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MODELS FOR MEASUREMENTS OF MULTIDIMENSIONAL QUANTITIES

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Abstract – A tendency is noted that the metrology scope extends to the field of non-physical multidimensional quantities. Special features of forming the models for measuring such quantities are demonstrated. Examples are given including those related to measurements of the food quality, state of health, properties of social-and-cultural processes as well as expected emotional response of listeners to music.

Keywords: measurement model, multidimensional quantity, multiparametric quantity, non-physical quantity

1. INTRODUCTION

The need for new knowledge about the environment is a stimulus for further development of metrology. At the postindustrial stage of the civilization development, a sphere of properties that should be measured, has started an intensive extension.

Partly this tendency is reflected in the International Vocabulary of Metrology [1], where it is formulated that a quantity can be not only a physical one. This fact has taken away a strict boundary of metrology. Metrologists have become interested in non-physical properties including those which previously were evaluated only by jury testing [2]. The evaluations of such properties did not meet the requirements for metrological comparability and traceability, which are the distinctive features of measurement results.

Most of these quantities are multidimensional (multiparametric). Formally, this feature does not prevent from measuring them, since according to [1] "a vector or a tensor, the components of which are quantities, is also considered to be a quantity" equally with a scalar.

Among such quantities are disease diagnosis, level of education, man's talents, parameters indicating the community state or dynamics of its development, product quality (wine taste, perfume aroma, naturalness of materials, product comfort), etc.

A need is being formed to obtain reliable metrological evaluations of the corresponding quantities characterized by metrological comparability and traceability and [3].

Measurements of multiparametric quantities are accompanied with a number of difficulties caused by formation of scales, definition of measurement units, and so on.

One of the most difficult, but the most important tasks for measuring the quantities considered, is the development of a measurement model.

2. MEASUREMENT MODEL

According to [1], measurement model is a "mathematical relation among all quantities known to be involved in a measurement

NOTE 1 A general form of a measurement model is the equation $h(Y, X_1, \ldots, X_n) = 0$, where Y, the output quantity in the measurement model, is the measurand, the quantity value of which is to be inferred from information about input quantities in the measurement model $X_1, \ldots, X_n$…"

In [4] it is explained that the measurement model can be represented as an algorithm, i.e., as a step-by-step set of mathematical, logical and joint operations linking the quantities that take part in measurements.

Any measurement model reflects a specified idea of relations between Y and $X_1, \ldots, X_n$. A definitional uncertainty "resulting from the finite amount of detail in the definition of a measurand" is intrinsic to the model [1].

If it is desirable to enhance the measurement accuracy, one should consider critically a measurement model applied earlier [5]. This can concern even the measurements of quantities that seem to be very simple. For example, if the task is solved to measure a distance between two surfaces, depending on permitted limits of uncertainty as well as assumed methods and conditions of measurements, it is necessary in some cases to take into account surface curvature, roughness, reflection coefficient, hardness index of materials as well as the role of influence quantities. In essence, all this means that the concept of the distance being measured should be improved and the corresponding value of definitional uncertainty should be changed.

The development of a measurement model is one of the most important stages of cognition. Such a

model gives an objective basis for judgments about processes and phenomena under investigation. Deviations of measurement results from the values forecasted by the model force these judgments and accepted model to be corrected.

The extension of the metrology sphere is accompanied by an intensive development of measurement models with multidimensional input quantities [6-12 and others].

If the model is considered to be a means of cognition, it is possible to single out several approaches to its development.

The first one consists in searching a relation between a multiparametric measurand and number of other quantities, which determine its value. Such an approach should be classified as phenomenological.

The second approach is connected with the use of the well-known relation between several quantities.

At least, it is possible to apply the approach that consists in the development and substantiation of a hypothesis about the relations between a measurand and parameters determining this measurand, using as a basis the well-known facts from other fields of knowledge.

Some examples related to various unconventional spheres of measurements are given below.

3. MEASUREMENTS OF PARAMETERS THAT CHARACTERIZE STATIC PROPERTIES

To evaluate the quantities that are rather stable quantitatively, as a rule, the measurement model is formed on the basis of the phenomenological approach.

If the measurand is characterized by a great number of parameters and a measurement result should be set according to a nominative scale with a relatively small number of gradations, panel or jury evaluations are often used.

For example, the quality of food is usually determined by organoleptic methods, i.e., by the methods based on expert sensation [13].

With the help of vision, the appearance of food, its shape or colour can be determined. With the help of sense of touch it is possible to evaluate the density of food, its elasticity, stickiness, plasticity, fragility, etc. The organs of olfaction are used to determine smell, aroma, and so on.

Various coefficients of significance K_i are assigned to these parameters for evaluating the quality of different products. The final evaluation is a mark obtained with the help of special scales taking into account these coefficients.

In particular, the model for organoleptic measurements of the cheese quality includes 6 parameters: package and identification (2 grades), appearantce (6 grades), colour (2 grades), piping (12 grades), taste and smell (11 grades), consistency (8 grades); $1 \leq K_i \leq 9$ [13].

A version of organoleptic method is application of sense organs of animals for detecting some multidimentional propertuies. In particular, evaluation of purity and potability of water in a water body can be carried out by the analysis of the cardiac rate of crawfishes. Narcotic drugs and explosives can be detected with the help of trained dogs that identify a special smell.

The advantages of the organoleptic methods are their high sensitivity and efficiency of realization.

The general drawback is the domination of a subjective factor.

The confidence in the results of such measurements depends not on the metrological comparability and traceability of a specific set of measurements, but on a brand of a company that produces the product. The authoritative brand is like a certificate “verifying” the reliability of the measurements.

Some investigations that can contribute to solving the problem of the comparability and traceability of jury evaluation results, have been performed recently, They are aimed at reducing the individual scales of property perception to the unified standardized scale.

A cardinal solution of the problem is to develop methods and technical means mimicking the sense organs of man.

Technical measurements in such situations are often accompanied by the organoleptic ones. This enables an accepted measurement model to be justified by proving the correspondence between the technical measurement result and expert evaluation.

A characteristic example is the cognac quality evaluation with the help of chromatography, which practically coincides with expert evaluations. It is significant, that the parameters analyzed using a chromatograph are determined on the basis of studying the cognac production technology [14].

MeasIuring systems that apply methods of bionics (biomimetics) are of the most interest. They use organization principles and structures of animal's sensor systems.

It is well-known that for a number of sense organs special sensor groups are characteristic. Each of the sensors determines a value of the quantity that it particular for it. The ratio between signals formed by these sensors determines a sensory image: taste, smell, or colour. Therefore, a biomimetic measurement model should include evaluations of a number of quantities and provide image recognition.

Publications are well-known that describe measuring systems intended for measurements of taste and smell (“electronic tongue” and “electronic nose”) [15-19]. They use from 3 to 30 various sensors, in particular, potentiometric ones, or sensor arrays. Their output sensor signals go to an image recognition unit.

To provide metrological comparability and traceability of organoleptic measurements it is necessary to develop international standards or guides.

The phenomenological approach is also applied in medicine. Any disease can be defined according to an interval of the nominative scale of a multidimensional quantity characterizing the state of health. This interval is determined by a group of parameters and their corresponding values.

Publications [20, 21] are of interest due to their specificity. The authors justified the use of electrocardiograms (ECGs) for diagnosing a number of internal diseases. For this purpose, about 600 cardiocycles are registered on the ECG. A specific feature of this method is that not only the cycle time interval is measured, but an amplitude, a ratio of the amplitude to a cycle time interval as well as variations of these quantities from one cycle to another are evaluated too.

The signs of the variations ("plus" or "minus") are taken into account. Special codes *Xi* are assigned to different combinations of the signs. For the diseases Y_i, diagnosed according to the data of several thousand clinical and laboratory investigations, characteristic code sequences are determined.

The measurement model of such a type makes it possible to decrease sharply the costs and time of medical investigations, identifying about 20 diseases only on the ECG basis. Besides the cardiovascular diseases, this measurement model reliably diagnoses such diseases as cholelithiasis, diabetes, peptic ulcer and others.

The disease diagnostics on the basis of usual procedures, in essence, also rests upon certain, but weakly-formalized measurement models. However, in the last years the computer diagnostic methods have been developed and standardized. They are based on the totality of parameter values obtained as the results of measurements applying clinical and laboratory methods. This trend points to the need of the society to provide the metrological comparability and traceability of measurement results in medicine.

4. MEASUREMENTS OF PROCESS PARAMETERS

Acceleration of the pace of technological expansion, economic globalization, frequent manifestations of interreligious conflicts and social tension in a number of world regions, and, at least, global crisis development, make investigating the dynamics of social-culture processes particularly important. It is impossible to acquire knowledge about the regularities of man's development, as well as development of society and its features, in particular, culture, without measurements. Such investigations usually apply the combination of phenomenological approach with well-known regularitues and hypothesis justified.

Development of the measurement models intended for studying the social-and-cultural processes, which variations become noticeable in a few months or even in many tens of years, meets with difficulties caused by:

- unclearenes of the concept of the measurand as well as a great number of parameters determining this measurand;
- unclearenes of the concept of the parameters mentioned and their relations with the measurand;
- mutual influence of the parameters mentioned;
- evaluation of various parameters specifying the measurand with the help of different scales, which can be applied in many cases;
- complexity of an experimental examination of the model efficiency, etc.

A valuable contribution to the methodology of developing the measurement models for quantities characterizing the social-cultural processes was made by Prof. Golitsyn and Prof. Petrov [22].

They have developed an approach that is called an "information approach". It rests upon the hypothesis that any system, including the biological, social or artistic one, tends to the maximum of average mutual information while exchanging with the environment. This is necessary for providing the survival under the changing environment.

This maximum that determines the variety of reactions on the environment changes is limited by system resources, which presupposes economy of their consumption including the economy at the expense of increasing the accuracy of the system reactions.

The information approach enables particular regularities that are typical for development of specific investigation objects to be revealed. For a number of objects such regularities are well-known and they can be applied in model development.

In particular, the Zipf's law describes the hyperbolic distribution that is typical for many social and biological objects.

The combination of the Zipf's law and information approach made it possible to develop a model for measuring the quantity that can be called the social-and-moral potential of a person [23]. In the model, the output quantity is obtained by aggregation of 79 parameters characterizing various aspects of the world outlook of questionnaire respondents, their social behavior and so on.

At the same time in this model the impact of influencing factors is weakened to the maximum degree:

- questionnaires do not contain any questions relating to information that could be distorted deliberately;
- answers to the questions are given in the form of "1" or "0", i.e., in that way excluding an ambiguity in processing the answers;
- national and cultural features of the population groups being questioned are taken into account.

The results of such measurements give grounds for determination of the relation between the social-and-moral potential of some region inhabitants and distribution of their incomings, efficiency of an education system, etc. This enables formulation of the topical tasks of cultural, social and economic politics.

The procedures realizing such models can be standardized as the reference ones.

Models for measuring the quantities describing social-and-cultural processes can also rely on the time variations of statistic distribution characteristics of representative objects reflecting these processes. Among them can be specific features of articles, books, works of visual arts, musical compositions, national languages, and so on. Such models makes it possible to reveal the alternating domination of emotional and rational factors in the art evolution, correlation between the changes in art styles and social processes, etc.

In contrast to the processes of the society development, the processes characterizing any conscious human's reaction, are very short: the changes being fixed lie within the time intervals from a few tenths of second to a few seconds.

The development of the model for measuring such human's reactions is complicated due to the above-mentioned difficulties. However, general difficulties concerning experiments are as follows:

- a number of physiological processes, including neurophysiologic ones, occur at the same time, but it is necessary to separate parameters characterizing just the process under investigation;
- special effects take place:
  - habituation to impacts used in experimental procedures,
  - memorization of these impacts,
  - concentration of attention on feelings and thoughts that does not concern the experiment.

As an example, the model linking the expected emotional response of the majority of listeners belonging to the same civilization group to music, is considered.

While developing the model, the authors have consecutively set and justified a number of interrelated hypotheses:

1) acoustic components-exciters stimulating a limited number of basic (the simplest) emotions are identical for music and other emotional soundings, e.g., a predator growl or purring;

2) general parameter values of these components are close to the values of emotional sounding parameters peculiar to the animals inhabited oceans long before the mankind appearance;

3) the component-exciter frequencies lie within the infrasound frequency range and a part of the low frequency sound range (hereinafter, all this range will be referred to as IR);

4) the basic emotions stimulated by the components-exciters are identified with the help of a genetic memory that "stores" the corresponding frequency values since the frequency is the most noise-immune parameter;

5) number of the basic emotions is determined by the number of corresponding reactions: it is limited by the time of the reaction origination delay acceptable for survival of population as well as by the IR boundaries;

6) generation of the emotion caused by the component-exciter shows itself in the form of activation of a biorhythm, the frequency of which is close to that of the component-exciter;

7) process of the component-exciter extraction from the "mixture" of sounds (including the sounds with the frequencies that lie outside the IR limits) is a non-linear conversion of the "mixture" combined with its filtration taking into account the inertance of the corresponding neuro-physiological process;

8) selection of components-exciters from a sound with changing frequency is carried out by a sound delay of approximately 0.2 c, subsequent "mixing" of the sound delayed with a sound being heard at a given moment, and then non-linear conversion and filtration of this "mixture" according to point 7);

9) small groups of the components-exciters form basic emotional images (common for all the mankind), identification of which is carried out by the comparison with the images memorized previously;

10) analogous combinations of the component groups causing emotional images form culture-specific emotional images (these images are different for nations characterized by different history and religion; accordingly, they are specific for national music);

11) the structure of emotional information resembles the structure of speech: it includes "letters" formed by 2-3 sounds, "words" consisting of several "letters", and "phrases" including a number of "words";

12) sound frequencies which carry the main energy of music or other soundings also contain information that is important for decoding the emotions.

The hypotheses considered above are substantiated in [24 and others].They are used as the basis of a 3-step model for measuring an expected emotional response to music:

- at the 1st step, the basic emotions are born;
- at the 2nd step, the universal (basic) images are generated,
- at the 3rd one, the images related to the national mentality and culture features, family history, recollections, etc., are formed.

A simplified scale linking a state of a wakeful man with activated brain biorhythms makes it possible to simulate the work of the first model step by software, to "read" the emotional content of some ethnic African music and ritual bell rings, decode the emotions accompanying a purring, growl and hiss of predators, and so on [[25, 26, and others].

At present, a further work with the model is carried out by metrologists together with neurophysiologists, psychologists, composers, art-therapists, and mathematicians.

5. CONCLUSION

Development of metrology is determined by the topical tasks of civilization evolution. The postindustrial stage is characterized by the growth of interest in measurements of multidimentional quantities related to the properties of man (state of health, level of talents, needs, etc.) and society as well as to the dynamics of their development.

This completely new trend in metrology evolution has resulted in the necessity to draw heightened attention to the development of the models for measuring non-physical quantities, resting upon the knowledge from the fields that are far from "exact science".

Metrology should integrate various approaches to the evaluations of properties "of a phenomenon, body, or substance" on the basis of experimental investigations. The laws for forming such evaluations should not depend on the science to which a measurand can be referred and of the number of the parameters used.

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