Metrology aspects in cyber-physical systems

R Niyazbekova¹ and M Konkanov¹,²
¹ Department of Standardization, Metrology and Certification, S. Seifullin Kazakh Agrotechnical University, Astana, 010000, Kazakhstan
E-mail: marcon@metrology.kz

Abstract. The modern trend of most advanced countries is the active development and implementation of Industry 4.0 technologies, Internet of things and "smart cities". Despite the "autonomy" of these technologies, they still remain dependent on the achievements of metrology. The article deals with the concept of cyber-physical systems, presents an analysis of the problems of their metrological support, and shows the main metrological problems in the development of these technologies.

1. Introduction
An active process is under way around the world to create an information society. Many countries are moving to the concept of a digital state. Creating a smart city infrastructure can be considered as one of the steps to implement this program. Perhaps the next step is the digital transformation of key sectors of the national economy, education, as well as the sphere of interaction between the state and society.

2. From smart cities to cyber-physical systems
There are many different definitions of a smart city. The Joint Technical Committee 1 ISO/IEC "Information technology" offers the definition of a smart city as a new model that uses a new generation of information technologies, such as the Internet of things, cloud computing, large data, spatial/geographical information integration, aimed at simplifying planning, construction and city management.

As can be seen from the definition, the components of Smart cities create an infrastructure, the application of which is much broader and goes beyond the "cities". Such an infrastructure in the world is usually called a cyber-physical system. In [1], the cyber-physical systems are considered as a new class of engineering system, which is expressed in close interaction between cybernetic and physical components. Thanks to cyber-physical systems, achievements in the area of personalized health and medicine, emergency response, traffic management are possible, as well as the extraction, processing and supply of various energy resources, including electricity, and in many other areas that currently are only outlined. In other words, the notion of cyber-physical systems includes the following:

- Industry 4.0 and industrial Internet;
- Internet of things;
- systems of control devices of excisable goods accounting;

² To whom any correspondence should be addressed.
smart cities, smart grids, smart metering systems; as well as other items or infrastructures with an adjective "smart" (for example, smart cars, smart homes, smart manufactures, smart clinics, etc.).

Figure 1. Conceptual model of the cyber-physical system

Cyber-physical systems are rapidly transforming from programmable automation into a standalone form, consisting of operations, i.e. become more intelligent. Ideally: decision-making in the cyber-physical system should be carried out by the system itself on the basis of the received data, including on the basis of measurement data. Thus, we are approaching the establishment of metrology tasks in cyber-physical systems.

3. The tasks of metrology

First, if we are talking about the intelligence of cyber-physical systems, we should single out the task of measuring the "intelligence" of the system as a whole, and of cities in particular.

Subcommittee 1 of the Technical Committee 268 ISO "Intellectual public infrastructures" is engaged in identifying indicators of the state of smart cities, assessment methods and metrics for smart urban infrastructures. That is, one of the tasks of metrology is the development of methods for measuring the level of intellectuality, and, in the final goal, the quality of life in smart cities.

Second, the functioning of cyber-physical systems requires the constant receipt of measurement information, which is often achieved through the use of primary measuring sensors and converters, which implies their metrological support. Consequently, another task of metrology is metrological support of cyber-physical systems, namely:

- development of measuring instruments (techniques) for the calibration and validation of the correspondence not only of real-time measuring converters but also of software components involved in the systems [2];
- creation of test benches/platforms (techniques) for testing cyber-physical systems taking into account the dynamic processes taking place in them and constant scaling. Particularly relevant is the issue of metrological support for intelligent power supply systems.

Information-measuring systems for metrologists are familiar relatively recently, moreover, cyber-physical systems, as shown above, are already systems of a higher level, both in terms of technologies used and in the vastness of the tasks performed. In our opinion, one of the main features of these systems, which you need to pay attention to is that processes in such systems occur in real time. Stopping cyber-physical systems, taking into account the specifics of their application, is not possible. Therefore, the calibration and monitoring of these systems, as well as their maintenance and repair,
should be carried out not only at the site of operation, but during operation (online). The difficulty lies in the fact that the result of measurements, as well as the components of uncertainty and measurement errors, are constantly changing and the "classical" methods of their detection and elimination are not sufficiently "effective" [3]. Furthermore, it is necessary to consider that cyber-physical systems may contain thousands of sensing channels that measure different parameters and having different units of measurements [4].

Analysis of the literature [5-8] in this area shows that modern trends in metrology are aimed at mathematical modeling of processes and estimated uncertainty in cyber-physical systems, studying the influence of dynamically changing components (primarily temperature, time and parameters associated with optical measurements), as well as evaluating the impact of software. Mathematical modeling in the calibration of cyber-physical systems is currently widely used due to the fact that the corrections obtained by direct calibration of detectors and sensors, as a rule, do not correspond to reality when the system is deployed or after its restart [5].

Another important factor is the sensitivity of the sensors and the influence on them and the system as a whole of dynamic parameters that can not be controlled, but it is necessary to evaluate the dependence of the components of the system. First and foremost, this is factors of the environment, time and optical parameters [6]. By environmental factors we mean temperature and humidity, that is, parameters that affect the sensitivity and hysteresis of the sensors; optical components such as photosensitivity, transmission speed in fiber-optic communication lines, and others can also be assigned to them. The time parameter is very critical because any processes in the systems are associated with receiving and transmitting data and therefore these processes must be synchronized in time. Due to the fact that the functionality of modern systems depends not only on physical components (sensors, detectors, processes), but also on software, studies on the impact of software [7] on the accuracy of measurements conducted by cyber-physical systems spread more and more, since the cybernetic component ("intellectuality") of such systems depends mainly on the software.

4. Conclusions

Cyber-physical systems all over the world are widely used and applied in various fields of activity, ranging from household energy metering to medicine and national security;

Metrological support of cyber-physical systems is not easy due to the following reasons: large number of sensing channels and various types of measurements conducted by one system; constant measurement of characteristics of object of measurement and environment; necessity in real-time processing of results of measurements; no uniform format for transferring of measuring data as the systems are formed of components from different manufacturers. At the same time, the "classical" methods of calibrating measuring instruments and estimating the result of measurements through the "theory of errors" and "uncertainty theory" are not effective. So, modern researches are aimed at studying the so-called "adaptive approach" to the calibration of cyber-physical systems, which is based on predictable and simulated multivariate calculations.

Various researchers undoubtedly offer solutions for the above mentioned problems at the moment. For instance, large number of research is directed to development of complex and program methods of testing and calibration for smart systems aimed at metering of energy resources for the purposes of legal metrology [9]. Other authors offer a theory on "adaptive approach" for calibration of cyber-physical systems. The theory is based on projected and modeled multiple metering [3]. Group of researchers have also offered phasechronomitrical method for processing of metering data [10].

Consequently, development of new approaches and methods for metrological support and traceability of measurements in cyber-physical systems is in progress.

The authors have analyzed main tasks of metrology aimed specifically for cyber-physical systems. They also contributed by searching for optimal solution for countries with developing metrological infrastructure or for small-scale enterprises that transfer to the model of smart production.

It might be hard for the specified users to implement new approaches for solving mentioned tasks. For instance, use of mathematic models and algorithms requires deployment of additional services and
equipment for processing of big data and highlighting data, which is important for metrology. Strong scientific base and competent staff are also required which in turn is not always possible for countries having developing metrological infrastructure or for enterprises that operate at internal market.

The authors in particular raise a question on calibration of cyber-physical systems used for monitoring of condition of buildings and structures that transfer data on deformation of constructional concrete, temperature in mines, humidity, angle of slope for structure, subsidence of foundation, metal corrosion in reinforced concrete structures and micro damages in supports. These systems also need to be periodically checked, and system sensors are embedded in the structure itself. Therefore, authors offer options on use of new composite selfsensing materials (i.e., intrinsic self-sensing concrete) or sensors as well as use of excessive number of “ordinary” sensors for control of parameters. Excess method of sensors is possible due to the use of additional and same elements in the system where their quantity exceeds minimal one required for metering. If conversion function of the gauge was used as dependence of average output signal from metered value, then statistical assessment of deviation of output signals from average value may be taken as the reference value (i.e., average deviation or dispersion of deviation). Temperature gauge may be an example of use of such method for obtaining excessive data. The sensor has several thermocouples that are very similar in accuracy. Conversion function of such sensor is dependence of average output signal of thermocouples from measured temperature. If probability for synchronic drift of conversion function is negligible, then the average deviation of output signals of thermocouples from their average value may be taken as critical deviation of the sensor. The value of such deviation defined at previous calibration is considered as reference value. After metering average deviation of output signals of thermocouples from reference value, it is possible to assess metrological operability of the sensor. Disadvantages of this method are that there are limits to mass and dimensions plus additional expenses for sensors integrated with metering systems constructed based on this method. However such expenses are much lower than those required for full metering of metrological support system according to new additive approach.

5. References

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