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Sensors signal processing under influence of environmental disturbances

Streszczenie. *W artykule przedstawiono metody przeciwdziałania wpływowi zmian warunków fizykochemicznych na wynik pomiaru. Zaproponowano graficzną reprezentację omawianych metod. Zmiana warunków występuje w pomiarach wielu procesów przemysłowych oraz środowiskowych. Założono występowanie czułości skrośnej na jedną wielkość fizyczną (temperaturę) w czujniku inteligentnym o wyjściu wielowymiarowym. Korekcja błędów związanych z wpływem wielkości zakłócających odbywa się za pomocą metod przetwarzania sygnałów.* ***(Przetwarzanie sygnałów z czujników przy zmiennych warunkach otoczenia)***

Abstract. *The article presents methods of counteracting the influence of environmental conditions on the measurement. Graphical representations of these methods have been proposed. Environmental disturbances occur in the measurement of industrial and environmental processes. It was assumed the presence of cross-sensitivity to one physical quantity (temperature) in an intelligent sensor with a multidimensional output. Correction of errors related to the influence of disturbances is done using signal processing methods.*

Słowa kluczowe: pomiary, rekonstrukcja mezurandu, czułość skrośna, zmienne zakłócające, analiza procesów.
Keywords: measurement, measurand reconstruction, cross-sensitivity, interfering variable, process analysis.

Introduction

The measurement process is often presented in graphical form as a signal flow diagram [1-2]. This presentation facilitates analysis of measurement and classification methods. Two basic operations that are carried out to obtain a correct measurement result are a calibration and measurand reconstruction. Inverse problem of measurand reconstruction is often ill-posed and ill-conditioned [3-4]. This article presents a graphical representation of the measurement process, where the sensor (transducer) is subjected to environmental effects, which causes the change of its parameters. As a measuring transducer the multi-output transmitter, sensors array, artificial nose and spectrometric transducer have been proposed. These sensors are a group of intelligent sensors, where the mathematical model is used in order to determine measured quantity. The sensor selectivity lack problems are eliminated mainly by attempting the interfering factor stable. It can be carried out only in the laboratory.

The main problem in the in-situ measurements is the conditions change with respect to those known in the calibration. In many cases, this results in significant errors in the prediction. Such problems are analyzed in many measurements, mainly in spectrometry [5-8] and also in measurements where various types of sensor arrays are used [9-11]. In the case of spectrometric measurements the calibration transfer is possible. The entire effort is focused on the problem of once more calibration elimination, which is often costly and time consuming. To simplify and generalize considerations, it is assumed that the temperature is the main disturbing factor in the measurements. This is the most common environmental factor which significantly changes the sensitivity of various types of transducers [5-14].

Information about object in many cases is inferred from indirect measurements[15-16]. As an alternative to a dedicated sensor systems the complex sensor systems consisting of sensors without high selectivity properties are proposed [17]. This solution has many advantages such as: high speed, low cost, simple measuring system. It also allows for environmental measurements. The main advantage is, however, the possibility of using nonselective sensors for the construction of a selective sensor system. Diversified sensitivity of individual sensors in the system for each of environmental impact is here the key element.

In-situ measurements in industrial processes

Monitoring devices and industrial processes require the appropriate experimental techniques. Online monitoring methods are preferred. Sampling and laboratory analysis may be often time-consuming.

The physical measurement elements must be adjusted or even dedicated to the monitored device or process. Direct effect of the device or process means that the sensor is exposed to the impact of various factors which are absent in laboratory measurements. Environmental impact can be reduced or eliminated by using a variety of methods. The main division can take place in the transducer construction and calculation methods of calibration and prediction.

In measurements related to the monitoring of industrial processes multidimensional data are processed. They are used to determine the relationship between the outputs of multiple sensors and the process parameters that cannot be measured directly [18]. The model calibration robustness in environmental conditions is a counterpart of repeatability, accuracy and uncertainty of the measurement instrument in the laboratory [19]. This robustness is defined as the sensitivity (in the sense of invulnerability) of calibration model to changes in external factors.

The problem of measurements at varying physical and chemical conditions

To create a calibration model, the appropriate reference standard is essential. Both the calibration measurements and determining the unknown values of physical quantities measurements must be carried out at the same conditions, primarily at the same temperature and pressure. The instrumental conditions must be also constant, which means lack of changes of the spectrometer apparatus function. Unfortunately, if conditions change, it is necessary to repeat the calibration procedure.

In many practical cases the temperature change is the main problem in in-situ measurements. The special temperature influence is in substances containing water (liquid or solid) or vapor (gaseous state). Temperature changes, even about 5 K, can cause significant errors in the measurement [7]. Errors appear especially when the calibration set is free from the parameters presented in reality. The sources of measured conditions variability not included in the calibration significantly reduce the possibility of calibration models prediction.

Calibration and reconstruction methods resistant to environmental variability

Standardization is the most often carried out way of model correction with less calibration data points in comparison to a complete new calibration. Changes of interfering parameters are included during the calibration process of robust models.

Matrix composed of many individual sensors allows to determine the parameters of interest at varying conditions under influence of disturbing factors. Both arrays of sensors and the spectrum of the spectrometric transducer can be analyzed in the same way as a multi-dimensional signal.

The basic division of algorithmic methods used to counter the influence of changes in physicochemical properties can be overridden as follows [6, 7, 20, 21]:

- finding the least sensitive part to temperature changes of a multi-dimensional signal,
- adaptation of a multi-dimensional signal to the environmental conditions in the calibration,
- global calibration (regression) methods.

The methods may require additional temperature measurement or they may not. Global methods or sensors actually insensitive to temperature can be used for inference without the temperature measurement. In global methods, all the existing temperature range should be present in calibration set applied to building calibration model.

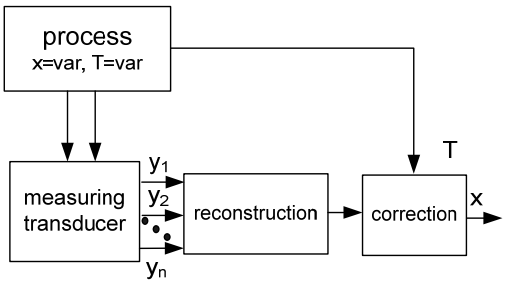

Fig. 1. Correction of the measured quantity taking into account the environmental conditions.

Global methods can be divided into these forming universal model for all temperatures, and these consisting in several sub-models appropriate for local temperature. Each local sub-model should be built for some temperature interval. Individual models should overlap each other in temperature domain.

Methods of searching signals independent of environmental condition

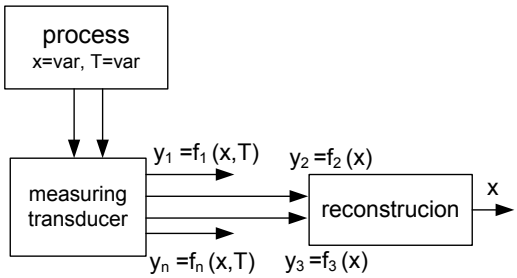

Fig.2. Reconstruction of measured quantity for signals independent of changes in the environment.

Searching sensors which are independent of the influence of environmental parameters is equivalent to searching for temperature independent part of spectra in spectrometric transducer. These methods involve two steps. First, the least temperature dependent part of the spectrum is searched. Next, the calibration is conducted with the use of this part of the spectrum. What is the advantage of this approach, it allows to use classical calibration methods, which are characterized by simple implementation. Moreover, the temperature-sensitive spectrum part can be used for temperature determination. Nevertheless, a lack of sensors (part of the spectrum) insensitive to temperature changes is the most important problem in this type of methods.

Methods of matching signals to standard conditions

These methods are used in spectroscopy when it is impossible to find part of the spectrum which is insensitive to temperature changes. Signals measured in different temperatures are adapted to the primary temperature.

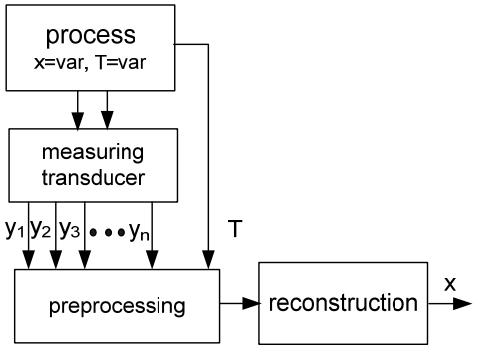

Fig.3. Reconstruction of measured quantity with signal preliminary adaptation to the reference conditions.

In this methods there is possibility of using a few or even all of the measured wavenumbers (output matrix sensors), because the part of spectra sensitive to changes in the content may be also sensitive to temperature changes. These methods are often referred as spectrum standardization methods (for spectrometric methods). Spectra measured for non-primary temperature are converted (standardized) to signal of primary (standard) temperature.

Global methods

Global methods are based on the construction of a model that correctly determines the value of measured quantity for the specified temperature range. They require measurement of a reference standard in entire temperature range. If all possible temperature in calibration procedure is not taken into account the obtained model may be inappropriate.

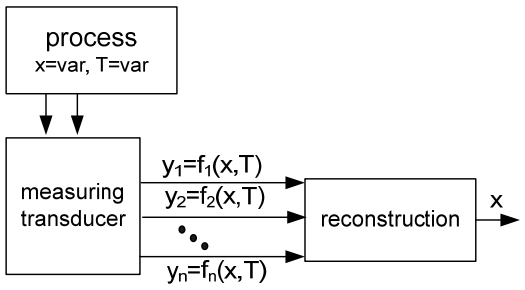

Fig.4. Global methods of measured quantity reconstruction insensitive to environmental conditions.

Different statistical methods will be preferred for linear and non-linear dependence between concentration and absorbance. Certainly, for linear data sets the PLS (Partial Least Square) regression method is the basic solution. For non-linear sets artificial neural networks or the newer support vectors methods are applied.

Reconstruction methods taking into account the environmental conditions

These methods, in contrast to classical laboratory calibration, introduce the temperature as additional independent variable. A method, which used PLS latent variables and temperature to determine component concentration, shows very good performance[6].

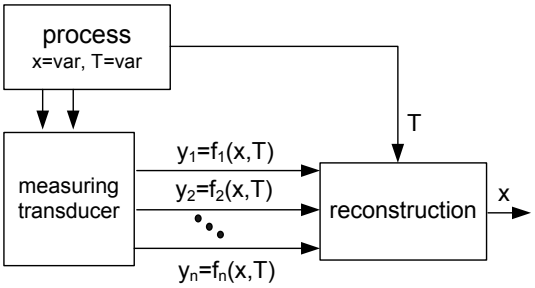

Fig.5. Environmental conditions as additional variables in measured quantity reconstruction.

In global models temperature can be used as an additional independent variable or for correction of the reconstruction model.

Conclusions

This paper presents methods of measured quantity reconstruction, in which the measuring transducer is additionally affected by influence quantity. Using the graphical representation, the division and systemisation of methods is shown. Cited literature allows to review the impact of temperature variation, which is the most common variable influencing the industrial environment, on parameters of example sensors. Some of the presented methods require additional measurement of physical and chemical conditions (signal adaptation to reference environmental conditions, environmental conditions as additional variables, correction of measured quantity). Some methods are able to provide valuable information even without measuring of disturbance variables (global methods, conditions independent sensors).

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