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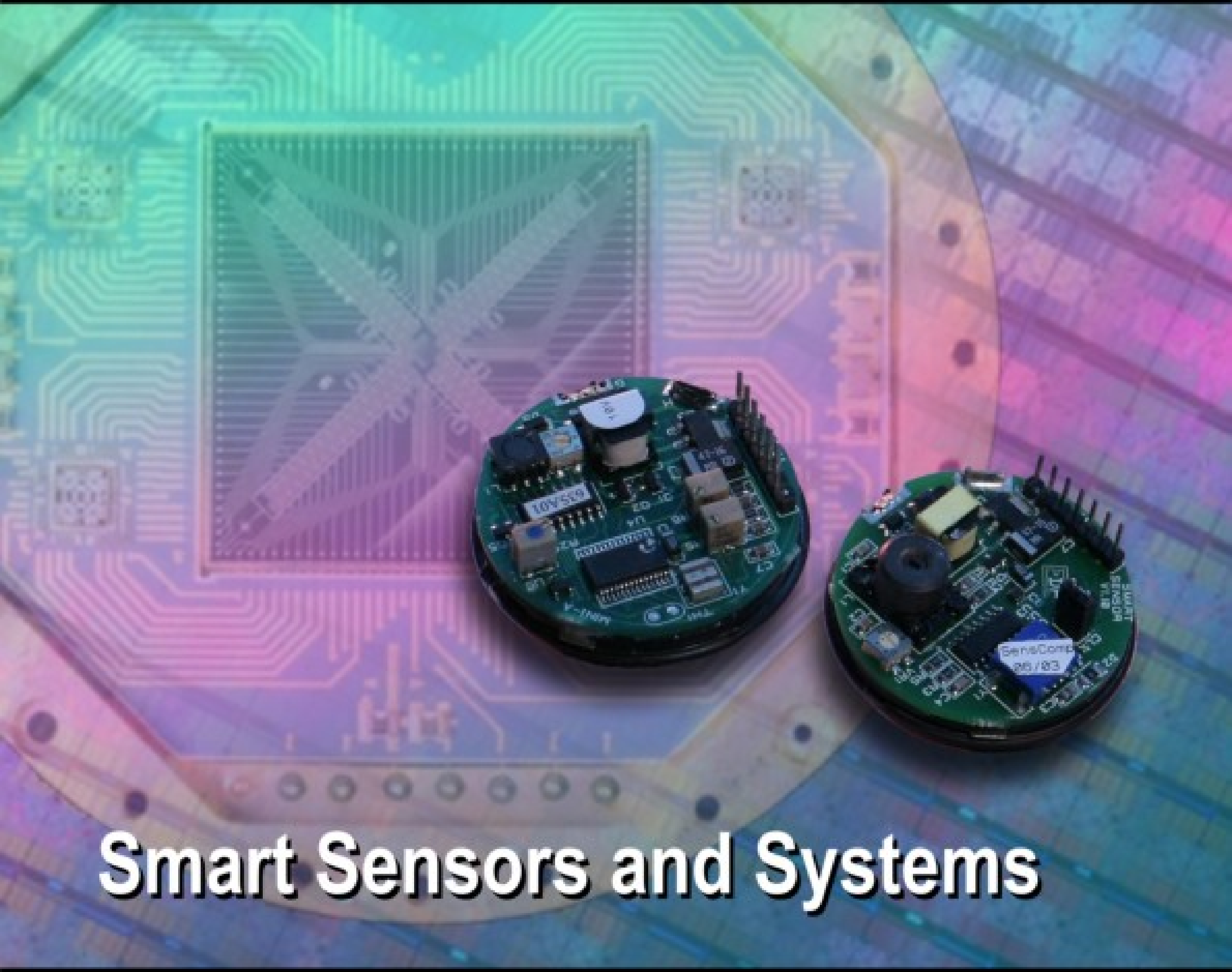

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Problems of Terminology in the Field of Measuring Instruments with Elements of Artificial Intelligence

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Abstract: The paper examines some problems that concern terminology in the field of measuring instruments which include sensors and elements of artificial intelligence. At present, a "common language" in this area does not exist. It is shown that application of an evolutionary method helps to systematize the concepts and creates a basis facilitating understanding of the relations between terms. Proposals on terms and their definitions in the field considered are given. *Copyright © 2009 IFSA.*

Keywords: Measuring instrument, Intelligent sensor, Smart sensor, Metrological self-check, Metrological serviceability

1. Introduction

Development of science and associated technical terminology is the integrated process. As it was shown by Prof. T. Kuhn, the scientific progress is the series of phases of "scientific revolutions" which concern a shift of concepts of further development [1].

These shifts relate to terminology too. Changes in terminology are practically connected with a tendency to determine more accurately the concepts specific for a new concept. Lack of monosemantic terminology, particularly under fast pace of the scientific and engineering progress as well as of the globalization of economics, complicates contacts among specialists, makes the search of information needed more difficult and becomes, in the long run, an obstacle for the development of science and engineering.

In particular, in industry and trade, this situation leads to the fact that goods with the same names can have consumer properties of various levels. Therewith, the price of these goods is determined also by their name, among other factors.

In a number of cases, lack of the established terms and their generally recognized definitions causes an unfair competition and leads to significant economic consequences.

To a great extent, the situation of such a kind exists as applied to measuring instruments or systems (hereinafter both of them will be referred to as MI) which include sensors and elements of artificial intelligence.

Appearance of the MIs of such a kind has led to a new stage in the metrological assurance of the MIs built in equipment [2]. At this stage a number of problems arise, which are caused by realization of such new functions as metrological self-check (self-diagnostics), self-correction, automatic prediction of metrological serviceability and so on. Strong growth of the number of theoretical and applied papers in the fields considered can be noticed last years [3].

Therefore, the problem of establishing and legalization of terminology in the field of MIs with elements of artificial intelligence increasingly becomes more important.

2. MIs with Sensors and Elements of Artificial Intelligence

Before turning to the discussion on the terminology in the field of MIs with the elements of artificial intelligence, it is expedient to examine the term "sensor" taking into consideration its definition in the VIM [4]: “sensor” is the "element of a measuring system, which is directly affected by a phenomenon, physical body, or substance that is the carrier of a quantity to be measured".

In practice, this term is applied for naming various components of measuring instruments, such as:
A) sensing element, e.g. "sensing coil of a platinum resistance thermometer",
B) separate unit isolated in a special case, which may be equipped with one or a group of sensing elements; and moreover, in a number of cases with additional transducers (an amplifier, an analog-to-digital converter (ADC), microprocessor, microcontroller, interface, and so on).

In this paper, the term "sensor" will be used only in strict accordance with item 3.8 [4] taking into account the explanatory examples given there, i.e. it will be applied to the devices indicated in item A). For various devices according to item B) in the world scientific and technical literature there is no any appropriate established term, but in Russia the term “datchik” is used. For such devices the term "module" could be used according to [5-7]. But it would be correct only if we add a special definition to it, e.g. "primary measuring module".

Hereinafter, taking into account the lack of any recognized legal term, these devices will be named as “datchiks”. (In the same way as the Russian language is enriched with foreign words, other languages, including the English one, have adopted Russian words, e.g. "shuba", "vodka", "dacha", "intelligentsia", "sputnik", and many others).

In scientific and technical papers, monographs and particularly in advertising prospects, diverse terms for the "datchiks" with elements of artificial intelligence are used, e.g., "intelligent", "smart", "adaptive", "self-validating", "self-diagnosing", "fault-tolerant", "self-checking", or even "brilliant" "sensor" (or "transducer") [8-30]. (The references here are illustrative rather than exhaustive.)

In some publications, e.g. [8], "smart sensor" is considered to be a combination of sensing element, analog interface circuit, ADC and bus interface. Eren and Chun Che Fung in [9] define a "smart sensor" as a device that contains a sensing element and complete signal condition circuits in the same chip. An integrated smart sensor is considered in [8]. It should contain: one or more sensors, amplifiers, a chopper and multiplexers, an AD converter, buffers, a bus interface, addresses, and control and power management.

Most authors deem "intelligent" or "smart" those measuring instruments that are equipped with a processor [10-15 and many others] and perform operations usually fulfilled by a human operator [14], in particular, zero adjustment, linearization, choosing a necessary measurement range, correcting for an influencing factor using a dedicated transducer and so on. Such "datchiks" are usually connected to a digital bus. According to Zvetkov [16], such sensors should be considered as merely “adaptive”, whereas “intelligent” instruments include a capability to optimize performance in compliance with a specified uncertainty.

In some cases, the term “intelligent sensor” is defined as the sensor that has one or several intelligent functions [11]. However, this definition does not bring to light the essence of the word "intelligent". Moreover, since "intelligent functions" are not fixed and a quantity of them seems to be increasing, the problem of distinguishing the sensors into more intelligent and less intelligent ones, will appear. Therefore, the application of the above term will be of no sense.

According to [15], "smart sensor" is an adaptive programmable measuring instrument that is equipped with a microprocessor. A lot of industrial "sensors", "transducers" or 'transmitters" have intelligence of this kind, which allows the measurement range to be adjusted using a HART-protocol or protocols of another type.

According to Allgood and Manges [17], a "smart sensor" is a programmed measuring instrument that has sufficient computational capacity to support the data acquisition, memory, and decision-making necessary to respond to algorithmic instructions, responds to calibration (verification) requests, reacts to interrogations about its health and status, and provides uncertainty estimates.

In [18] the term "smart sensor" implies that "some degree of signal conditioning is included in the same package as the sensor. On the more sophisticated end of the spectrum, the "sensor" unit can include devices with elaborated signal processing, displays, and diagnostic or self-calibration features".

In [19] a structure of "self-calibrating sensor" is described. This structure comprising a calibration circuit having a microprocessor, differential circuitry and external reference measure allows an "operating bias point of the sensor" to be adjusted.

Definition of smart or intelligent sensor in [20] is based on two definitions given in [21] and [22]. In accordance with [20], "smart sensor is an electronic device, including sensing element, interfacing, signal processing and one- or several intelligence functions as self-testing, self-identification, self-validation or self-adaptation". However, this definition does not distinguish instruments with significantly different consumer features and complexity. For example, it levels

- the "datchik" with self-check of processing unit (secondary transducer) only and the "datchik" with self-check of both primary transducer (sensor) and secondary transducer;
- the "datchik" with self-identification and with self-adaptation.

According to Duta and Henry [23], "intelligent sensor" is a self-validating sensor that produces an estimation of measurement value, measurement uncertainty and a discrete valued flag indicating how the measurement value and uncertainty have been calculated. In essence, a similar definition was used in [24], where such a sensors were called self-diagnosing, self-validating, or self-calibrating.

Wang, Zhang et al. in [25] consider the intelligent instruments which are based on fieldbus and can perform such functions as self-calibration, self-compensation, self-validation, etc.

The authors of [27] associate the word "smart" with the instruments which are designed by humans and “seem” intelligent. In order to "seem" intelligent, a smart system must invariably, first, acquire information on the environment, second, determine the appropriate action to be undertaken, and, third, act accordingly (this necessary process is, obviously, an imitation of the natural behaviour of living beings).

Some managers working at the companies that produce sensors, were interviewed about their opinion what a "smart" sensor exactly is. The following different definitions were given:

- "Smart sensors are sensors and instrument packages that are microprocessor driven and include features such as communication capability and on-board diagnostics that provide information to a monitoring system and/or operator to increase operational efficiency and reduce maintenance costs".

"A smart sensor has the ability to communicate information beyond the basic feedback signals that are derived from its application… This can be a HART signal superimposed on a standard 4-20 mA process output, a bus system, or wireless arrangement…".

"Smart sensors can self-monitor for any aspect of their operation", including "photo eye dirty, out of tolerance, or failed switch".

"A smart sensor must monitor itself and its surroundings and then make a decision to compensate for the changes automatically or alert someone for needed attention".

A number of definitions of MIs with elements of artificial intelligence were included in some national standards and international documents which do not refer to the sphere of metrology, e.g. [31-34]. In particular, according to [31], "smart transducer is a transducer that provides functions over and above that necessary for generating a correct representation of a sensed or controlled physical quantity. This functionality typically simplifies the integration of the transducer into applications in a networked environment". "Smart sensor is a sensor version of a smart transducer".

Thus, it is evident from these examples that, on one hand, the same terms are interpreted in a different way, but on the other hand, different terms are used to express the same ideas. At the same time, the hierarchy of terms is not clear, e.g. the relation between the concepts of "adaptive" and "intelligent" ("smart") and so on.

The corresponding terms were not included in the VIM [4].

3. Evolutionary Method

In order to find a way for adjusting the terminology in the field of MIs with elements of artificial intelligence, it is necessary to have some "corner stone". As it was shown by Prof. Finkelstein in [35], the Turing classical test cannot be useful for solving the problem being considered.

In our opinion, for the "corner stone" of such a kind, an evolutionary method can be used. Prof. N. Wiener [36] and Mr. S. Lem [37] have proved the efficiency of applying the analogy between the development of biological and technical systems. At present, this analogy is developed in evolutionary cybernetics [38, 39] and gives an opportunity to predict the evolution of technical systems on the basis of the study of biological system evolution.

Accordingly, if we formulate the ultimate purpose of intelligence in the Nature and find its analog for "datchik", it will be possible to single out the *minimum necessary set of features* which allows "datchik" to be identified as the “intelligent” one [3, 40].

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The analysis shows that the ultimate purpose of intelligence is to ensure the survival of a “biological complex”.

The time scale of biological evolution and of "datchik" development is different. However, the tasks solved were similar: with time, the methods providing the survival in the Nature and the methods providing metrological reliability of "datchiks" built in the equipment intended to be used under changing environmental conditions, were improved.

In the early period in the development of both natural and technical systems, prolonging of life was achieved through the use of conservative methods of enhancing the "reliability". For example, protection of a turtle with a shell or protection of a "datchik" with a sheath, certainly could prolong their respective lives. The use of materials that are robust to influencing factors (wear, pressure, temperature, etc.) may also contribute to achieve this goal.

However, the role of conservative methods described in [41] should not be over-emphasized. As a rule, the ambient conditions of measuring instruments as well as those of living organisms are characterized by a significant level of unpredictability.

Adaptive methods allow to take into account the variability of the environment [3, 40]. The adjustment of the insulating properties of an animal’s pelt with the season increases the likelihood of survival under a changing environment, as does the active thermoregulation of measuring instruments.

In order to extend lifetime, negative feedback is used for both

- the modification of the oxygen metabolism rate while changing the animal physical load and
- the automatic control of the conversion gain of an instrument.

Intelligence is a means that provides the most developed ability of adaptation. The growth of biological intelligence relates to ensuring the survival under increasingly rapid environmental changes. Intelligence enables to forecast and take into account future changes of dangerous character, including those of an intelligence carrier state. New abilities of adaptation to the environment have appeared.

During the process of evolution, intelligence turned out to be the most powerful factor for enhancing the survival of biological systems under changing conditions.

Thus, the purpose of artificial intelligence in a "datchik" is increasing the lifetime (calibration interval) of a "datchik" during which the uncertainty is kept within specified limits [42, 43].

The purpose of intelligence is achieved by cognition of reality. The cognition of reality depends on the ability to process information about both

- the environment in which the subject (or object) provided with intelligence (artificial intelligence) lives (operates)
- and the state of this subject (or object).

This is fulfilled by applying a special brain mechanism that tests the stability of vital activity characteristics. This mechanism, known as an "error detector" [44], was discovered by the famous

Russian academician, N. Bechtereva.

It follows from the above said that evolution of intelligence is associated with development of complexity of the "biological datchiks" (sense organ) as well as increase in the number of sensing elements in the sense organs, including those which provide identification of illness or the sense of pain.

Accordingly, "datchik" which could be named "intelligent" shall have the abilities:

- to perceive and process additional (in comparison with the "unintelligent datchik") information about measurement conditions,
- to check (diagnose) automatically its metrological condition.

In the "datchik", "cognition" of the environment and estimation of its influence can be carried out on the basis of redundant elements, which are added to the "datchik" structure. Processing of the corresponding basic and additional information can be performed in a microprocessor or microcontroller.

Using such additional information, it is possible to check of the stability of metrological characteristics during calibration interval and estimate metrological serviceability of sensor. In order to form this information, it is useful to take into account the experience of application of redundancy, gained within the frames of the invariance theory [45, 46]. Redundancy implies the ability of a "datchik" to perform additional functions due to built-in additional elements.

Development of the "datchiks" with a structure that enables organizing automatic metrological diagnostics and self-validation during their operation was started in Russia at the end of 80s [47-49]. A little later scientists in the UK, USA, Germany and China also began actively develop this field [24, 26, 29, 50-53, and others].

It follows from the analysis on the basis of evolutionary method that the corresponding works are the natural stage of development of measuring instruments. Therefore, these works have a long perspective.

4. Suggestions on Terminology in the Field of MIs with Elements of Artificial Intelligence

Nowadays, in Russia a state standard is being under development, the purpose of which is to establish the terms and definitions related to intelligent sensors and intelligent measuring systems. A draft of the above standard explicates the terminology [4], as well as takes into account a concept [3, 40] and grounds [54]. Below, the most important terms and their definitions are given.

Metrological serviceability of "datchik" in the process of operation: the state of a "datchik", for which its error in the process of operation under operation conditions lies within the specified limits.

Metrological self-check of "datchik": automatic procedure of testing the "datchik" metrological serviceability in the process of its operation, which is realized with the help of additional (redundant) embedded elements. The metrological self-check of a "datchik" can be realized in the form of metrological calibration self-check or metrological diagnostic self-check.

Popular synonyms of term "metrological self-check" are metrological "self-diagnostics" and "self-testing". Metrological self-check accompanied by evaluation of error or uncertainty is usually named "self-validation".

Metrological calibration self-check of "datchik": metrological self-check of a "datchik", performed by means of evaluating deviation of a "datchik" signal value from a value of a reference signal formed by an additional embedded element (redundant measuring transducer or measure) of a higher accuracy.

Example: automatic estimating of deviation of a measured temperature value from a reference value in a temperature sensor. The reference value is a melting-point of metal in a capsule embedded in the sensor. The capsule with metal serves as an embedded measure of a higher accuracy.

Critical (dangerous) error component: dominant error component or component inclined to fast increase over the specified limits. The critical error component is detected on the basis of metrological studies at the stage of the "datchik" development.

Metrological diagnostic self-check of "datchik": metrological self-check of a "datchik", performed by evaluating the deviation of a reference parameter from its value established in a previous procedure of verification or calibration. The reference parameter of a "datchik" is formed with the help of additional (redundant) embedded elements and characterizes a critical error component. Metrological diagnostic self-check of a "datchik" is performed without any embedded elements of a higher accuracy.

Examples:

- Metrological diagnostic self-check of a temperature "datchik" that contains two thermocouples of different types, which have close accuracy. Let us suppose that a critical error component is due to an unequal trend of the thermocouples characteristics. Then the difference of output voltages of the thermocouples at an operational temperature measured with the help of one of the thermocouples can be chosen as a reference parameter.

- Metrological diagnostic self-check of a temperature "datchik" that contains several thermocouples of the equal accuracy. Let us suppose that a critical error component is due to an unequal trend of the thermocouples characteristics. Then the deviation of output voltage of a thermocouple from a mean value of voltages of all the thermocouples at the temperature corresponding to the mean value of voltages of all the thermocouples can be chosen as a reference parameter.

Microprocessor "datchik": "datchik" that includes a microprocessor which provides processing of signals and/or storage of current data, as well as the possibility of interaction with upper level equipment of a measuring system.

Microprocessor "datchik" can perform the function of self-identification.

Adaptive *"datchik"*: "datchik" that contains additional elements which provide improvement of sensor efficiency by taking into account measurement conditions and/or sensor state. The improvement of efficiency (measurement accuracy and level of confidence, as well as decrease in man-hours during operation) is realized, e.g. by automatic change of measurement range or measurement time, by correction of the "zero", etc. Such changes can be provided with the help of signals from an influence quantity transducer and/or other signals. An adaptive "datchik" can be carried out on the basis of a microprocessor sensor.

Examples:

- A pressure "datchik" inside which the parameters are controlled through an interface with the help of a button, communicator or computer with special software, including a process of zero adjustment in the absence of external pressure.

- A pressure "datchik" in which automatic correction of an output signal under a temperature variation is carried out using a built-in resistance thermometer and microprocessor or microcontroller.

Intelligent "datchik": adaptive "datchik" which includes an additional (redundant) primary measuring transducer or measure and performs a function of metrological self-check.

Example: a capacitive "datchik" of distance between the "datchik" and a conducting flat body, which contains at least, two flat electrodes (primary and additional ones), as well as a microprocessor. The additional electrode is shifted with respect to the primary electrode in a direction perpendicular to its surface. Let us suppose that a critical error component is due to contamination of the surface of the electrodes. Then the voltage difference evaluated for the shifted electrodes at the distance measured with the help of the primary electrode can be chosen as a reference parameter.

An intelligent "datchik" can
- transfer information about metrological serviceability;
- perform automatic correction of an error resulting from ageing of components and effect of influence quantities;
- in a number of cases, perform self-recovery of the "datchik" if a single defect appears in it;
- forecast metrological serviceability and provide necessary preventive steps;
- provide increasing metrological reliability and calibration interval.

Self-recovery: automatic procedure of lowering of metrological consequences of a failure (up to the level which is reasonable for a customer), i.e. the procedure of providing fault tolerance.

Fault tolerance: capability of a "datchik" to keep metrological characteristics within the permissible limits, if a single failure arises in it. Usually, in case of a failure the permissible error limits are increased.

Intelligence-oriented "datchik": "datchik" that includes an additional measuring transducer or measure and performs a function of metrological self-check, when the sensor is connected to a stand-alone signal processing unit.

Example: a temperature "datchik" that contains a thermocouple and a capsule with metal, which serves as an embedded temperature measure of a higher accuracy, as well as a microprocessor. The reference parameter is the value of a melting-point of metal in a capsule, which is measured when the "datchik" is heated or cooled. The metrological self-check can be realized if the "datchik" is connected to a stand-alone signal processing unit.

The need for intelligence-oriented sensors is caused by the necessity of spatial separation of a "datchik" and a data processing unit in a number of cases. Such a need can arise either if the "datchik" environment is harsh (not appropriate for electronics) or in case of centralized data acquisition in a measuring system.

Main features of the definitions given above can be applied to a multi-channel measuring system.

In particular, according to the concept described, a multi-channel intelligent measuring system is an adaptive multi-channel system which includes an additional (redundant) "datchik" or reference measure and performs a function of metrological self-check of all the "datchiks" included in the system.

4. Conclusions

The development of MIs with elements of artificial intelligence is associated with the necessity to solve new problems with regard to assurance of the metrological traceability. In order to facilitate solving of these problems it is necessary to form the unified technical language, i.e. the corresponding system of terms and their definitions.

In the paper it is shown that there is no such a language in this sphere. Application of the evolutionary method for establishing the terminology in the field of measuring instruments with elements of artificial intelligence is grounded. A number of terms and their definition were formulated and proposed for discussion.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

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