Metrology challenges of Industry 4.0

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Abstract. Society dynamics development has led to the origination of new metrology challenges. Among the most actual problems are the issues related to forming efficient measurement models and forecasting long-term variation of multidimensional, mainly, non-physical quantities as well as to automation of checking measurement result trustworthiness, to timeliness and security of measurement result transmission. The necessity to perform investigations and the development of international standards in the above-mentioned fields has been pointed.

1. Introduction
In the last 10-15 years, qualitative changes started to occur regarding general concepts of metrology. These changes are interrelated with improving the quality of life, globalization of trade, industrial, and scientific links, as well as massive migration of people. In addition, they are associated with the coming revolution “Industry 4.0”, the manifestations of which in the form of cyber-physical systems, robots, or Internet of Things, but mainly based on sensors or other measuring instruments, step by step penetrate all the spheres of life.

Measuring instruments were, are, and will be the instruments for cognition, while the metrological traceability enables an opportunity to provide the unified interpretation of quantitative evaluations. Nonetheless, the snowballing increase in the role of measurements and change in the notions on their possibilities, raise the questions on the philosophical comprehension of the metrology concepts [1-6] and the problems concerning dynamics of the metrology development: borders of measurable and opportunities to provide the trustworthiness (reliability) of measurement results.

2. General concepts of metrology and their development
In the past, like today, the increase in the number of links between the cells of society resulted in the large-scale changes in metrology. The Metrical Convention, which was signed in 1875 and coincided with the time of intensive railroad construction, can be mentioned as an example. Until the end of the 20th century, the society interests were aimed at the improvement in machinery controlled by man. Regarding metrology they reduced mainly to the studies of physical quantities and their measurement.

The situation has changed in the 21st century: the role of accumulated knowledge and intellectual work increased sharply. It would seem that the concepts of “measurement” (as a “process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity”) and “quantity” (as a “property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference”) formulated in [7] comparatively recently, would not have caused strong objections in the last century. However, the Notes specify that the “concept “quantity” may be generically divided into, e.g. (1) “physical quantity”, “chemical quantity”, and
“biological quantity”...” and a “reference can be a measurement unit, a measurement procedure, a reference material, or a combination of such.”

Legitimation of the concepts related to the possibility of measuring various properties and broadening the metrological traceability due to the application of measurement procedure as a reference, turned out to become crossing the Rubicon by metrologists. This pivotal breakthrough was caused by the need for quantitative evaluations of the quality of products, human’s health, university training, etc. [8, 9] and aimed at developing artificial intelligence, robotic complexes, cyber-physical systems, and so on.

The necessity to measure such non-physical, predominantly, multidimensional quantities as well as the need for the communication opportunities providing noise-immune transmission of measurement results and their final centralized processing, brought about the increased interest in the development of corresponding measurement models. The model for measuring a multidimensional quantity is the most efficient if it is built as the model of the “mechanism” or process forming a measurand [10]. The efficiency of such a model is determined by the fact that for it, the number of parameters measured directly is minimized and coefficients of parameter significance can be evaluated by the analysis of the model structure. (The variation limits of other parameters that can influence the multidimensional measurand should be fixed). Minimization of the number of the parameters being measured enables a development engineer to decrease the volume of data processing, place, at least, a part of a data processing unit close to a primary transducer, and evaluate the multidimensional quantity in digital form, which facilitates transmission and timely reception of measurement results.

Unfortunately, the development of such a model, as a rule, is based on hypotheses since information on the process under research is incomplete. This circumstance results in a significant definitional uncertainty. However, these difficulties are incommensurate with the advantages that this model opens for understanding the processes that take place, e.g., in human organism or society, or even in manufacturing processes (if the product quality parameters that are the most significant for customers is necessary to form).

The experience of the authors of the present paper concerning the development of the models of such a type has proved their efficiency regarding measurements of expected emotions being caused by bioacoustic signals, music, and speech intonations as well as diagnostics of the infants’ brain development and measurements of the quantity characterizing the level of society development.

Broadening the spectrum of measurands has resulted in the growth of interest in the models of the development processes and corresponding measuring instruments enabling long-term forecasts of the random and systematic variation of multidimensional quantities to be obtained.

Characteristic examples are prognosing the equipment maintenance term, disease development, economic development of society, expected changes of education system, etc. In such cases, the model is also based on the hypotheses related to the role and variation limits of influence quantities, although the forecast relies on the results of consecutive measurements of multidimensional quantities in the course of the part of the time interval considered. The definitional uncertainty of the model should be decreased with the confirmation of hypotheses accepted. In particular, this can be performed by machine self-learning. Informational content of the development model can be improved by emphasizing the most important prospects that can be avoided or approached with the help of the forecast being formed. The link between probable deviation of the forecasted quantity value from its average value and potential losses or benefits, is useful to show.

The difficulties related to the development of efficient models of measuring multidimensional non-physical quantities, are caused not only by the definitional uncertainty but, as a rule, interdisciplinary character of this work.

Given this background, publications appeared, in which an expert’s opinion is considered a result of a single measurement [11]. Seeming possibilities connected with this approach have caused euphoria. Certainly, at the stage of developing the measurement model, the application of expert’s evaluations is possible and appropriate (provided that they are transformed to the unified scale [12]). However, to provide the metrological traceability of product quality, medical diagnosis and other similar multidimensional quantities, is possible only if a special complex infrastructure has been organized. It
should enable tests to confirm the conformity of the adopted estimates to international norms and rules based on “a measurement unit, a measurement procedure, a reference material, or a combination of such”.

In this regard, the development of methods and instruments simulating perception of complicated impacts by human, i.e., of the method for measuring the comfort of chairs, instruments for measuring taste (artificial “tongue”) and odor (artificial “nose”) [13], expressiveness of musical performance [14], are promising. In the near-term, such instruments will consider how customers belonging to a certain cultural society will perceive specific features of products and services.

The number of properties that should be measured, increases, which puts forward the question where the borders of measurability are. Since the properties “of a phenomenon, body, or substance” [7] are measurable, the original question takes the following form: “Does any general carrier of all the properties of “of a phenomenon, body, or substance” exist? and, if “yes”: “Does this general carrier have any borders and name?”.

The concept of the world, which is classical for materialists, that the world is the combination of matter and its reflection in consciousness, enables us to give an answer: “Matter is a carrier of measurable properties”, and “consciousness is a system that organizes itself for survival, forms measurement algorithms, and processes data based on information about previous measurements and their models. From this point of view, “matter” and “consciousness” are not only epistemological but also metrological concepts.

3. Dangers caused by quick increase in the measurement role

With regard to broadening the measurement field, certain changes have emerged, but the situation with the issue of providing the trustworthiness (reliability) of measurement results is addressed inadequately. Various information flows are dramatically increasing. On one hand, they relate to automatic systems controlling operation of industrial facilities, e.g., nuclear power plants, transportation, etc. On the other hand, they include information on the location of a person, his/her state of health and actions, bank account, and so on.

In the course of operation, metrological characteristics of measuring instruments are changing. At that, usual methods intended for checking their metrological health based on calibration being fulfilled once a year (or two years) are economically unacceptable considering the multiple growth of the number of instruments. To suppose that the reliability of new measuring instruments (except those based on quantum mechanical effects) in the near-term will increase many times, is not reasonable.

Besides, the volume of measurement results processing by cloud servers continues to grow. Hacks of even closed information systems have become rather frequent.

The increase in the volume of information flows causes an additional problem: the probability of unacceptable delay while transmitting important information, grows. All this raises the danger of wide range tragedies and catastrophes. However, the danger growth is not accompanied by the adequate strengthening the measures for providing this information timeliness and trustworthiness including security (protection from unintended and unauthorized access, change, damage, destruction, or use).

The opportunity to avoid such events is associated with organization of automatic check of measurement result trustworthiness due to the application of redundancy of various types, i.e. intellectualization of measuring instruments and measuring systems [15], including those that provide automatic uncertainty correction. The optimization of measurement information flows as well as transition to maintenance taking into account forecast results, are necessary too.

Unfortunately, only a few national standards and guides that are of informational character, have been developed in this field [16-19]. There are no international standards related to measuring instrument and measuring systems with the measurement reliability estimated automatically.

Partly a reason, according to the Kuhn’s law, is that many metrologists counteract the application of the concept of metrological maintenance automation, which, in fact, can take away a significant sum of money from those who deal with routine calibration procedures.
4. Conclusions

According to Aristotle, without the sense of touch, living creature cannot exist. In a similar way, without measurements civilized society cannot exist. The rate of measurement development and efficiency of measurement application can characterize the civilization level reached.

The industrial revolution Industry 4.0 requires qualitative changes in the metrology development.

Among the priority fields of investigations associated with these changes are the search of solving the metrological challenges related to measurement of multidimensional quantities (in most cases, they are non-physical ones), provision of the trustworthiness of measurement results as well as security and optimization of measurement results flows considering the growing number of measuring instruments.

Because these changes are actual, to organize the development of international standards regulating the special requirements of the Industry 4.0 for measurement methods as well as measuring instruments and systems, is necessary.

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