On Ontological Modeling of Measurements in a Complex Monitoring System of Technical Object

Maria N. Koroleva
Bauman Moscow State Technical University
Moscow, Russia
maria.svyatkina@gmail.com

Georgy B. Burdo
Tver State Technical University
Tver, Russia
gbtms@yandex.ru

***Abstract*—A complex problem of monitoring sophisticated technical object (bridge) is faced. Some important peculiarities of measurement tasks and their organization in monitoring system are described. In order to represent and engineer measurement knowledge an ontological approach to measurement specification is presented. A hierarchical system of measurement ontologies is proposed, some basic low-level ontologies are constructed by using mind maps. A special attention is paid to the analysis of uncertainty types in measurement.**

***Keywords*—ontology; measurement; ontological modeling; ontological hierarchy; measurement uncertainty; sensor networks; monitoring**

I. Introduction

The new industrial revolution under the name of Industry 4.0 based on Cyber-Physical Systems and Internet of Things supposes the concept formation and implementation of so-called Ubiquitous Measurements with Sensor Networks. Such networks can be viewed as a community of autonomous agents located in different places and maintaining communications to generate a distributed cognition system. Enabling mutual understanding and joint work of these agents requires a system of measurement ontologies. This problem is faced in our paper in the context of monitoring sophisticated objects in railway infrastructure (by taking an example of bridge).

II. Measurement in a Complex Monitoring System

A complex problem of bridge monitoring (Fig. 1) includes the following tasks:

1) specification of keynote characteristics of the bridge state (e.g. bridge deformation, uneven draft of the structure, vibrations), measurement of main meteorological parameters (first of all, wind strength and direction, etc.);
2) interpretation of measurement results;
3) analysis of the processes in the construction of the bridge and diagnostics of its current state;
4) prognosis of the further evolution in the state of the bridge structures;
5) decision making related to possibility and safety of bridge operation.

Thus, measurements are a principal information source to perform subsequent monitoring tasks.

This work is supported by RFBR, grant No 18-07-01311 and 19-07-01208

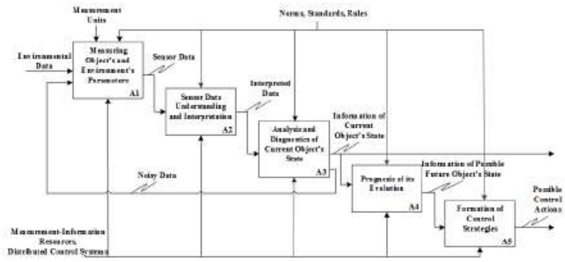

Figure 1. Tasks to be performed in the course of monitoring

According to the branch road methodical document [1] monitoring means an experimental checking of quantitative parameters (measurement) and qualitative factors specifying a technical state of the bridge. These are:

- geometrical parameters;
- stress-strain state;
- temperature of bridge structures;
- dynamic characteristics;
- defects;
- loads and impacts;
- atmospheric conditions of bridge operation;
- stiffness, strength and other properties of structures and materials.

Both current parameters values and their changes while monitoring can be specified. Measurements in monitoring can be performed by using both devices with continuous data registration and in the form of periodic instrumental measurements by using sensors and devices pre-installed in the bridge structures.

Measurement theory encompasses knowledge about measurement types, methods, tools, instruments, results, conditions. In order to develop metrological intelligent systems on the basis of knowledge engineering [2] let us consider an ontological approach to measurement.

III. Ontological Approach to Specifying Measurement

Ontology (in Computer Science) is usually seen as a formalized description of some problem area. Two classical approaches in ontological modeling are known —- relational and logical; these approaches rise to the foundational papers by T.Gruber [3] and N.Guarino [4]. So Gruber defines ontology as an explicit formal specification of a conceptualization shared by the members of some community. Here basic keywords are:

- ”conceptualization” – synthesis of abstract conceptual model of external world phenomena by identifying keystone concepts and studying main relations between them;
- ”formal” – such a conceptualization should be expressed in a machine readable format to be understood by computer (sensor) system;
- ”explicit” – it means that the type of concepts used and the constraints of their use are explicitly defined;
- ”shared” – ontology captures consensual knowledge accepted by a group in order to enable mutual understanding and joint work of various agents (a communicative aspect of ontology).

According to Guarino, ontology is a logical theory that gives an explicit partial account of a conceptualization. It includes some basic terms forming taxonomy, their definitions and attributes, related axioms and inference rules.

It is often very difficult or even impossible to construct single, comprehensive, coherent and practically useful ontology. To simplify ontology development and reuse, a modular approach is taken and some hierarchies of ontologies are formed [4]–[6]. On the low level apart from domain ontology, both task ontology and application ontology are constructed, and on the high level upper ontologies [7] are viewed to represent general categories encountered in many problem areas.Besides, meta-ontology (”ontology of ontologies”) is given that provides both an exact mathematical specification of various ontologies and formal analysis of their properties. Specifically, it includes methods and forms of representing, developing and merging different ontologies.

An example of foundational measurement ontology is QUDT (Quantity, Unit, Dimension, Type) ontology [8], where class properties and restrictions are defined to model physical quantities, units of measure and their dimensions in various measurement systems. The goal of the QUDT ontology is to provide a unified model of measurable quantities, units for measuring different kinds of quantities, the numerical values of quantities in different units of measure and the data structures and data types used to store and manipulate these objects in software. Among other perspective ontological approaches to measurements Kuhn’s functional ontology of observation and measurement [9] should be mentioned.

Below a three-leveled system of measurement ontologies is suggested (Fig. 2) in the framework of solving complex monitoring problem. Here low level ontologies include measurement domain ontology, ontology of measurement properties, ontology of sensor networks as measurement tools, measurement applications ontology (measurement for monitoring). Following the Guide to the Expression of Uncertainty in Measurement (GUM) (see [10], [11]), we take uncertainty ontology as upper ontology. Finally, we have granular ontology [12] on the meta-level.

Such visual tools as mind maps [13] are worth employing to represent ontologies. A basic idea of mind map is to automatically transform some text fragments in a graphical form. Such a map possesses the following features:

1) it has a form of a bush;
2) a studied object is placed in the center of the picture that corresponds to the center of attention;
3) primary topics related to the object of investigation diverge from the center as branches explained with keywords;
4) secondary topics are also branching;
5) the branches form a connected nodal structure.

Four low-level ontologies are depicted as mind maps in Fig. 3 – Fig. 6: ontology of sensor networks, ontology of measurements, ontology of measured properties (with using

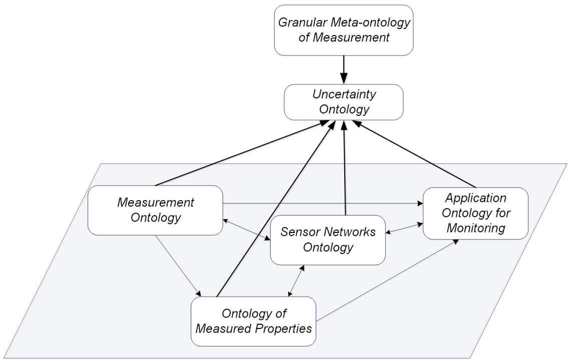

Figure 2. Ontological hierarchy of measurements

Doynikov’s classification of measured properties [13]) and ontology of bridge monitoring as application ontology for monitoring [15].

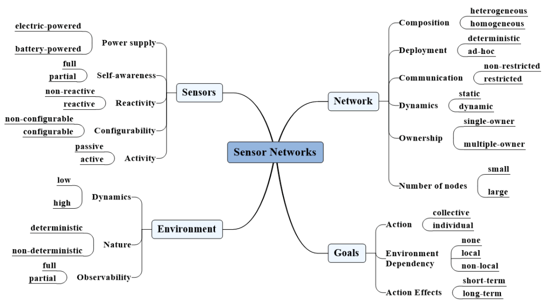

Figure 3. Visual representation of sensor network ontology

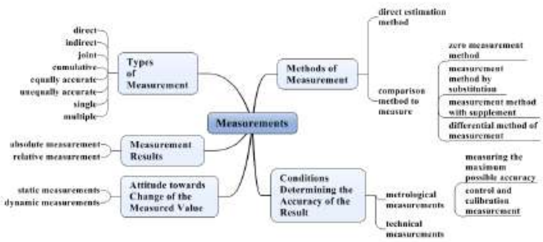

Figure 4. Mind map for measurements ontology

It is seen from Fig. 3 that the problem area ”Sensor Networks” is revealed through such concepts —- classes as ”Sensors”, ”Networks”, ”Environment”, ”Application Goal”. Here measurement tasks ontology is tightly connected with measurement applications in the framework of monitoring problem. Main measurement tasks in monitoring situation are both formation of judgments and support of reasoning. These judgments and reasoning concern diagnostics of current state of monitoring object (bridge), prognosis of their change tendencies, decision-making and recommendation development. For example, ”if the wind speed measured by the anemometer on the bridge is 25-26 m/s and considerable bridge vibrations are observed, then the traffic on the bridge is prohibited”. It is the case of joint, multiple, dynamic measurements.

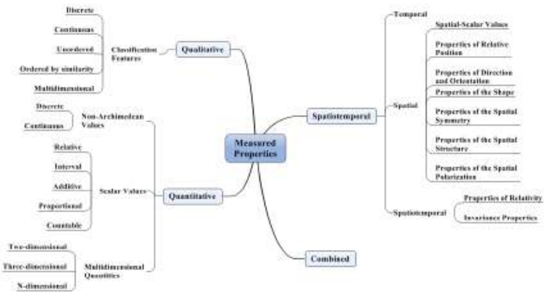

Figure 5. Mind map for ontology of measured properties

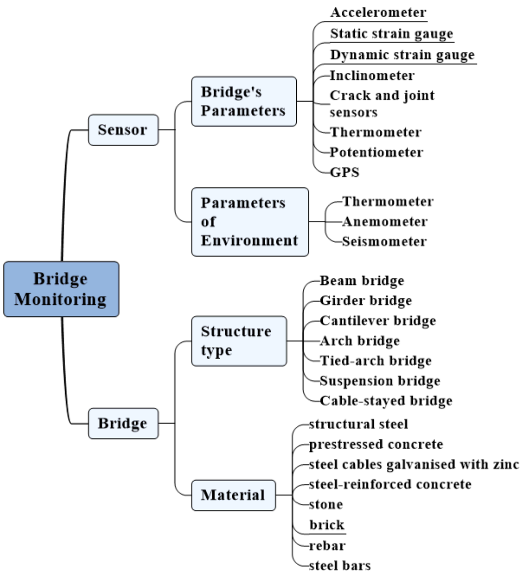

Figure 6. Mind map for ontology of bridge monitoring

IV. On Uncertainty Types in Measurements

Any measurement is an experiment under uncertainty. Thus it always has an error. Measurement results depend on measurement-information system, measurement techniques, external conditions, human-operator's qualification and so on. An old idea of measurement with exact result largely has outlived itself.

In International and Russian standards an ordinary term "measurement error" or its inverse "accuracy of measurement" was replaced by a wider term "measurement uncertainty" [10], [11]. Measurement uncertainty is a general concept associated with each measurement. By taking into account measurement uncertainty, we are able to compare measurement results with existing standards and norms, perform diagnosis of the monitoring object and prognosis of its future behavior, make important practical decisions and manage risks.

In [16] some analogies between classical measurement science and new concept of measurement uncertainty have been traced. Nevertheless, the matter is not only terminological differences, but a quite new representation of the sense by measurement results. According to GUM, certain measurements do not exist.

In [10], [11] measurement uncertainty is viewed as a principal lack of exact knowledge about measured value. In other words, the result of measuring some quantity x has two components:

- some value x_0;
- its uncertainty u_x.

Generally we have $(x_0 \pm u_x)\ mu$, where mu means measurement unit.

The result of measurement is only an approximation of measured value. It cannot be expressed by a singleton and it is characterized by a distribution on confidence interval.

A. Uncertainty of type A and B

On the one hand, in analyzing measurement uncertainty the GUM materials [10] have to be taken into consideration. On the other hand, the limitations of classical stochastic techniques require the development of more general approach to the modeling of uncertainty in measurement related to such concepts as granule and measurement information granulation [17]–[19].

In [10], [11] the difference is made between type A and type B uncertainty. Type A uncertainty evaluation is performed by the statistical analysis of series of observations. Type B uncertainty requires a new evaluation method other than the statistical analysis of series of observations, for instance, fuzzy variable, fuzzy interval, fuzzy number, possibility distribution. Here, type B uncertainty (more exactly, a complex of various types of non-stochastic uncertainty) encompasses such factors as:

- incomplete or inaccurate definition of the measure and, for instance, the lack of justified uncertainty value u_x;
- a non-representative sample;
- an open character and dynamics of measurement procedures, their dependence on measurement goals, environment and available instrumentation;
- instrumentation imperfection due to its finite resolution or discrimination threshold;
- inaccurate or incomplete knowledge of both environmental conditions and their impact to measurement results.

B. Classification of type B uncertainties

Let us take as a basis Borisov's uncertainty classification [20] that was introduced in 1980's. In this classification uncertainty was also divided into two classes – stochastic uncertainty and non-stochastic (linguistic) uncertainty. It is suitable to modify it for measurement with using sensor networks by taking into account inaccuracy, incompleteness, ambiguity, contradictoriness, fuzziness in measurement (Fig. 7).

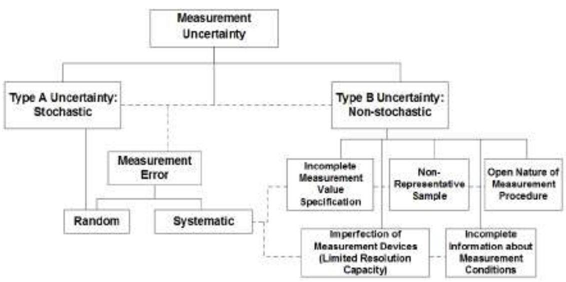

Figure 7. Classification of type B measurement uncertainties

Measurement inaccuracy means a limited sensor resolution capacity due to the nature of measured parameter.In every measurement there exists an unrecoverable error depending on the sensor threshold. For instance, an acoustic range finder determines the distance to objects within the limit of 0,2—80 m with an error 2%.

Incomplete measurement information supposes that in sensor network a few sensors are inaccessible, and total ignorance means a loss of communication with the sensor or malfunction of measuring element.

Contradictory indications may appear for homogeneous sensors measuring the same parameter. For example, two strain gauges measure structural stress: the first sensor indication is interpreted as "normal", and the second sensor indication is seen as "out of norm".

Measured data ambiguity supposes the use of some (non-probabilistic) distribution. Fuzzy value is attributed to the terms of linguistic variable. For instance, "the measured wind speed on the bridge is almost in the norm".

V. Conclusion

As a result of this research, some proposals on granular measurement uncertainty models and cognitive structures of measurements have been introduced. In order to develop distributed cognition systems a hierarchical system of ontological measurements has been proposed, basic low-level ontologies are constructed. All above allows to develop intelligent monitoring systems based on distributed cognition systems.

References

[1] Handbook on Monitoring the State of Operated Bridges. The Branch Road Methodical Document. Moscow: Avtodor Editions, 2008 (in Russian).

[2] T. A. Gavrilova, D. V. Kudryavtsev and D. I. Muromtsev, Knowledge Engineering: Methods and Models. The Textbook. St.Petersburg: Lan' Publishers, 2016 (in Russian).

[3] T. R. Gruber, "A Translation Approach to Portable Ontologies" in Knowledge Acquisition, vol.5, #2, 1993, pp. 199–220.

[4] N. Guarino, "Formal Ontology and Information Systems" in Proceedings of the 1st International Conference on Formal Ontologies in Information Systems (FOIS'98, Trento, Italy, June 6-8, 1998), ed. by N. Guarino. Amsterdam: IOS Press, 1998, pp. 3–15.

[5] A. V. Smirnov, M. P. Pashkin, N. G. Shilov and T. V. Levashova, "Ontologies in Artificial Intelligence Systems. Part 1" in Artificial Intelligence News, #1, 2002, pp. 3–13 (in Russian).

[6] G. S. Plesniewicz, V. B. Tarassov, B. S. Karabekov and Nguyen Thi Min Vu, Methods and Languages for Ontological Modeling. Almaty: IICT MRS KR Editions, 2017 (in Russian).

[7] J. F. Sowa, "Top-Level Ontological Categories" in International Journal of Human-Computer Studies, vol. 43, 1995, pp. 669–685.

[8] R. Hodgson et al., The NASA QUDT Handbook, 2014.

[9] W. Kuhn, "A Functional Ontology of Observation and Measurement" in Proceedings of the 3rd Workshop on GeoSemantics (GeoS'2009, Mexico City, December 3–4, 2009). Lecture Notes in Computer Science, vol.5892. Berlin: Springer-Verlag, 2009, pp. 26–43.

[10] ISO/IEC Guide 98-3: 2008. Uncertainty of Measurement. Part 3. Guide to the expression of uncertainty in measurement (GUM: 1995). Geneva: JCGM, 2008.

[11] GOSR 54500.1–2011/Guidebook ISO/IEC 98-1: 2009. Measurement Uncertainty. Part 1. Introduction to Measurement Uncertainty Guide. Part.3. Guide to the Expression of Uncertainty in Measurement. Moscow: Standartinform Editions, 2012 (in Russian).

[12] V. B. Tarassov, A. P. Kalutskaya and M. N. Svyatkina, "Granular, Fuzzy and Linguistic Ontologies Enabling Mutual Understanding of Cognitive Agents" in Proceedings of the 2nd International Scientific and Technical Conference on Open Semantic Technologies for Inteligent Systems (Minsk, BSUIR, February 16–18, 2012). Minsk: BSUIR Editions, 2012, pp. 267–278 (in Russian).

[13] T. Buzan and C. Griffiths, Mind Maps for Business.Using the Ultimate Business Tool to Revolutionise How You Work, 2nd ed. New York: Pearson, 2014.

[14] A. S. Doynikov, "Classification of Measured Properties" in Proceedings of the 5th International Conference on Soft Computing and Measurements (SCM'2002, St.Petersburg, St.Petersburg State Electrotechnical University ≪LETI≫, June 25–27, 2002). St.Petersburg: LETI Editions, 2002, pp. 46–49 (in Russian).

[15] G. B. Burdo, E. V. Vorobyeva, "Ontological Approach in Designing Technological Processes" in Open Semantic Technologies for Intelligent Systems, 2015, pp. 461–464 (in Russian).

[16] A. E. Fridman, Fundamentals of Metrology. Modern Course. St.Petersburg: SPU Professional Editions, 2008 (in Russian).

[17] L. A. Zadeh, "Toward a Theory of Fuzzy Information Granulation and its Centrality in Human Reasoning and Fuzzy Logic" in Fuzzy Sets and Systems, vol.90, 1997, pp. 111–127.

[18] L. Reznik, "Measurement Theory and Uncertainty in Measurements: Application of Interval Analysis and Fuzzy Set Methods" in Handbook of Granular Computing, ed. by W. Pedrycz, A. Skowron and V. Kreinovich. Chichester: John Wiley and Sons Ltd, 2008, pp. 517–532.

[19] V. B. Tarassov, "Granular Measurement Structures in Ambient Intelligence: Vasiliev's and Belnap's Sensors and Their Communication Models" in Information-Measurement and Control Systems, #5, 2013, pp. 65–74 (in Russian).

[20] A. N. Borisov, A. V. Alexeev, O. A. Krumberg et al. Decision-Making Models on the Basis of Linguistic Variables. Riga: Zinatne, 1982 (in Russian).

ОБ ОНТОЛОГИЧЕСКОМ МОДЕЛИРОВАНИИ ИЗМЕРЕНИЙ В КОМПЛЕКСНОЙ СИСТЕМЕ МОНИТОРИНГА ТЕХНИЧЕСКОГО ОБЪЕКТА

Королева М. Н., Бурдо Г. Б.

Рассмотрена комплексная проблема мониторинга сложного технического объекта (на примере мостового перехода), описаны особенности организации и задачи измерений в системе мониторинга. В интересах представления и систематизации знаний об измерениях изложен онтологический подход к спецификации измерений, предложена иерархическая система онтологий измерений, построены основные онтологии измерений нижнего уровня с помощью ментальных карт. Особое внимание уделено описанию видов неопределённости в измерениях.

Received 10.01.19