RESEARCH ARTICLE

Design a System for Multifunctional Reconfigurable Intelligent Sensors

Ezekiel Oluwadamilare Akintona, Ejichukwu Emmanuella Obiageli
Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Anambra State Nigeria

Abstract: Experimental studies of some object or phenomenon testing of industrial products control of mechanisms or processes is inconceivable without measurements of physical quantities that characterize the state of the object. Therefore, the composition of any measuring, testing or control system as the most important components includes primary measuring transducers - sensors. The main function of the sensors is to convert the values of various physical quantities into electrical voltage. Strength time parameter of the electrical signal. In the list of tasks that need to be solved in the development and application of measuring systems, one of the most important is that it is necessary to measure not one, but different physical quantities for example, pressure, vibration, rotation speed, deformations, use different in principle of operation, characteristics and sensor design.
Keywords: Sensor Design, Mathematical model for different types of sensor, Multifunctional configurable smart sensor

Citation: Ezekiel Oluwadamilare Akintona, Ejichukwu Emmanuella Obiageli, 2020. Design a System for Multifunctional Reconfigurable Intelligent Sensors. *World Construction*, 9(1): 12-20. http://doi.org/10.26789/JWC.2020.01.003

1. Introduction

The analysis of methods for obtaining information using sensors, carried out by specialists for many years, showed that it is necessary to solve these problems in a complex, taking into account the peculiarities of integrating sensors into systems, taking into account the prospects development of microelectronics, circuitry, microprocessor technology and other factors. And this is possible if the sensors perform not only their main function - the transformation of physical quantities, but also a number of functions that are implemented by subsequent links of the measuring system, including special functions. The purpose of this dissertation work is to develop and study new principles for constructing information-measuring systems and creating multifunctional reconfigurable intelligent sensors that make it possible to simplify and facilitate the development of information-measuring systems. To achieve this goal, the following tasks were identified: Analysis of the IEEE 1451 family of standards for smart sensors and development of a sensor design diagram with spreadsheets. Investigation of the dependences of the measurement results of the primary converters on the influencing parameters and the creation of a mathematical model for different types of sensors. Analysis of the requirements for a multifunctional reconfigurable smart sensor. Development and research of a generalized algorithm for the functioning of multifunctional reconfigurable intelligent sensors. A definition of a multifunctional smart sensor is given, complex dependencies of sensors are studied, a generalized smart sensor equation and a generalized algorithm based on this equation are formulated. Development of a design system for intelligent sensors and assessment of the main parameters of the algorithms embedded in the created system.

2. Analyzes the State of Affairs of Intelligent Measuring Systems

The questions of the definition of intelligent measuring systems are touched upon; the analysis of the IEEE 1451 family of standards is carried out. The definitions of the multifunctional sensor are considered. The definitions of a smart sensor available today generally only take into account one aspect of its operation - or the presence computing unit, or correction of readings, or performance of additional functions. In regulatory documents, only metrological correction of readings is taken into account, but the possibility of performing other equally useful functions is not taken into account. According to the authors, there is a need to include in the definition, the increased capabilities of smart sensors. The authors proposed to understand an intelligent sensor as a transducer containing one or more primary transducers and equipped with an ADC for digital representation of measured data and a computing unit for correcting the measured value taking into account influencing factors and performing additional functions: processing, converting, storing and transmitting data. The basis for the proposed classification of functions of smart sensors is their distribution by purpose, types of information used and objects of action.

3. Result of Primary Converter on Influencing Parameters and Mathematical Model for Different Types of Sensors

A definition of a multifunctional smart sensor is given, complex dependencies of sensors are studied, a generalized smart sensor equation and a generalized algorithm based on this equation are formulated. Taking into account the work proposed by the authors of the classification of functions of multifunctional smart sensors (Figure I), a definition based on a functional approach is proposed. Multifunctional intelligent sensor - an intelligent sensor containing one or several primary transducers that perform basic measurement and additional functions: analysis (forecasting) control. Each sensor in its actual operation is exposed to influencing factors. Measurement results can therefore depend on the values of specific influence quantities. For a simple sensor with a single primary converter, the task of monitoring the influence of factors is difficult. In practice, sensors with several primary converters are becoming more and more widespread, for which it is already quite possible to track the influence of other quantities on the main measurement result. In the literature, such authors as Aleinikov A.F., Gridchin V.A., Tsapenko M.P., the first sensors are called one-dimensional, the second - two- and more-dimensional. For those sensors that are subject to the influence of another quantity on the main measurement result, it makes sense to talk about complex dependencies. By complex dependence, we mean here the mathematical equation of the output value, which includes more than one input value.

To obtain these dependencies, we estimated sensor readings but the schedule specified in the specifications of a particular sensor conversion functions. Evaluations of the dependence of the readings on the change external parameters were carried out in a similar way. Further, to obtain analytical expression, in the given examples we used least squares approximation in Microsoft Excel.

Smart Sensor functions	
Conversion functions	• Perception of physical size • Supplement the gel hairs • Converting a value to a code • Correction of the result
Informational functions	• Type of Sensor • Factory number • Main technical characteristics • Set measuring range • Installed scale • Sensor settings • Identifier of the working person an software • Archive of metrological verification • Term of the next verification
Functions configuring	• Range and units • Measurement interval • Filter parameters
Functions Control and projection	• Analysis of the change in the measured value. • Analysis of the change in the state of the measurement medium. • Control of the measured value out of permissible limits. • Control of the outflow of the values of environmental parameters outside the permissible limits
Self-diagnosis functions	• Non-critical • Critical
Control functions	• Automatic regulators • Locking devices • Automatic on / off devices

Figure 1 Scaling function of smart sensors

The following are examples of dependencies for gas sensors. Detection of explosive, toxic gases and humidity sensor. The curves of the graphs are built on the basis of the official passport data of these converters. The TGS2610 sensor (manufactured by Figaro) is shown in Figure 2.

The need to obtain these dependences in an analytical or approximated form is due to the following considerations:

1. Curves of dependencies until now were available only in the form of graphs in the specifications of sensors, but now they can be used in the measuring system

2. The dependence curve reflects the behavior of a family of sensors, taking into account the calibration of specific specimens; it will be true for all sensors of this family

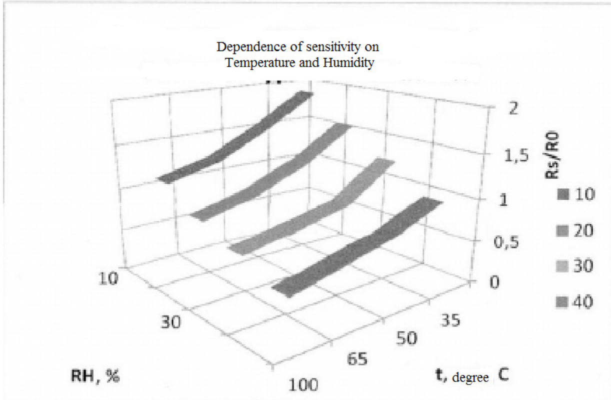

Figure 2 - Graphs of dependences on humidity at different temperatures for Sensor TGS2610

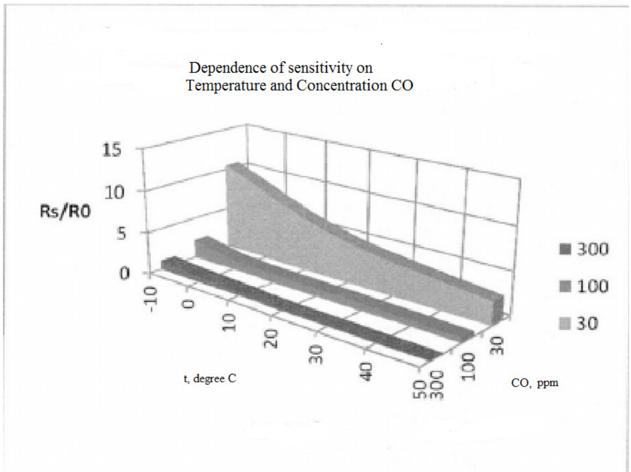

Figure 3- Dependences of sensitivity on temperature and CO concentration Sensor TGS2442

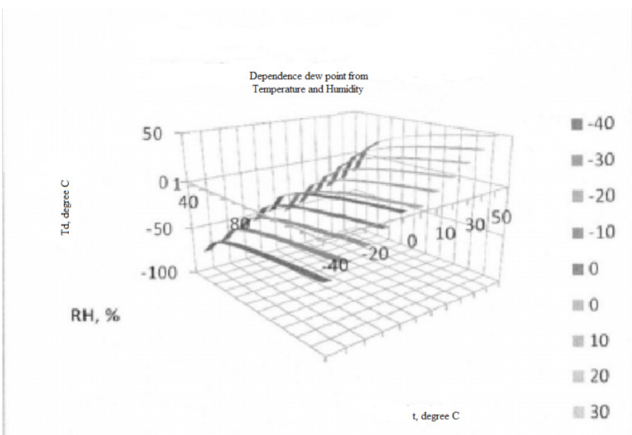

Figure 4 - Graph of dew point versus temperature and humidity

3. Initial provision of dependencies in digital form by sensor manufacturers will simplify the design and configuration of measuring systems.Several examples of the obtained equations of sensors with different dependencies, for the main factor - the measured value: $y = 357.2408e^{0.0344x}$, $y = 10632.2857x^{-1.9697}$, $y = 0.0003x^2 - 0.0436x + 1.9625$.The resulting equations can have a very different form, in particular, exponential, power, polynomial of the nth degree. In addition, the coefficients included in these equations may have a dependence on the influencing factor, thus, the final dependence will already have a two-dimensional form, for two initial parameters - the main and influencing factor. To describe the whole variety of equations, the author proposed to systematize them and write them down in the form of a general equation. The main characteristic of the transducer can be determined either empirically or theoretically. In the first method, finding is reduced to testing a series of sensors and finding the equation of the curve from the results tests. In the second method, knowing the material of manufacture, the technical solutions used and physical phenomena, it is possible to analytically derive the main characteristic that is valid for all instances of a given model. The main characteristic of the sensor can be recorded:

$$A = F(\{U, I, R\})$$

Where A is the response from the value measured by the sensor (the value of interest to us),

F-function characteristics,

U, I, R - electrical quantities at the output of the sensor associated with the measured value. Further, for brevity, it is assumed that the voltage and is used at the output of the sensor U. The characteristic function can be linear, exponential, exponential, or more complex. Therefore, we represent the main characteristic as

$$A = \sum_{i=1}^{N} a_i * \psi_i(u)$$

Here: A' is the required value, i are the coefficients, - are the basic functions. Basic functions can be functions of the form:

$$S = a + h * \ln(u)$$
$$S = a * e^{k-u}$$
$$S = a * k^{u}$$
$$S = \sum_{i=1}^{N} a_i * u^1$$

Let's write down our characteristic taking into account corrective factors

$$A = F(\{U, I, R\}) + K + Z$$

K - is the factor of the influencing minor value, Z - factor due to the characteristics of a particular instance (calibration characteristic)

The factor of the influencing minor quantity can be presented in general form

$$K = F\{f(A_k))$$

A_k - influencing quantity

$f(A_k)$- transfer function of the influence quantity for a given specific sensor

$F\{f(A_k))$ - conversion function The calibration characteristic factor can be represented as

$$Z = Z\{U, I, R) = \sum_{-0}^{N} a_i\, x^i$$

Where x - is the values at the calibration points, a- are the coefficients. As a rule, the function is represented as a table of values. In practice, the influencing factor can be one-dimensional and two-dimensional. Let us write an expression for the one-dimensional correction

$$\sum_{i=1}^{k} a_i * \psi_i(u)$$

Let's write the expression for two-dimensional correction. Let us take into account that the influencing function can have both analytical dependence on the second quantity, and tabular.

$$K = \sum_{i=1}^{k} a_i * \psi_i(u, A2)$$

$$\begin{cases} K = \sum_{j=1}^{k0} a_{0j} * \psi_{0j}(u), A2 = a_0 \\ K = \sum_{j=1}^{k1} a_{1j} * \psi_{1j}(u), A2) = a \\ K = \sum_{j+1}^{k2} a_{2j} * \psi_{2j}(u), A2) = a \end{cases}$$

Separately, it should be noted the effect of time drift on the sensor readings Based on the assumption that the time drift does not depend on the measured

$$A'' = F_1(U) + F_1(t)$$
$$A'' = F_1(t)$$

A' can also be represented as a sum of basic functions

In this case, it is possible to distinguish between short-term and long-term drift. Indications, short-term drift - within an hour after switching on, and long-term - the total operating time is from a day or more.

$$A = F(u) + F_k(A_k) + F_1(t) + Z$$

Where F (u) - main characteristic

$F_1(A_1)$ - correction taking into account the influence quantity

$F_1(t)$ - correction for time drift

Z - correction based on the calibration characteristic. The final form of the generalized

Equation

$$\sum_{i=1}^{N} a_i * \psi_i(u) + A = \sum_{j=1}^{N_K} a_{K_j} * \psi_{K_j}(u) + \sum_{i=t}^{N_j} a_{t_i} * \psi_{t_i}(t) + \sum_{i=0}^{N} a_i * x^i$$

The resulting generalized smart sensor equation is a transformation equation that takes into account the magnitudes of influencing factors, time drift, as well as the calibration data of the transducers. The generalized equation of the multifunctional smart sensor is the basis for the algorithm of this sensor. Using this equation, it is possible to represent the characteristics of primary converters and sensors in digital form. Thanks to this, it becomes possible to create such an algorithm for the operation of the multifunctional intelligent sensor software, which would be invariant to the characteristics. Primary converter, The generalized equation will allow:

- take into account all influencing factors of the measurement result and implement two- or more-dimensional interpolation of complex dependencies;
- Encode the components in digital form for use in measurements;
- To unify the software of intelligent sensors;
- To set the characteristics of an intelligent sensor only by changing the parameters of the equation, without changing its program;
- To achieve a reduction in the cost of designing and manufacturing measuring systems.

4. Analysis of the Requirement for a Multifunctional Reconfigurable Smart Sensor

A hardware implementation of a reconfigurable multifunctional intelligent sensor is proposed, which makes it possible to implement a generalized algorithm for working with any primary converters, and a system for developing such sensors. The authors propose a unified reconfigurable platform for creating sensors. Reconfigurable Smart Sensor An intelligent sensor that can be easily reconfigured for use with other sensors and other applications without hardware changes. Figure 5 shows the proposed block diagram of the MRID. Primary transducer (sensor / sensor) - a device that converts a non-electrical signal into an electrical one, a device that perceives the input impact. Measuring circuit - a set of electronic elements necessary for the operation of the primary converter, as well as for scaling filtering the input signal. The number, purpose and parameters of the measuring circuit elements depends on the type and parameters of the primary converters. Primary measuring transducer circuit

The multifunctional reconfigurable intelligent sensor is designed to measure several quantities taking into account the characteristics of the environment and perform any additional functions, such as: transformations (measuring), information, configuration, monitoring and forecasting, self-diagnostics, control. In the maximum version, it is assumed that there are measurement objects and control objects.

The intelligent sensor core is controlled by a special master program. This program is the same for all instances based on the same microcontroller architecture. The differences between different microcontroller architectures come down to taking into account the peculiarities of memory organization and input / output in this microcontroller architecture. The master program has two modes of operation - “measuring” and “configuring”. “Measuring” mode is the main one. In this mode, the program works taking into account the configuration specified for the sensor: the number of channels used, the types of used converters, the characteristics of the used converters, the basic equation of the sensor conversion, and other configured sensor functions. This configuration is set for the sensor in the “configuration” mode completely

This fully describes the functionality, characteristics and parameters of the sensor. The block of configuration parameters is formed and recorded using the smart sensor configuration system. The smart sensor configuration system is central to the overall design and use of

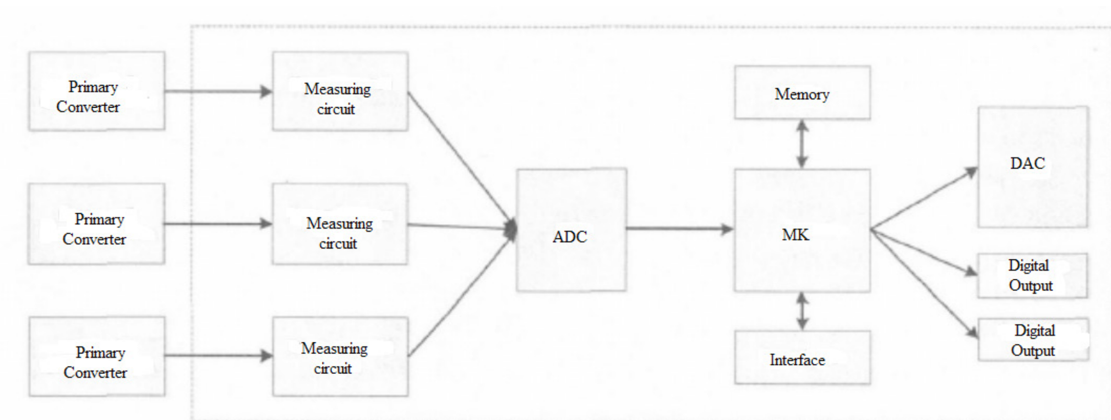

Figure 5 - Block diagram of MRID

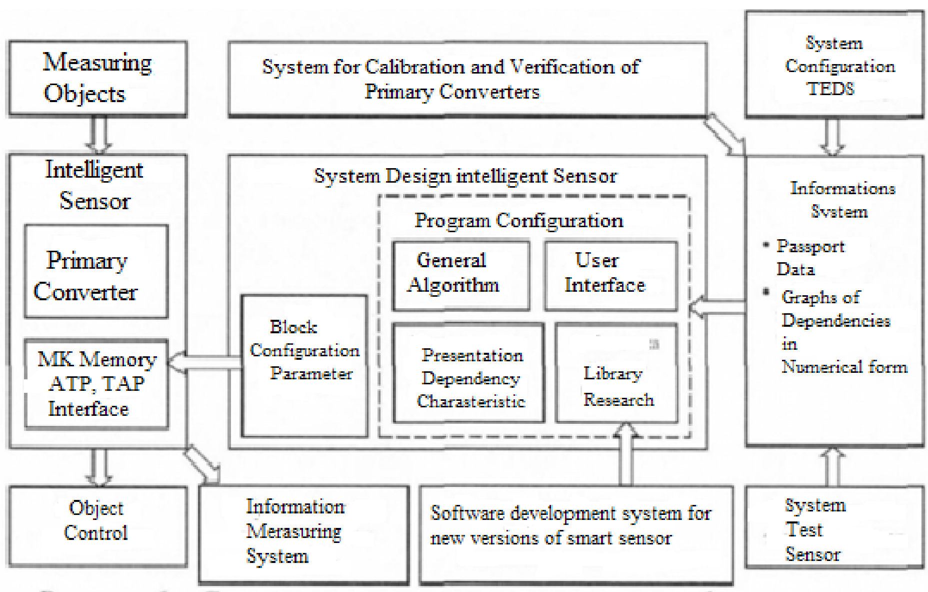

Figure 6 configuration block is written to the sensor,

multifunctional smart sensors. Process Configuration is implemented by a smart sensor configuration program that implements several basic provisions. The first position is a user-friendly user interface that allows the operator to set the parameters of the smart sensor being designed without the need for too high qualifications. The second provision is the use of a generalized equation to set the transducer transformation equation. The generalized equation includes the measuring, corrective, calibration and temporary parts. The third provision consists in the numerical specification of the dependencies of the used primary converters. Dependencies of transducers are divided into basic, calibration and influencing. All these dependencies are presented and stored in the information system in numerical form. A special data storage format based on the IEEE 1451 (TEDS) standard is used to represent the dependency in numerical form in the smartest sensor itself. The fourth provision is to use a separate repository for versions of master programs for different microcontroller architectures used in the designed multifunctional intelligent sensors. The master programs themselves are developed in the program development system for new versions of smart sensors. All parameters of a smart sensor are collected in a configuration block, which fully describes the functionality and characteristics of the sensor instance. The configuration block contains, in short, the following groups of parameters: identification parameters of the sensor and used primary converters, calibration and influencing characteristics of primary converters, writing the generalized equation of the smart sensor, taking into account its characteristics, functionality and specific parameters for the functions involved from all six groups of functions. Together with the use of a single master program, it becomes possible to vary widely the functionality and characteristics of the same sensor instance.

5. Design System for Multifunctional Reconfigurable Smart Sensors

The structural and custom aspects of the software for configuring reconfigurable smart sensors are discussed in detail. The issues of the implementation of the user interface, the implementation of the exchange protocol with the reconfigurable smart sensor device, the implementation of the information part of the design system are being addressed. The design system is designed for faster, easier and more successful configuration of sensor parameters using a graphical interface. Tasks solved by the design system

1) Setting the basic parameters of the designed sensor;

2) Determining the functionality of the sensor;

3) Storage of previously specified configurations for later use;

4) Convenient specification of the characteristics of converters and their storage.

Figure 7 shows a simplified block diagram of the operation algorithm of the MRID configuration program. The first part of the algorithm configures system-wide parameters such as identity data, measurement data, equa-

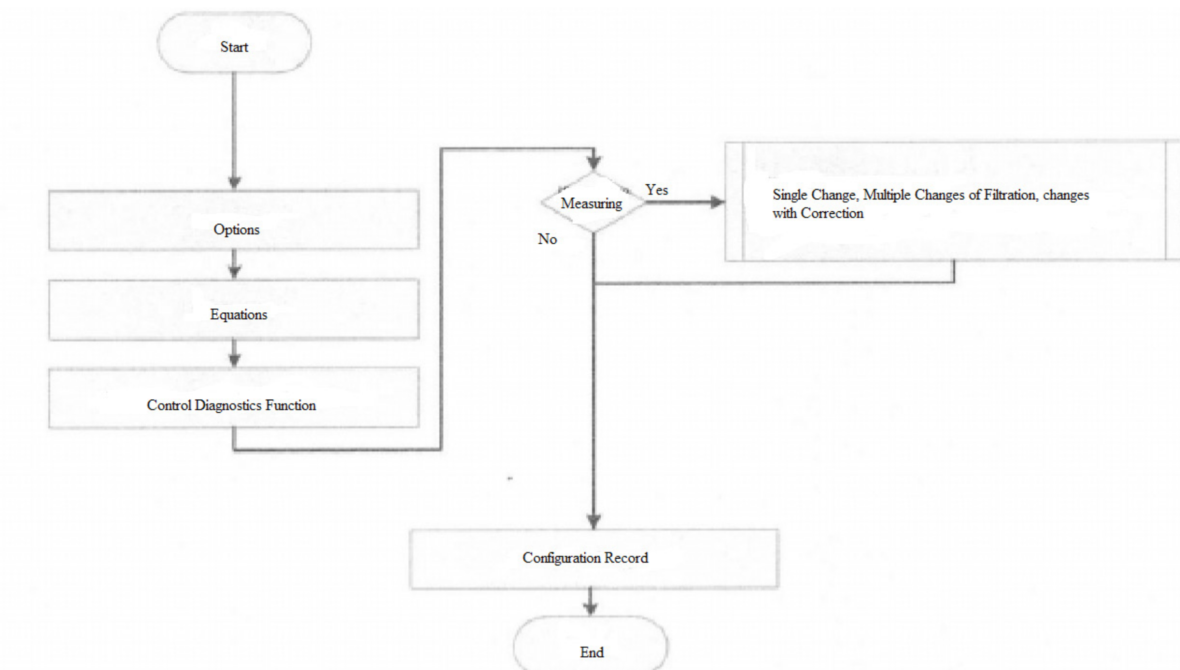

Figure 7 - Simplified block diagram of the configuration program algorithm

tion data, and so on. The second part configures the performance of each of the predefined functions of the smart sensor.

6. Analyzes The Results Of Using The Design System For Multifunctional Reconfigurable Intelligent Sensors.

Presents the results of a preliminary assessment of the effectiveness of using MRID.As part of the work, a preliminary assessment of the effectiveness of using MRID was carried out. The main task of this assessment was to clarify quantitative indicators when correcting various components of the generalized equation of an intelligent sensor, first of all, correcting the influencing factor. Evaluation of the correction of the influencing factor is aimed at clarifying the quality of the correction of the MRID readings with primary converters under the influence of the influencing factor. The tests were carried out in two stages. In the first experiment, two primary converters were connected to the MRID, for one of them the use of correction of the influencing factor was configured, for the other, the correction was turned off. At the second stage, the correction was turned off for the first transducer, and turned on for the second. The measurements were carried out for each transducer independently on its own channel. A VT20N photo-resistor from PerkinElmer Optoelectronics was used for the experiment. The temperature varied in the range from +10 to +40 degrees Celsius, the lighting was constant at 100 lux.

1 N measurements were made according to the K values of the influencing factor. The test results were averaged with the preliminary exclusion of the minimum and maximum values. This test analyzed the difference in readings. The absolute difference was determined by the following formula:

$$\Delta_{K1} = (V_1)_{K1} - (V_2)_{K1}$$

where K1 means the value for the influencing factor at point K.1, averaged values over N samples at point K.1. Maximum difference in readings from experiments for uncorrected sensor is shown in Figure 8. Figure 9 shows the difference in readings for those the same experiments for the sensor with the included correction. In numerical form, the difference in readings for the sensor without correction is from 3% up to 6% in one direction or another, for a sensor with a correction of 1%

Also, an analysis of design tools for smart sensors and systems based on them was carried out, based on the results of which it was decided to design a multifunc-

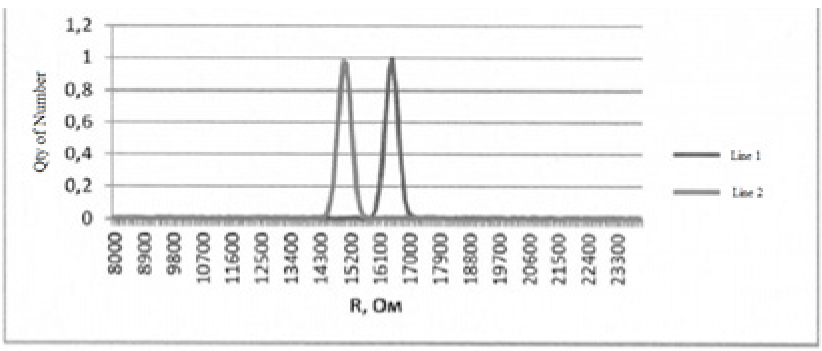

Figure 8 - Difference of readings for the sensor without correction of the influencing factor

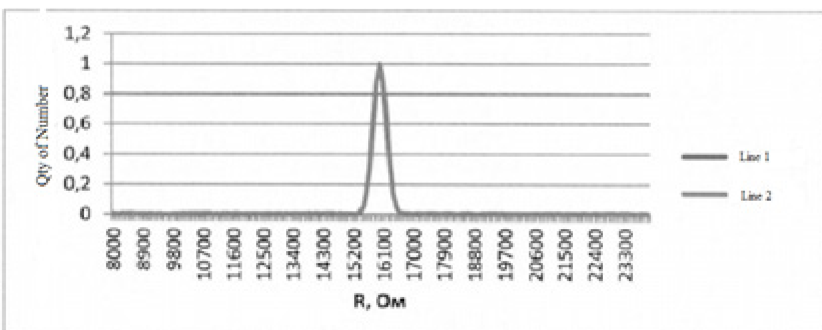

Figure 9 - Difference of readings for the sensor with the included correction of the influencing factor

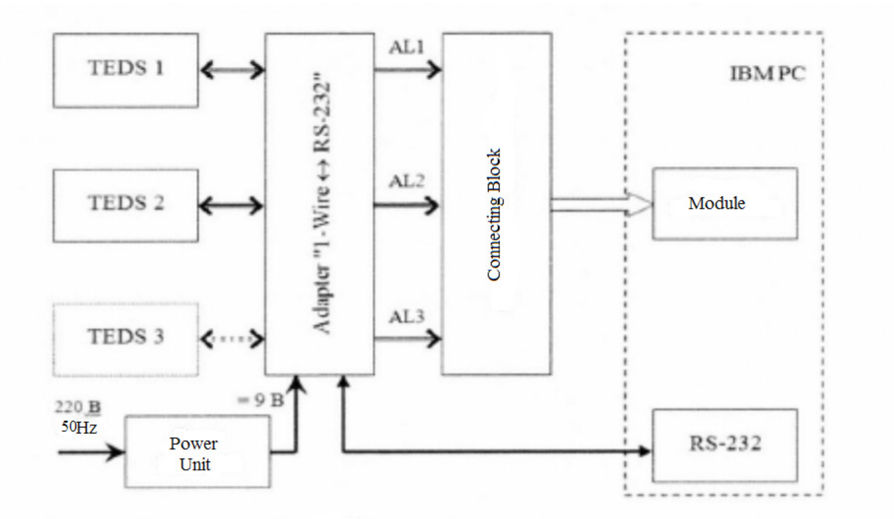

Figure 10 - Block diagram of the stand

tional software and hardware complex "Smart Sensors with Spreadsheets". This complex, the structure of which is shown in Figure 10, is intended for design. TEDS smart sensors, made in accordance with the IEEE 1451.4 standard, studying design software - a library of TEDS LabVIEW functions and special utilities, teaching the principles of designing measurement channels in automation systems for experimental research, testing and control using smart sensors.

The development is a design system for both intelligent TEDS sensors and measuring systems, implemented using equipment and software from National Instruments corporation, supplemented with a set of intelligent sensors and an interface adapter "1Wire - RS-232"

The developed hardware and software complex is used to teach senior students of technical specialties to design smart sensors with spreadsheets and measuring systems based on them.

Result and conclusion

As a result of this work, the following main results were obtained.

1. It is shown that the IEEE 1451 family of standards addresses the issues of storing mainly the passport characteristics of sensors as primary converters and the organization of a communication channel with the memory in the sensor, while little attention is paid to the description of more complex sensors. The definitions of a multifunctional intelligent sensor and multifunctional reconfigurable smart sensor. The classification of functions of smart sensors is proposed.

2. It is shown that the proposed generalized equation of a multifunctional reconfigurable smart sensor allows taking into account the influencing dependences on various factors, as well as describing these dependences in digital form, due to which it is possible to form sensors with the required parameters using a large number of types of primary converters. It is also shown that the MRID operation algorithm developed on the basis of the generalized equation greatly simplifies the design of multifunctional reconfigurable sensors. On the basis of the generalized equation and the generalized algorithm, a design system for multifunctional reconfigurable intelligent sensors has been developed.

3. A study of MRID test samples was carried out to verify the effectiveness of correction of influencing factors and general testing of the functioning of the samples, which showed the success of the adopted approach.

4. Developed, tested and implemented in the educational process of several universities software and hardware systems for teaching the design of smart sensors with TEDS and monitoring of environmental parameters.

Conflict of Interest

On behalf of all Authors, the Corresponding author state that there is no conflict of interest

References

[1] Baran, ED *Research and construction of intelligent sensors with electronic tables* / ED Baran, IO Marchenko, V. JI. Polubinsky // Scientific Bulletin of NSTU. - 2010. - T. 1. - p. 23-34.

[2] Marchenko I.O. The design system for reconfigurable intelligent sensors [Text] / I.O. Marchenko // Sensors and systems. -2012, -№2. -WITH. 2-5.

[3] Marchenko, I. O. *System for designing multifunctional reconfigurable sensors in the educational pro-*

cess [Electronic resource] / “Engineering Bulletin of Don” – 2013 http://ivdon.ru/magazine/archive/n4y2013/1916 (free access) - Title. From the screen. Language. Russian (Date of treatment 12/15/2014).In other publications

[4] Baran E. D. Automated training workshops and laboratories. Educational, scientific and engineering applications in the LabVIEW environment and National Instruments technologies [Text] / E. D. Baran, A. V. Kukhto, A. Yu. Lyubenko, I. O. Marchenko, S. V. Cherkashin // Proceedings international scientific and practical conference “Educational, scientific and Engineering applications in the LabVIEW environment and National Instruments technologies, Moscow, Russia, November 17-18, 2006 - M.: RUDN,2006.- pp. 18-24.

[5] Baran E. D. Automated educational laboratory "Electronics and circuitry" [Text] / E.D. Baran, A.V. Kukhto, I.O. Marchenko, S.V. Cherkashin // Virtual and Intelligent Systems-2007. Polzunovsky almanac. -Barnaul: Publishing house AltGTU im. I.I. Polzunova, 2007 .-- S. 122-124.

[6] Baran E. D. Equipment and software for educational laboratory stands [Text] / E.D. Baran, A.V. Kukhto, I.O. Marchenko, V.B. Harhota, S.V. Cherkashin // Educational, scientific and engineering applications in the LabVIEW environment and National Instruments technologies. Proceedings of the conference.- M: RUDN Publishing House, 2007 .-- S. 501-508.

[7] Baran, Efim. Laboratory Test Benches Development for Engineer's / Efim Baran, Andrew Kukhto, Ilya Marchenko, Sergey Cherkashin // Education International Conference on Computational Technologies in Electrical and Electronics Engineering “SIBIRCON 2008”. Proceedings Novosibirsk: Publishing house of NSTU, - 2008. - p. 68-72.

[8] Baran E. D., Laboratory stands "Monitoring of environmental parameters" and "Automatic control system” / E. D. Baran, A. V. Kukhto, I. O. Marchenko, V. B. Kharkhota, S. V. Cherkashin // Educational, scientific and engineering applications in the LabVIEW environment and National Instruments technology. Proceedings of the VII scientific and practical conference. M: RUDN, - 2008.-p. 7-10.

[9] Marchenko, I. O. System for designing intelligent sensors with electronic tables / I. O. Marchenko, V. L. Polubinsky, E. D. Baran // Materials of the X international conference “Actual problems of electronic instrumentation” APEP-2010 at 7 volumes. Novosibirsk: NSTU, -2010.-T. Z.-s. 143-148.

[10] Marchenko, I.O. Generalized equation of multifunctional intelligent sensor [Text] / I.O. Marchenko. // Collection of scientific works of NSTU No. 3 (65), - Novosibirsk: NSTU, 2011, - P. 14-21.

[11] P. Marchenko, I. O. Application of the design system for multifunctional reconfigurable intelligent sensors in the educational process / I. O. Marchenko // Virtual and intelligent systems-2013. Polzunovsky almanac. Barnaul: Publishing house AltGTU im. I. I. Polzunova, -2013.-e. 127-130.

[12] Marchenko, IO Advantages of multifunctional reconfigurable intelligent sensors / IO Marchenko // Materials of the XII international conference “Actual problems of electronic instrumentation” APEP-2014 in 7 volumes. Novosibirsk, September 22-24: b.n., 2014.-T. Z.-s. 198-200.