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Increasing Measurement Trustworthiness as a Necessary Part of Technology Development

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Abstract: The authors have analysed the development trends of the main technologies related to the application features of measuring instruments (MIs) and multichannel measuring systems (MMSs) as well as provision of their trustworthiness. The analysis has made it possible to propose a methodology for automatic checking metrological health of MIs and MMSs in the course of their operation, which was called "metrological self-check". The self-check enables calibration / verification intervals to be significantly increased. In case of virtual test and artificial intelligent application, automation of the trustworthiness provision becomes possible for traditional measurements. It has been shown that the problem of trustworthiness related to soft measurements taking into consideration the growing interest in them, also becomes actual.

Keywords: Industry 4.0, Measurement trustworthiness, Metrological self-check, Digital twin, Virtual tests, Artificial intelligence, Soft measurement.

1. Introduction

Provision of measurement trustworthiness is the basis of legal metrology. Measurements plays a meaningful role in communication between people and, in a figurative sense, between human and processes under control. The discrepancy between a measurand value expected by its "recipient" and a real quantity value measured, can lead to undesirable situations, sometimes with tragic consequences.

A fundamental metrology requirement aimed at providing the trustworthiness is as follows: for any sensors and measuring channels (hereinafter, this set is called measuring instruments (MIs)) as well as multichannel measuring systems (MMSs), measurement uncertainty should remain within permissible limits under specified external conditions throughout the lifetime. As a consequence, to check the fulfilment of this requirement, i.e., to check metrological health, is necessary. Since over time, characteristics of any MI are changing due to arisen defects, systematic worsening of material properties, or, e.g., weakening component fasteners, the concepts have originated related to periodic calibration / verification and intervals between such procedures.

These procedures involve the cost of their implementation. In the course of human civilisation development, methods of measurements and MI technologies have been improved, the number and accuracy of MIs being increased. Accordingly, the total costs on the metrological health maintenance have increased; to reduce them has been desirable. As a result, the evolution process of trustworthiness provision methods has become an organic part of technology development.

The pace of technology development at the second part of the 20th century and beginning of the 21st century is many times higher than that inherent in the earlier period. The analysis of correlations between technology development stages, on the one hand, and features of the methods for measurement trustworthiness provision, which were developed during these stages, on the other hand, gives the basis for revealing the regularities of the considered process. Looking under this angle, to foresee new tasks in this field, which specialists in metrology will face in the near and more distant future, becomes possible.

This paper is an extended version of the paper presented at the ARCI'2021 [1].

2. Provision of Measurement Trustworthiness as a Part of Technology Development in the 20th Century

In the context considered, the most meaningful technological solution that has been applied since the beginning of the 20th century, is conveyor production with the elements of control automation.

Significantly, any forced conveyor shutdown and resulting operation downtime that concern, in particular, carrying out calibration / verification, result in costs due to the output reduction, while the occurrence of a metrological failure in applied MIs leads to supplement costs related to production spoilage.

As a consequence, the requirements for checking the metrological health of MIs used in technological processes, including those embedded in equipment, have arisen. These requirements should have taken into account the possible effects of varying loads on the MI, which depended on a technological process.

Ideally, the procedure should be carried out after a measurement series being fulfilled by the instrument under checking, but without stopping the equipment. The duration of the interval between checking procedures is determined by a permissible value of an expected change in uncertainty during this interval. While choosing the interval, economic losses that will arise in the case of an unhealthy MI eventually can serve as the main criterium. To carry out such a periodic checking is possible based on indirect features, in particular, production features, e.g., to measure the finished part sizes which should correspond to the specified values, is possible [2].

In the years that followed, these technological solutions have been improved and used more and more widely in automatic machinery, power units, transport, including aviation and spacecrafts, in medical technology, etc. The value of metrological failure consequences has been growing up. Accordingly, the requirements for checking have been tightening. In technical systems of high importance, calibration / verification intervals should have been reduced to the values that were significantly lower than those being determined by the expected changes of the measurement uncertainty.

Simultaneously, the human role in automatic control systems (ACSs) was concentrated on the equipment operation failures (e.g., those caused by appearance of untrustworthy measurement information), and prevention of situations which could result in accidents.

The search for new solutions has led to the understanding that the prototype of ACS first emerged in living organisms. Accordingly, evolutionary experience could be useful in improving technologies. Cybernetics has emerged relying upon the analogy between the biological evolution and development of technical systems [3-5]. Then, computer technologies have become a part of production process, which provided tools for ACS improvement.

At the end of the 20th century, the rapid growth in the number of MIs and MMSs included in ACS was noticeable. That process was accompanied by

- The transmission of measurement information over significant distances in order to carry out control operations and
- The wide use of computer technologies including cloud ones for processing measurement information.

The mentioned tendencies have stimulated the search for methodology that allows minimizing costs for provision of measurement trustworthiness by transition to automatic checking the metrological health (metrological self-check / self-validation) of MIs and MMSs [2, 6, 7].

The end of the 20th century has brought strengthening the links between professionals living in various countries. People were increasingly treated or studied abroad. The tendency has been marked to integrate processes across sciences while developing new technologies, in particular, those related to the re-engineering of clinical medicine. The need for provision of metrological traceability and accordingly, of measurement trustworthiness has emerged not only in engineering and physics, but also in chemistry, laboratory medicine, biology, biochemistry, molecular biology, food science, forensic science, etc. All this indicated the arrival of the next technological revolution, which was reflected in the 3rd edition of the International Vocabulary of Metrology [8].

3. Changes in Technology and Associated Metrology Solutions at Industry 4.0 Stage

3.1. Metrological Self-Check in MIs and MMSs

At the stage of Industry 4.0, the range of mass-produced MIs and MMSs noticeably expands. This is especially true with regard to the devices assigned for chemical manufacturing processes and medicine. Among the latter, MMSs automatically forming a medical diagnosis based on many parameters, are of particular interest, e.g., [9, 10]. Accordingly, a variety of methods and means for ensuring measurement trustworthiness increases. For the first time, this statement concerns measurements of multidimensional quantities, the influence of each parameter on the measurement result being not equal.

A noticeable part of MIs and MMSs are produced by small batches. Their cost is high, which, in many cases, excludes the possibility of their duplication. The situation with built-in MIs, e.g., used in hazardous production, is similar. For them, calibration / verification on site, as a rule, is impossible. To deliver the devices to a specialized metrological centre can cause a long downtime. Consequently, it is highly desirable for an owner of these devices to provide their high metrological reliability This will make it possible to maximize the interval during which the owner can be confident in the measurement trustworthiness.

To improve the trustworthiness of measurements, to apply a metrological self-check / self-validation in MIs and MMSs, is necessary [1, 2, 6, 7, 11-13, 14-17]. The use of these methods does not contradict ISO standard [18] that does not limit metrological maintenance methods to traditional ones. The idea of the metrological self-check was proposed in the 1980s [6], but only at the stage of Industry 4.0 its implementation becomes inevitable. The metrological self-check relies on the redundancy that should be revealed or artificially introduced in a MI or MMS.

The applied redundancy can be of spatial (structural), temporal/frequency, functional (informational) character. In some cases, it is expedient to use a combination of two or more types of redundancy in the same MI or MMS. The metrological self-check can be developed in the form of a diagnostic one or direct resembling calibration [19-21]. Moreover, it can be organized both at the level of the MMS as a whole and in separate sensors or measuring channels.

The self-check enables revealing a metrological failure or significant uncertainty growth, which as a consequence, opens the way for the automatic correction of the latter [2, 11, 14, 19].

The self-check methods provide the ground for meaningful extension of calibration / verification intervals. In the event of metrological failure, such methods enable taking measures to eliminate it quickly with the minimum costs.

The diagnostic self-check has resulted in the emergence of a concept "critical uncertainty component" that was new for measurement science. The thing is that the reason of the growing uncertainty can concern several influence quantities. The most dangerous ones cause a predominant or rapidly increasing uncertainty component that is called the critical one [19-20].

To determine it, at the first stage, it is necessary

- To analyze the operation experience of an analogue MI or develop and manufacture a prototype,
- After that, to test this prototype or the analogue for the impact of influencing factors which are considered essential.

At the second stage, the analysis of uncertainty components should be carried out. From them, the component corresponding to the above definition should be singled out. If some of the components can be significantly reduced by changing the design elements of the prototype, to do so is appropriate.

Numerous realisation examples of the metrological self-check (both direct and diagnostic ones) of sensors and MMSs are given in [14-16, 19, 20, 22, 23]. Recently, information on new interesting developments has been published.

In Russia, these themes are of particular actuality since the metrological maintenance of a significant part of MIs and MMSs falls within the scope of the state regulation. Most of the examples below relate to developments fulfilled in Russian organizations.

In particular, Kalashnikov in [24] proposes that the metrological diagnostic self-check of a level meter based on the conductometric principle can be carried out at an NPP by using the functional redundancy.

The main element of this level meter that, in essence, plays the role of MMS, is a set of conductometric cells. The difference of the electric conductivity at the border of fluid and vapour, enables determining the fluid level.

The functional redundancy is realized due to the periodical switching of the conductometric cell set to an EMF measurement mode. In polar fluids, particularly in water, the value of EMF is significant, while in the case of saturated steam, it is equal to zero. By comparing the results of measurements in the conductometric and the EMF measurement modes, to judge about the trustworthiness of level measurements is possible.

The authors of [25] describe the organization of the metrological diagnostic self-check of a sensor assigned for measuring the tension force of reinforcing steel ropes located on the concrete containment of nuclear reactor.

The sensor includes 12 primary transducers and can also be considered as MMS, although the tension force is ultimately determined by the sum of forces measured by individual transducers. In this device, functional redundancy is used. Its basis is the presence of a reference virtual plane that can be constructed taking into account the location of transducers as well as their characteristics. The deviation of output signals of individual transducers from this plane, indicates the change in their metrological characteristics. Accordingly, measurement results are not considered to be trustworthy.

Khodunkov in [26] proposes a self-calibrating temperature sensor comprising a thermoelectric transducer, cold junction unit, microprocessor control unit, and cooling unit of a cold junction unit. Under a wide range of influencing conditions, it can be considered as the sensor with the metrological self-check based on time and functional redundancy. In the sensor, the cold junction unit includes a heater and reference thermosensitive element, cooling device of cold junction unit being installed on thermoelectric transducer head. In the self-check mode, the cold junction is heated, the thermoEMF of the thermoelectric transducer is measured using the microprocessor control unit, while a temperature deviation is determined with the help of the reference thermosensitive element. To calculate the thermoEMF coefficient is possible on the basis of the difference between the thermoEMF values before and after heating as well as temperature deviation. This coefficient should be compared with the calibration parameters. If the obtained value lies within permissible limits, measurement information from the thermoelectric transducer is trustworthy.

In [27], the same author shows the way to improve this sensor operation and turn from a statical version to a dynamic one. The aim is

- To reduce the time interval necessary for self-checking and
- To provide this operation under changing temperature of the environment being measured by the thermoelectric transducer.

To achieve this aim, when the cold junction is heated, both current thermoEMF values of the thermoelectric transducer and the cold junction temperature are registered simultaneously. Then, the time derivatives of these parameters and thermoEMF coefficient taking them into account, are calculated.

A four- channel radiation thermometer [28] developed by Ionov, *et al*. applies the direct self-check (a special lamp that plays the role of a reference standard) and diagnostic one. In this device, the metrological self-check relies upon all the main kinds of redundancy.

By the use of redundancy, the authors reveal and correct the influence of both ageing of the transducers and external factors such as imperfection of object surface, radiation weakening due to atmospheric aerosols as well as absorption of thermal radiation by water vapour.

Koenig in [29] calls analogues functions "self-X capabilitues" and includes, e.g., self-monitoring and self-healing in them. In essence, these concepts correspond to self-check and self-correction, respectively.

As one of the examples, the author considers a magnet rotary encoder. The use of signal harmonics (frequency redundancy) enables providing wide diagnostic capabilities with regard to the signal quality and device parameters.

It follows from the above that application of the metrological self-check is effective in separate MIs and MMSs. However, below there will be shown that the metrological self-check is the most demanded in cyber-physical complexes.

3.2. Metrological Self-check in Cyber-physical Complexes

A characteristic feature of the new technological revolution is the widespread application of cyber-physical complexes. They include "smart manufacturing", "smart transport", "smart houses", "smart cities", "smart healthcare", etc. The exploitation life of such complexes before being modernised is highly likely to be estimated not less than 10 years, while common calibration / verification intervals is equal to 1-2 years.

ASC of cyber-physical complexes include computerised MIs and MMSs as the main element. With the present-day instrumentation technologies, there exists a significant probability that the metrological characteristics of the used MIs and MMSs will lie outside the tolerance before they are modernised. As a result, the efficiency of such complexes can be reduced to unacceptable level.

Centralised supply systems for such resources as gas, electricity, water, and petroleum products can be considered as examples. The need for controlling resource flows and measuring their parameters has led to the emergence of appropriate ACSs with numerous MMSs distributed over large areas. In many cases, measurement results obtained in MMS measuring channels are directly or indirectly interlinked. Then, there exists a possibility to organise the metrological self-checking based on the available functional redundancy (at the level of MMSs as a whole).

In particular, to estimate the required resource amount in various districts and maintain ACSs in a serviceable condition, the data on resource consumption received by each customer which is confirmed by device indications, should come to control centres.

If the data from customers do not correspond to the centre data on the resource amount that has come to this district, the measures should be taken on detecting the places where failures occurred. In many cases, the reasons for such a situation can concern metrological failures of sensors or measuring channels of the MMS.

In order to organise the efficient metrological self-check, MMS should be multilevel, each channel from the centre at any level being divided into next level channel groups that transmit the resource to a part of users.

The metrological self-check can be performed with the help of subsystems that link the input MIs of channels related to a previous level with the input MIs of subsequent level channels. These subsystems should carry out checking the correlation between the amount of the transmitted resource and data on summarised resource received by a group of consumers.

In case of discrepancy, the results of such a check will enable automatic localising an unhealthy MI or give grounds to draw the conclusion that, e.g., the reason of the revealed discrepancy is the initiation of the leakage in the channel between the MIs of previous and subsequent levels.

A failure signal that indicates the necessity for a specialist to come and take corrective maintenance should be sent to the centre.

However, in such MMSs, the probability exists that this information will not come to the centre in time due to

- A too prolong cycle of message collection from all measuring channels of the MMS, and
- Malfunction of the message collection sequence.

In order to exclude such a risk and economic losses related to it, when being sent to the centre, each message should receive a priority rank [30], information on more significant failure having a higher one. In this case, the measures for elimination of an occurred failure will be taken promptly with the minimum losses.

Such ACSs with various automation level exist in a number of cities and districts. They are being improved, but no publications concerning the developed metrological self-check in them could be found.

However, according to the information we have, in Saint Petersburg, the work is planned to organize the metrological self-check of city water supply system in 2021.

In analogues systems, as resources are being transmitted to consumers, their amount, density (in case of precipitations), chemical composition (in case of the breach of transmission condition), etc. can change.

The metrological self-check enables quickly determining problems originated as well as their possible reasons with the minimum costs. After that, the methods for troubleshooting can be found.

A characteristic example is considered in [31].

In a centralised system of a megapolis water supply, a bioelectronic system assigned for early diagnostics of sudden drinking water contamination is included. The system applies crayfish as biosensors. Using an optical system, the heart rate is determined for each crayfish which shows whether the water is pure enough.

The proposed method of the metrological self-check is based on the functional redundancy. For a rest state of the crayfish and a healthy measuring channel, the standard deviation (RMS) of the heart rate should be constant within some limits or can decrease. If a significant increase in the RMS within the same frequency range takes place, it can be caused by a decrease in the signal-to-noise ratio that leads to an increase, primarily, in the random measurement error, i.e., to a measurement trustworthiness reduction.

It does not matter whether the reason of this effect is a decrease of the useful signal (due to the decrease in a laser emissivity, degradation of contact quality or optical properties of the shell, contamination of the optical system, change in the position of the crayfish heart, etc.) or an increase in the noise level.

3.3. Virtual Tests

The concept of virtual tests has been widely spread in recent years. Virtual tests can be defined as tests carried out with the help of a digital twin [32, 33]. At present, there exists many definitions of digital twin depending on the application field.

For example, according to the ISO standard [34], a digital twin in manufacturing systems is a “fit for purpose digital representation of an observable manufacturing element with a means to enable convergence between the element and its digital representation at an appropriate rate of synchronization”.

The most generalized one is the definition [33]: a digital twin is “a formal digital representation of some asset, process or system that captures attributes and behaviors of that entity suitable for communication, storage, interpretation or processing within a certain context.”

In the case of MI and MMS, virtual test can be defined as a tool simulating the state and behaviour of the environment and material system affecting the test object. The examples of digital twins of MIs are given in [35-40].

In preliminary investigations related to the operation condition impact, if the direct testing of the object under study (e.g., spatially separated MIS channels) is extremely difficult or impossible, it is also reasonable to use the digital twin.

In practice, virtual tests can be carried out with the aim to quantitatively estimate such a metrological reliability characteristic of MIs and MMSs as the calibration / verification interval. These tests are reduced to testing

- Transducers included in each MI or MMS channel providing transmission of the measurement information to a data processing unit;
- The data processing unit itself, forming signals for an ACS operator.

Sensors with converters of measuring information to a digital code are not subject to virtual tests. (It is desirable to test them for impacts expected in the process of operation in real mode). Accordingly, the signals from the digital twin at the input of each tested channel must simulate the signals from the sensors in the course of their operation.

Ideally, the digital twin is implemented taking into consideration the sensor characteristics.-However, in a number of cases, the situation takes place that the data related to the operation of the sensors being planned for application are not accessible.

As a possible way, the data that are obtained from slightly different sensors previously operated under the same conditions, can be used. To pay attention to this methodical feature of virtual tests is necessary.

Mainly, such tests are performed by the application of records of the most typical fragments representing measurand changes and their combinations obtained in the course of a close analog operation. Sometimes, these records are supplemented with dangerous combination fragments designed as a result of the mathematical simulation, which take into account rare and/or unlikely situations and impacts.

The resulting estimate of the metrological reliability should correspond to the value sufficient for realising the required calibration / verification interval of the MI or MMS.

In each specific case, interpretation of concepts "the most characteristic fragments" and "dangerous combinations of fragments" is subjective. This circumstance gives the basis to consider virtual tests as a version of "soft" measurements of the quantity characterizing metrological reliability.

Taking into account [41-43], by "soft" the authors imply measurements carried out under conditions of significant definitional uncertainty. This also concerns the considered case. The mentioned association between virtual tests of such a kind and soft measurements enables soft measurement methods to be applied when performing similar virtual tests.

3.4. New Methods of Measurement Trustworthiness Provision. Dynamics of Application

The widespread introduction of the metrological self-check / self-validation concept is delayed because of psychological problems formulated by T. Kuhn's law [44]. The thing is that when self-check is used, the role of metrologists will change dramatically. The volume of routine work associated with calibrations and verifications will significantly decrease. At the same time, the role of metrologists as engineers developing new measurement methods as well as MIs and MMSs that provide the required measurement trustworthiness during long-term service life, should increase. These changes result in the desire of numerous metrologists, especially elderly specialists, to oppose them. However, according to the Kuhn's law, progress is inevitable, as evidenced by the growing interest in this concept which is illustrated by Fig. 1.

The situation is complicated by the fact that the further development of Industry 4.0 is associated with the emerged need to measure the properties that characterize human and society.

Understanding the relevance of extending the boundaries of the measurable was clearly shown at the last IMEKO TC 1 – TC 7 – TC 13 – TC 18 Symposium held in Saint Petersburg in 2019. About one third of presented papers concern the measurements of quantities that before were considered as qualitative properties.

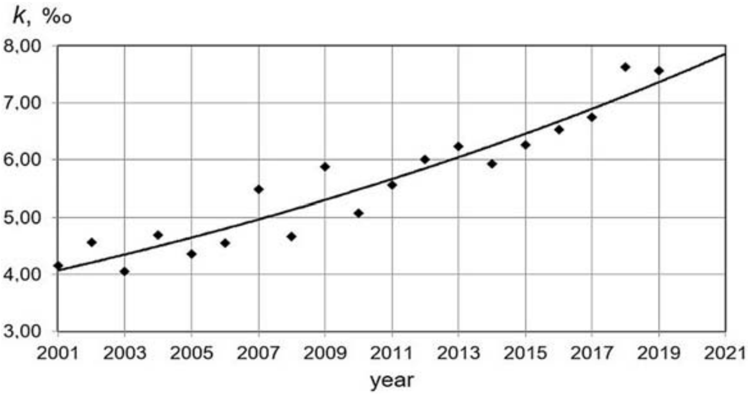

Fig. 1. The level of interest in the metrological self-check *k* - the share of publications in the field of "measurement", which contain the term "metrological self-check" or words close to it in meaning (as of March 13, 2021).

The same trend has been confirmed by the analysis of Scopus data. The proportions of publications dealing with measurements in special fields and those related to measurements in all fields were calculated. In 2001-2019, this proportion increased by 1.7 times in what concerns measurements in education, twice in the case of sociology, by 2.3 for zoology, and by 5.5 for psychology.

It is logical that that exactly at this time, new concepts related to the wide use of expert judgements, provision of their comparability and compatibility as well as active application of artificial intelligence in measurements have emerged in measurement science. Apparently, it is artificial intelligence together with metrological self-check and virtual tests that eventually leads to

- Mass implementation of automatic diagnostic methods in clinical medicine,
- Wide application of measurements in humanities.

However, even in these cases, the development of new measurement methods and ways for provision of trustworthiness will take place with the delay related to the Kuhn's law. We can only hope that in the new epoch, the time of delay will become shorter due to the increase in the pace of technology development.

4. Artificial Intelligence and Provision of Measurement Trustworthiness

Industry 4.0 has just begun, but the pace of technological development is such that we can already foresee the contours of its completion and start of the next stage (Industry 5.0).

A key feature of artificial intelligence is adaptability, i.e., the ability to adjust to changing conditions.

Mass production will become customized. The role of artificial intelligence will increase significantly, while human involvement in production processes will decrease and, in some cases, be reduced to nothing. Cyber-physical cognitive systems, including robots, will be widely spread. They will often use procedures that are characteristic of intellectual activities, such as image recognition, analysis of trends and their consequences, prediction, decision-making, etc.

At present, many types of sensors and other MIs are produced which measurement range can be adjusted. However, there have emerged the first sensors with an embedded neural network being capable of searching and selecting optimal parameters that correspond to the input signals and influence quantities.

If they are provided with the metrological self-check function, they can be called intelligent, because according to GOST [19, 20], an intelligent sensor / intelligent MMS is an adaptive sensor / adaptive measuring system, with the function of metrological self-check. In considering this definition, to take into account is necessary that the intelligence can be of different level.

The intelligent sensor, as a rule, should have a digital output and provide transmission of information on a metrological failure occurred.

To increase calibration / verification interval without worsening measurement trustworthiness, self-check methods should be supplemented with automatic metrological correction methods (i.e., methods of compensation for uncertainty changes).

The combination of metrological self-check and self-correction functions brings the implementation of MIs and MMSs realising them closer to sensor systems of mammals (surely, including humans) with advanced intelligence. In fact, this makes the intelligence level of the former ones higher. (The behaviour of people who experience visual or hearing impairment, but do not have a possibility to use glasses or hearing aid, is characteristic. They take possible measures to compensate for the originated defect by increasing the attention to information from other sensory systems that are healthier. Besides, they behave more carefully.)

At the end of Industry 4.0 stage, intelligent sensor with necessary calculation resources will enable not only revealing metrological failure and automatic correcting uncertainty that appeared as a result of influence quantity impact and/or material ageing, but also

- Self-recovering if a single sudden malfunction has occurred in the sensor,
- Self-learning.

Self-recovery means an automatic procedure that weakens the metrological failure consequences, i.e., it is a procedure for fault tolerance provision, while fault tolerance is the ability to keep metrological characteristics within permissible limits in case of a single defect.

Self-learning implies the ability to automatically optimise parameters and operation algorithms. Its basis is the dynamics analysis of the events taking place. One of the important purposes of self-learning is developing the reaction to unexpected events.

In a near future, intelligent MMS will include

- Intelligent sensors,
- Several sensors that measure the same quantity and are located at a distance, one of them being more accurate and reliable than the others (direct metrological self-check at the level of MMS),
- Sensors that measure various quantities the relation between these quantities being known with a required accuracy (metrological diagnostic self-check at the level of MMS).

Accordingly, besides revealing metrological failure in one or several measuring channels, intelligent MMS will be able (like in case of intelligent sensors) to carry out automatic correction of uncertainty, self-recovery, and self-learning.

At the stage of Industry 5.0, new ACSs will have the capability for self-learning to parry unexpected events (so called, "black swans"). Given the likelihood of robot "communicating" with each other and with humans, including situations not foreseen by technological instructions, ethical constraints must be built into the robots' artificial intelligence. This aspect should also be taken into account in the formation of self-correction and self-recovery algorithms.

If an intelligent sensor or intelligent MMS is provided with the self-learning capability, a corresponding built-in neural network should be able to be checked, i.e., should be able to reproduce algorithms being realized, including those related to occurrence of unexpected situations. Ideally, the neural network will automatically check whether the solutions made as a result of self-learning correspond to specified limitations.

5. Conclusions

The analysis of tendencies in development of methods and means for providing measurement trustworthiness has been fulfilled. Its results demonstrate that for traditional types of measurements, organisation of the metrological self-check based on the available or artificially introduced redundancy is the most perspective way. In new MIs and MMSs, the metrological self-check should preferably be supplemented with the self-correction of growing measurement uncertainty.

Requirements for terminology, methods as well as the level of metrological self-check and self-correction should be reflected in a set of international standards. The conformity of the realised level to the requirements of the standard should be substantiated in MI or MMS documentation.

Virtual tests have shown to be effective, but there exists a need to systematise the experience gained and issue standards in this field to make the results more evident.

Soft measurement methods and corresponding instruments will become widespread both in the near and more distant future. To ensure trustworthiness of their results, methods for diminishing the subjectivity role in expert evaluations should be developed and included in international standards.

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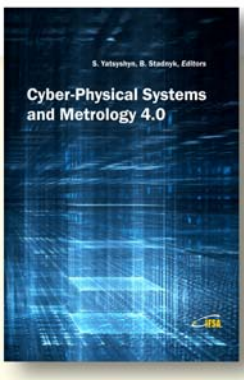

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