development.

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