Smart measurement and control system of condition of a local technosphere

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Abstract. This article proposes a smart system of measurement of and control over a local technosphere’s condition. A basic element of this system, which allows for minimizing control errors, is a smart sensor which gives an opportunity to measure, transform, and automatically detect and correct measurement results. In order to minimize control errors within threshold values of parameters, we suggest transforming the sensitivity of a smart sensor using the Monte Carlo method. Structural schemes of a smart measurement and control system and an intelligent sensor are proposed, as well as an algorithm for transforming the sensitivity of an intelligent sensor based on the Monte Carlo method.

1. Introduction
A local technosphere (LT) is a complex, dynamic, and multi-parameter entity which includes natural and artificial subsystems such as the biosphere, society, and technogenetics. [1] The parameters which characterize each subsystem change over time due to extrinsic and intrinsic factors. They influence all subsystems and an entire LT. In order to develop means used to control an LT as a dynamic system, mathematical modeling should be used, with the purpose to study the influence and impact of all its elements in various modes of functioning. [2] Moreover, accurate results of measurements of numerous controlled parameters (CPs) are needed. Due to the reasons of cost-effectiveness and control over an LT, the most significant CPs whose change gives control over various parameters are selected. In order to minimize control errors within threshold values of CPs, we suggest transforming the sensitivity of a smart sensor using the Monte Carlo method (MCM).

2. Problem statement
LT quality control is an area of interest in today’s world, which is why it remains relevant. [3-8] Authors understand LT quality as a state of its subsystems characterized by physical, chemical, biological, or other parameters and/or sum of these parameters; meeting the society’s demands, and providing equilibrium within the biosphere, as well as effective and accident-free functioning of technogenic objects. We believe that, in order to perform quality control of an LT, we need an engineering solution which will allow for automatic measurement and processing of various types of LT parameters through an extended period of time. This is especially relevant for the quality control of LT facilities located in remote or dangerous areas where it is crucial to minimize control errors (for example, the Arctic region, aggressive environment, or complex impact on the biosphere, society, and technogenic objects).
According to [9], one of these engineering solutions is a smart measurement and control system (SMCS) whose parameters and algorithms may change during its use depending on signals from its transformers; and which performs metrological self-control. SMCS automatically checks its metrological accuracy during its use, thanks to embedded technological and software tools. [9] As an element of SMCS, a control subsystem ensures accumulation of data regarding the controlled subsystems and contains tools to influence their condition.

3. Theoretical part
SMCS perform control, computational, and service functions. Control functions consist in switching measurement channels and ranges, management of computational power, detectors, external memory, and means of communication with the operator. Computational functions include distributed data processing, calibration, scaling, filtering, statistical processing etc. Service functions include detection and localization of breakdowns. SMCS structure is shown in figure 1 [10].

![Figure 1. SMCS structure.](image)

Legend: SS – smart sensor, ICTS – structure of information change and transformation, IPSS – structure of information processing and storage, ID – structure of information display, CD – control devices, OD – output device, ED – execution device.

SMCS’ functioning principle consists in the following. The system contains a dynamic LT model pre-built using experimental data; this model accounts for all CPs, control actions, and dependencies of output parameters (including those not pertinent to CPs) from input control actions.

SMCS receives current CP values from sensors, inputs it into the model, and calculates output parameters which represent the forecast of an object’s behavior. Structure of information processing and storage, using set criteria and in compliance with set limits, calculates control actions on the specific number of control strokes. If the calculated and the current control actions are the same, then there is no need for adjustments. Otherwise, a control action adjusts the object’s condition, and the steps are repeated during the next stroke. To minimize control errors when determining the condition of LT, authors suggest using automatic adjustment of errors of measurement of the most significant CPs.

An important feature of the measurement system is the CP measurement error. It reflects the degree of discrepancy between measurement results and actual CP values. However, often this degree of discrepancy does not coincide with passport data or is unknown. Moreover, the measurement error is subject to constant changes during operation. Some of the reasons for changes in the measurement error include: changes in operating conditions (extrinsic factors), drifting of system’s physical parameters (intrinsic factors), disturbances in communication channels between the sensor and the recording equipment, sensor breakdown etc. With that in mind, the development of the respective algorithms of error adjustment is a relevant task. There is a clear need for adaptive approaches which may be used in uncertain conditions and conditions of environmental changes.
In accordance with [11], when error adjustment is necessary, the measured value can be represented as follows:

$$\lambda_j^* = \lambda_j^* - \Delta_{\text{kop}} \lambda_j^*$$  \hfill (1)

wherein $\lambda_j^*$ is the measurement result in the j-th experiment; $\lambda_j^* = L \gamma_j$ is the preliminary result of CP measurement, measurement channel error included; $\gamma_j$ is the input action (carrier of information regarding the measured value) measured by an intrinsic or an extrinsic impact $L$;

$\Delta_{\text{kop}} \lambda_j^*$ is the value of adjustment of the measured value, which is calculated using this formula:

$$\Delta_{\text{kop}} \lambda_j^* = \Delta_{\text{kop}} \lambda_j^* + \delta_{\text{kop}} \lambda_j^*$$ \hfill (2)

at $\Delta_{\text{kop}} \lambda_j^* = 0$, the adjustment will lead to changes in composite error $\Delta_{\text{kop}} \lambda_j^*$ by $\delta_{\text{kop}} \lambda_j^*$. This leads to the increase in SD of error because the composite error may be determined as the sum of adjustable $\Delta_{\text{kop}} \lambda_j^*$ and non-adjustable $\Delta_{\text{nonkop}} \lambda_j^*$ errors according to the following formula:

$$\Delta \lambda_j^* = \Delta_{\text{kop}} \lambda_j^* + \Delta_{\text{nonkop}} \lambda_j^*$$ \hfill (3)

Thus, we get the value without adjustment:

$$\Delta \lambda_j^* = \Delta_{\text{nonkop}} \lambda_j^*$$

And with adjustment:

$$\Delta \lambda_j^* = \Delta_{\text{nonkop}} \lambda_j^* - \delta_{\text{kop}} \lambda_j^*$$

Using [11], the procedure for error adjustment $\Delta_{\text{kop}} \lambda_j^* \leq \Delta_{\text{IF}}$ ($\Delta_{\text{IF}}$ is the threshold level $\Delta_{\text{kop}} \lambda_j^*$ which determines the boundaries of using adjustment), we get $\lambda_j^* = L \gamma_j \vee \Delta_{\text{kop}} \lambda_j^* > \Delta_n$ and $\lambda_j^* = R_{\text{kop}} L \gamma_j$.

Various approaches to measurement error adjustment are proposed in scientific and reference literature. [11] We believe that the most effective one is the approach related to the development of algorithmic methods of adjustment according to a mathematical model. This is the smart sensor concept. [9] Apart from parameter measurement and transfer, a smart sensor performs such functions as self-diagnostics, protection and blocking, control over the condition of nodes of operation units. That is why the devices which perform additional functions are called ‘smart.’

Nowadays, thanks to one-crystal low-consumption microcontrollers, embedded precise analog-to-digital switches, and non-volatile memory, leading manufacturers have switched from analog methods of error adjustment to the digital ones. A smart sensor has a digital output and is able to transfer data regarding metrological viability through the interface. Since it has computational capabilities, it provides for the following: automatic adjustment of errors emerging due to influencing quantities and/or aging of components, self-restoration after a single sensor defect, and self-training. Smart sensor creates a technological basis for establishing two values of recalibration intervals (with and without the metrological self-control function). Thus, smart sensor is responsible for error $\Delta_{\text{kop}} \lambda_j^*$ adjustment.

In order to automatically correct errors of measurement of the most significant CPs, it is suggested to use the algorithmic adjustment of smart sensor sensitivity based on MCM [12]. This adjustment consists in comparing and adjusting the measured smart sensor value depending on the correlation of the adjustment value $\Delta_{\text{kop}} \lambda_j^*$ and the threshold measurement error $\Delta_{\text{IF}}$, which determines the viability of making the adjustment.

4. Practical significance, suggestions and results of implementation

The authors have developed a scheme for the algorithmic correction of SS sensitivity based on MMC, presented in figure 2.
Modern smart sensor has multivariate block structure. The main units are a primary measuring transducer (sensitive element, or sensor) (PMT), a switch (K), an analog-to-digital converter (ADC), a microcontroller (MC), and a digital-to-analog converter (DAC).

Analog signals go from PMTs through switchboards and are converted into the digital ones using ADCs. MCs use MCM-based data processing algorithms, calibration data, non-linearity adjustment data, impact of destabilizing factors, and aging stored in memory units to correct measured values and converts them into the required measurement units. MCs adjust for error caused by the impact of extrinsic and intrinsic factors. Besides, MCs control the condition of PMTs and evaluate the accuracy of measurement results. The processed signal carrying data regarding the measured value is transferred in digital form for subsequent registration and display or used for control. In addition, it is converted to analog form and transmitted using communication protocols (IEEE 1451, RS-485, HART, etc.) and industrial networks (ProfiBus, DeviceNet, Interbus, CANbusLIN, Modbus, etc.). Using the interface and communication protocols, the functions of PMT calibration, requesting and receiving information about its current state and the SS as a whole are implemented. It is convenient to integrate such sensors into a network, and access to the data they provide is possible through user level software [13].

Sensitivity adjustment is performed by MCs based on the developed algorithm (see figure 3), comparing the measurement error of CP values with the boundary value of the validity of applying adjustment in the zone of parameter limiting values. Based on the results of this comparison, scaling $R_m$ is performed, non-linearity $R_1^{-1}$ and transformation features $R_{kor}$ are adjusted $\Delta_{kor}^{*} \lambda^{*}_j$.

The result of implementation of this algorithm is the decision to make adjustments within boundary CP values.

Internationally, requirements for smart sensors are listed in standards IEEE 1451.2-1997, IEEE 1451.1-1999, IEEE 1451.3-2003, IEEE 1451.4-2004.

The following smart sensors are used as industrial automation facilities [10]:

- **STT 3000 temperature sensors** include STT-170, STT-250, STT-350 which have the following accessory functions: programming and configuration options using MCs; use of an extensive library of HCX temperature sensors and FF and HART industrial bus interfaces; remote diagnostics and data exchange with remote devices, as well as remote adjustment of the working range [14];

- **pH/ORP perform** the following functions to carry out measurements: automatic calibration by buffer solution, solution temperature compensation, and automatic cleaning of electrodes;

- **concentration sensors perform** the following functions: thermal compensation of readings, calculation of CO2 concentration and its conversion into various units of measurement, as well calculation of pH by differential conductivity;

- **7866 gas analyzer manufactured by Honeywell remotely transfers readings through distances of up to 300 m and generates alarms and communication via Modbus for data configuration and accumulation;**

- **DT300 density sensors manufactured by Smar are equipped with systems of autocalibration, autodiagnostics, and autoconfiguring by FF and Profibus PP networks [15].**
5. Conclusion
The proposed SMCS processes quantitative data using methods of expert systems, which include Advanced Process Control (APC) methods. [10] Smart devices included in the SMCS are smart sensors, such as primary temperature, pressure, and level transducers; concentration analyzers, pH/ORP, electric conductivity sensors, operation units etc.

![Algorithm Diagram](image)

**Figure 3.** Algorithm of implementation of MCM for an SMCS.

Due to simultaneous use of APC and SS, the proposed SMCS may offer smart support necessary for solving various control tasks and quality management of LTs. It is made possible by the following functions:
- processing and analysis of large sets of measurement data;
- control of LT state in the conditions of limited data or uncertainty;
- detection of abnormal LT states;
- adaptation and self-training in changing conditions etc.

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