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INDUSTRY 4.0 AND INTERNET OF THINGS: TO BE OR NOT TO BE? THAT IS THE QUESTION TO METROLOGY

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Abstract: It is shown that the era of Industry 4.0 and Internet of Things will bring expected results only in case of efficient solution to a number of metrological problems related to multichannel measuring systems. Possible prospects are outlined.

Keywords: multichannel measuring system, measurement information reliability; redundancy, transmission of measurement information

1. Introduction

In the last century, H. Wells, E. Zamyatin, A. Huxley, G. Orwell, R. Bradbury, R. Kurzweil, M. Kaku, and many others have emphasized different sides of the future. However, one can find some common features in their conceptions that are characteristic for coming era of Industry 4.0 and Internet of Things: from great variety of objects and subjects, enormous volume of measurement information will come into various automatic control systems (ACSs). This will result in:

1) the increase in the number of multidimensional quantity measurements characterizing:

• individual features of people, their state of health, the level of abilities, mood, as well as their location, peculiarities of behaviour, etc.;

• quality of educational, medical, and other services;

• efficiency of traffic organization, as well as heat, water and power supply and other activities carried out for inhabitants;

• quality of products, and so on;

2) multiple increase in the number of measuring instruments including sensors (hereinafter referred to as MIs) and expansion of their application areas (up to a MI set as a bracelet or chip implanted into a body);

3) integration of MIs into multichannel measuring systems and integration of their sets into cyber physical systems being a core of automatic control systems (ACSs) intended for “smart cities”, “smart healthcare”, “smart manufacture”, etc.;

4) variation of the channel number, and sometimes, of measurands in the course of ACS operation process;

5) growth in the share of wireless communication of MIs with measurement data processing units, including cloud complexes.

Such evolution of the role of measurements in the civilian life will cause inevitable difficulties related to designing measuring systems. If they are not overcome, the concept of the future should be supplemented by the pictures of wide range tragedies and catastrophes caused by error decisions made in ACSs. These difficulties are caused by the following reasons:

• growth of the operation condition uncertainty for many MIs;

• tightening the requirements for the time interval between the moments of forming measurement information and making a decision in the ACS;

• reduction in the number of personnel that can maintain MIs;

• increase in the requirements for the level of interference immunity of measurement information taking into account the expected increase in the number of attempts to deliberately distort it or steal.

2. Metrological problems

In spite of the difficulties mentioned above, a new generation of ACSs should provide the reliability (trustworthiness) of measurement information coming to data processing units.

Measurement results are generally referred to as reliable if they are received with the help of the MIs that are “healthy” in the metrological sense. (Such MIs are characterized by the measurement uncertainty that does not exceed the uncertainty given in their specifications [1]).

This definition should not be considered satisfactory. In the course of an operation process, some non-standard variations of measurement conditions can take place. They are associated, e.g., with magnetizing a part that performs the function of a “target” in an eddy current sensor, increasing air humidity in the gap between the electrodes of a capacitive sensor, etc.

It will be more specific if we recognize reliable such a result that is produced by a MI, for which, with a rather high probability, the metrological characteristics and measurement conditions correspond to those specified in the documentation.

To achieve the required trustworthiness by organizing the metrological maintenance of all the MIs included in ACSs of new generation by a traditional way is economically unacceptable, since the usual calibration interval is equal to 1-2 years.

However, without any metrological maintenance, to justify a multi-year lifetime, which is close to the “moral obsolescence” time, is unlikely, even taking into account the possible growth in the component reliability.

The opportunity to avoid hard consequences of erroneous actions of the ACSs is to identify automatically the fact that the measurement result uncertainty is approaching to the permissible limit. After that, depending on of the system features:

- to transmit a danger signal for performing urgent metrological maintenance or
- to correct the measurement result of the MI automatically.

Meanwhile, the time interval between the moment of forming the danger signal and moment of its coming to the ACS data processing unit should not exceed a permissible value.

The situation is aggravated if it concerns multidimensional quantities, since variation of any parameter determining the measurement result influences the measurement reliability. This circumstance forces engineers to seek the multidimensional measurement models with the minimal dimensionality.

The task of automatic tracking the uncertainty growth is associated with another topical task of the coming era, namely, prognostics concerning the changes in multidimensional measurands in the course of time. This aspect requires special attention to the analysis of the reasons of the parameter change as applied to the tasks examined.

Thus, the development of efficient ACSs for the Industry 4.0 and Internet of Things is only possible if some important metrological problems are solved. They concern:

- increase in the metrological reliability of MIs and methods of its experimental evaluation;
- automatic check of the reliability of measurement information coming from MIs;
- automatic correction of the uncertainty of measurement results;
- timely transmission of a warning signal if the measurement uncertainty exceeds a permissible limit;
- optimization of measurement information flow coming to the data processing unit based on the actuality level;
- protection of information from interferences and unintended or unauthorized intervention;
- provision of noise immunity and security of measurement information transmission;
- development of the models for measuring multidimensional quantities with the minimal dimensionality;
- prognostics (with the uncertainty evaluation) concerning the course of the process of multidimensional quantity changes.

3. Possible ways for solving metrological challenges

Evaluation of the metrological reliability of MIs is carried out by accelerated tests that have to be performed at several stages. At the first stage, under the forced impact of the influencing quantities specified in the documentation, the distribution of uncertainty components and identification of those characterized by the fastest growth rate, should be carried out.

Further, one should determine the parameters that affect these components to the greatest extent, and then to evaluate experimentally the time interval during which these components will lie within acceptable limits under operating conditions.

If the result does not satisfy the requirements, it is necessary to correct the design of the MI for reducing this component and after that to repeat the tests.

For the automatic check of the MI metrological health and of the measurement result reliability, some additional measurement information is required. It should be based on the MI redundancy (functional, temporal, structural, or combined). The concept of the automatic checking [2, 3] was formed in the USSR in the 80s, because it could rely upon the invariance theory being developed by B.N. Petrov, K.L. Kulikovsky, Yu.M. Tuz and their co-authors. By now, the concept has been outlined in many articles and reports and supported by national standards [4-6].

According to the terminology given in [4], such a check is called metrological self-check. It can be performed in two forms: a direct one, presupposing the integration of a measurement standard in a MI or multichannel measuring system, and an alternative one that is a diagnostic check. MIs and systems with the metrological self-check are called intelligent ones [4]. The measurement standards also include a description of self-check methods [5] and requirements for accelerated tests [6].

A number of examples are given in [3, 5, 7, 8]. Recently, to calibrate optical MIs measuring linear sizes, images of objects with known dimensions have been increasingly used [9]. This is a version of the direct metrological self-check.

A disadvantage of the direct self-check is that, as a rule, it can be implement only in one or several measurement range points. Therefore, it can be applied if a measurand value can be within the zone of the material measure value quite frequently. The use of an embedded wide-range MI of a higher accuracy raises doubts as to compatibility of a greater accuracy, greater metrological reliability, and efficiency.

The tendency to reduce the cost of measurement standards based on quantum effects [10] opens up new opportunities for such self-checking, but it does not eliminate its disadvantages. As applied to measurements of non-electrical quantities, the direct self-check usually gives way to the diagnostic one in efficiency, although the latter enables tracking the growth of not the whole uncertainty, but only of its component that is dominant (critical) under operating conditions of the MI [4, 5].

The choice of the critical component should be justified by investigations at the initial stage of the intelligent MI development.

In its structure, the redundancy should be revealed or introduced artificially. By using the redundancy, a quantity, which is affected by measurement conditions significantly weaker than the critical component, should be determined. Then to select a diagnostic parameter characterizing the level of the critical component is necessary.

At the calibration stage, the reference values of the diagnostic parameter have to be evaluated. Using them, it is possible in the automatic mode to correct the increasing uncertainty, predict the MI residual life, and transmit the danger signal to the data processing device, if necessary.

As a result, for the intelligent MIs, the prospect to provide the reliability of measurement results during an extended lifetime without metrological maintenance becomes real.

Intelligent MIs of various non-electrical quantities were developed in Russia (including the MIs developed by the present paper authors from the VNIIM), in Ukraine, UK, USA, China, and other countries. However, at present, the mass production of such MIs has not been organized yet, which probably is in line with the Kuhn's law.

Therefore, in the next few years, ACSs of the new generation most likely will apply the metrological self-check organized within the frames of multichannel measuring systems by intellectualizing the systems as a whole. Such type of intellectualization is based on the correlations between measurement results obtained in different channels of the system.

A system measuring the space distribution of a quantity that is slowly changing with time can be considered as an example. In [11] the authors suggest to introduce a correction into the readings of some MIs in accordance with measurement results obtained in neighboring channels. The checking and correcting algorithm relies on the method of incremental machine learning and Unscented Kalman Filter. However, the proposed method has a disadvantage: it does not reveal a measurement uncertainty component caused by unidirectional drift, the speed of which is close for the most part of sensors.

Another example is the organization of the metrological self-check of fastening the hydro-turbine cover. Here, measurements of displacement (stretching) of bolts fastening the cover, relative to rods fixed inside them, at 8 equidistant points along the cover circumference, are carried out. A water pressure change in the turbine leads to the change of the mutual positions of the rods and bolts. Due to the stiffness of the cover, the bolt displacements are correlated with each other.

The abnormal stretching of the bolts or the appearance of other fixation defects, changes the initial ratio of displacements, which makes it possible to draw attention of an operation personnel to this fact in time. If original ratios of displacements are kept within the acceptable limits, this fact confirms the "health" of both the fastenings and measuring system. As a result, the cost of measuring system maintenance can be reduced by increasing the calibration interval.

In the future, to include intelligent MIs into channels of measuring systems is expedient. This will enable reducing the dangerous effect of an undetected systematic component of the uncertainty common for all the channels or the most part of them.

It should be emphasized that in the new generation ACSs, the concept of the urgency of measurement information and that of determination of its priority degree is significantly complicated and depends on the changing situation.

For example, in the ACS of urban traffic, not only information about the threat of a possible metrological malfunction, but also about an accident that has taken place [12], a potential accident, and related information, deserves a priority.

One of the methods aimed to optimize measurement information flow coming from a large number of MIs, is substantiated in [13, 14].

Under the limited bandwidth of communication channels, it enables the system to reduce the delay of critical data triggered by important events. The method using a cluster tree topology is applied for developing a prioritized transmission scheme named Pritrans.

However, this method requires significant calculation and time resources. The uncertainty is corrected at the lowest network levels. The flow of the rest information should be optimized according to the modern approximate solutions to the Kemeny task.

In order to enhance the reliability of measurement information transmission, the methods, which are traditional for radio communication, are useful: frequency or code modulation with redundant encoding, as well as measurement information duplication or encryption.

In this context, PRISM technology based on application of a fully recursive, dual output, FIR filter [15] is useful. It can be applied to autonomously detect, track, and compensate for an undesired measurement uncertainty component of data transmitted from any frequency output sensor.

For the systems with open access to the Internet, organization of pseudorandom changes in IP-addresses for the objects included in the system [16] is reasonable.

Multidimensional measurement models with the minimal dimensionality become particularly relevant in the context of the projects “Smart healthcare”, “Smart and safe city”, “Smart manufacture”, etc. being developed in a number of countries. Usually, such a model distinguishes itself by an important advantage: it reflects a real mechanism of multidimensional quantity formation. As a result, new opportunities arise to carry out controlled changes of the measurand.

However, to develop such a model, the complex consideration of the process under modelling is necessary, requiring interdisciplinary cooperation of specialists in many cases. The experience of the VNIIM co-authors of the present paper, which concerns the model for measuring emotions caused by acoustic impacts, testifies that cooperation of metrologists with neurophysiologists, psychologists, and mathematicians is successful and eventually gets positive assessments of the work participants.

In recent years, the theme of predicting the processes of quantity changes has become the popular one due to the increase in the available amount of measurement information.

The need for it has grown in medicine, since it enables facilitating the choice of a treatment method and minimizing the probability of undesirable consequences as well as in technology since it allows optimizing the costs of equipment maintenance, in social process management, etc. [1, 17, 18]. In prognostics, the application of the linear extrapolation of consecutive experimental data and their correction is expedient. Thereby, it is possible to use weight coefficients depending on the distance of interpolation nodes from a current value, data sets displaced from an initial set as well as results of the analysis of expected change reasons.

4. Conclusions

The revolution Industry 4.0 is inevitable. However, the pace of its realization and efficiency, to a great extent, will depend on solving a number of metrological problems that are not always adequately understood and taken into account. Among the most actual challenges are the issues related to:

- trustworthiness of measurement results being obtained;
- timeliness and security of their coming to a data processing unit,
- forming the prognoses of the course of the process analyzed.

International standardization concerning possible solutions, which are accepted by the metrological community, to these actual metrological problems, is necessary.

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