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ADAPTIVE OPERATION ALGORITHM OF AN INTELLIGENT HUMIDITY SENSOR

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Abstract: The article describes an adaptive operation algorithm of an intelligent humidity sensor that allows determining a moisture content of a paste material with a reasonable accuracy in case of failure of device components.

Intelligent sensors are traditionally improved by developing their designs and elements, as well as by using methods for the description and subsequent analysis of measuring procedures [1]. An analytical approach is commonly used in the synthesis of intelligent sensors that contributes to the development of optimal data processing algorithms based on increasingly complex stochastic models of an impact on a sensor. An alternative to this strategy is a method of smart sensors implementation using neural networks. Functioning of intelligent sensors is provided by using actual data, which characterize a physical object of research.

It is necessary to perform the following steps for creation of algorithms:

– determination of operation modes of intelligent measuring system in a variety of situations, including an extreme ones;

– training of a smart sensor considering peculiarities of a process of research;

– formation of logic of diagnostics system functioning in case of failure of some sensor.

The basis of intelligent humidity sensor (**IHS**) hardware is a MSP430 microcontroller from Texas Instruments. This device uses SH15 humidity and temperature sensors from Sensirion, external ones to measure the initial temperature and humidity of drying agent and internal ones to measure the current temperature and humidity in the sections. There is also a conveyor speed sensor, a general exhaust fan switching-on sensor, common to the entire dryer, as well as individual sensors of controlled cameras: degree of opening of release gates and air intake windows. The required information is stored in non-volatile DataFlash memory device.

One of important properties of the monitoring system is a self-diagnostics feature. The ability to self-control characterizes a property of sensor to retain the characteristics within acceptable limits for a consumer in the event of sensor or information channel failure.

Evaluation of pasty material humidity is carried out using a neural network with multilayer perceptron architecture, trained by back propagation algorithm.

Network inputs are normalized values: x_1 is initial humidity of material, x_2, x_3 are ambient temperature and humidity, x_4 is speed of a plate conveyor, x_5 is switching on or off of agitator, x_6 is percent of time when exhaust fan works, x_7, x_8 are average weighted temperature and humidity of drying agent in the *i*-th camera; x_9, x_{10} are percentage of opening of air intake window and release gate. Training of a neural network is organized by exemplary measures of technological parameters in the adaptive range of the *i*-th camera with fixed precision.

Data normalization is performed using the following formula:

$$x_q^{\text{n}} = x_q \cdot K_{\text{amp}}^{\text{n}} + K_{\text{of}}^{\text{n}}, \quad q = \overline{1,\Theta}, \tag{1}$$

where q is serial number of network input; x_q^{n}, x_q are normalized and non-normalized values of q-th network input; $K_{\text{amp}}^{\text{n}}$, K_{of}^{n} are amplitude and offset scaling factors; Θ is number of network inputs used to calculate humidity φ_i^{k} in *i*-th camera [2].

Analytical model of multilayer perceptron for evaluating moisture content in *i*-th camera, trained by algorithm that mentioned above, is represented as:

$$\overline{\varphi_i} = \left[1 + \exp\left(-\beta_{\text{out}}^{(i)}\left[\sum_{j=1}^{N_i} w_j^{(i\ \text{out})}\left(1 + \exp\left(-\beta_j^{(i)}\left[w_{1,j}^{(i)}\overline{x_1} + w_{2,j}^{(i)}\overline{x_2} + w_{3,j}^{(i)}\overline{x_3} + w_{4,j}^{(i)}\overline{x_4} + \right.\right.\right.\right.\right.\right.$$

$$\left.\left.\left.\left.\left.\left. + w_{5,j}^{(i)}\overline{x_5} + w_{6,j}^{(i)}\overline{x_6} + w_{7,j}^{(i)}\overline{x_7} + w_{8,j}^{(i)}\overline{x_8} + w_{9,j}^{(i)}\overline{x_9} + w_{10,j}^{(i)}\overline{x_{10}}\right] - \theta_j^{(i)}\right)\right)^{-1}\right] - \theta_{\text{out}}^{(i)}\right)\right]^{-1}, \tag{2}$$

where for sigmoidal activation functions of neurons are denoted by $\beta_j^{(n)}$, $\beta_j^{(n+1)}$ – angles for hidden layer and $\beta_{\text{out}}^{(n)}$, $\beta_{\text{out}}^{(n+1)}$ – for output layer of neural network, $\theta_j^{(n)}$, $\theta_j^{(n+1)}$ – shifts for hidden layer and $\theta_{\text{out}}^{(n)}$, $\theta_{\text{out}}^{(n+1)}$ – for output layer of network; $w_{i,j}^{(n)}$, $w_{i,j}^{(n+1)}$ and $w_j^{(n\ \text{out})}$, $w_j^{(n+1\ \text{out})}$ – weighting relation factors for hidden and output network layers, N_i – number of neurons in hidden network layer when calculating moisture content in *i*-th camera of dryer; normalized values of material humidity data $\overline{\varphi_i}$, initial humidity of material $\overline{x_1}$, ambient temperature and humidity $\overline{x_2}$, $\overline{x_3}$; speed of a plate conveyor $\overline{x_4}$, switching on or off of agitator $\overline{x_5}$, percent of time when exhaust fan works $\overline{x_6}$, temperature and humidity of drying agent $\overline{x_7}$, $\overline{x_8}$, percentage of opening of air intake window and release gate $\overline{x_9}$, $\overline{x_{10}}$ [2].

Output of network is denormalized by the formula for obtaining data about material humidity in real-world units:

$$\varphi_i = \frac{\overline{\varphi}_i - K_{\text{of}}^{\text{dn}}}{K_{\text{amp}}^{\text{dn}}}, \tag{3}$$

where $K_{\text{amp}}^{\text{dn}}$, $K_{\text{of}}^{\text{dn}}$ are amplitude and offset denormalizing factors [3].

The resulting analytical dependence (2) allows evaluating material humidity in *i*-th camera of dryer in real time during its drying. Similar models are made for other cameras.

Let us extend the set of humidity determination models to eliminate the significant impact on accuracy of failure of one or a group of sensors. Models of the form (2) are used in case of a faultless operation of sensors, where information from all sensors is used. In the event of failure of one or more sensors it is proposed to carry out calculations on models, which take into account these situations.

Let us distinguish four groups of sensors in order of importance of information coming from them to create an extended set of models.

Zero group is class of situations G_0 (trouble-free operation of all sensors).

First group is class of situations G_1 (soft sensor failures) includes sensors, information from which is interference on measurement channel, for example, external sensor of initial temperature and humidity of drying agent or sensor of switching on or off of agitator, that responsible for uniformity of the material layer on the tape. Off-season average temperature and humidity in workshop and average thickness of the paste are taken into account in the case of failure of sensors from that group.

Second group is class of situations G_2 (medium sensor failures) that includes windows and gates opening sensors, information from which represents dryer cameras setup.

If a failure occurs in this group of sensors, the models without taking into account the degree of opening of gates and windows in the sections are used.

Third group is class of situations G_3 (hard sensor failures) that includes conveyor speed, agitator switching on or off, temperature and humidity of drying agent in sections sensors, failure of which is most dangerous because it leads to errors of humidity measurement and drying process control.

Table shows the correspondences of classes with situations, missing model parameters and identifiers of models that used in this case.

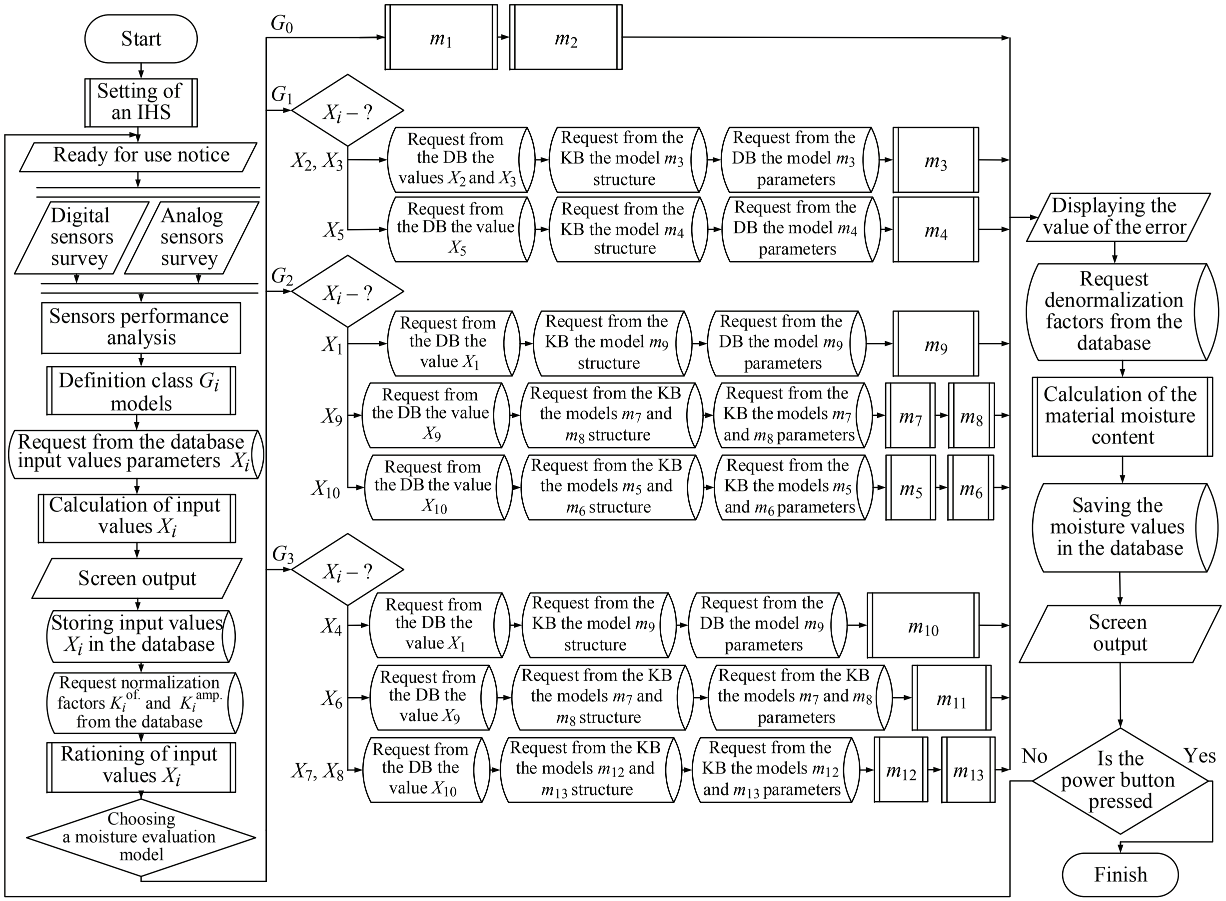
Extended set of models includes the following models for n and $n+1$ controlled cameras of following groups:

– G_0 is models m_1 and m_2 similar to model (2), wherein model m_1 output is model m_2 input.

– G_1 is models m_3, m_4, distinctive feature of which is obtaining information about initial temperature and humidity of drying agent not from sensors but from database. Model m_5 similar to m_1, but without taking into account an agitator;

Classes of situations and failures of sensors

Class of situation	Situation	Unknown model parameter	Model identifier
G_0	Trouble-free operation of all sensors of IHS	–	m_1, m_2
G_1	Failure of workshop temperature and humidity sensor	x_2, x_3	m_3
	Failure of agitator switching on or off sensor	x_5	m_4
G_2	Failure of gates opening sensor	x_{10}	m_5, m_6
	Failure of windows opening sensor	x_9	m_7, m_8
	Failure of initial material humidity	x_1	m_9
G_3	Failure of conveyor speed sensor	x_4	m_{10}
	Failure of exhaust fan switching on or off sensor	x_6	m_{11}
	Failure of temperature and humidity of drying agent sensor in sections	x_7, x_8	m_{12}, m_{13}



The adaptive operation algorithm of IHS

– G_2 is models m_6 and m_7 without taking into account changing of opening degree of release gates; models m_8 and m_9 without taking into account opening degree of air intake windows in n and $n+1$ sections respectively;

– G_3 is model m_{10} without taking into account operation periodicity of exhaust fan, model m_{11} without taking into account an exhaust fan work, model m_{12} without taking into account drying agent temperature, model m_{13} without taking into account drying agent humidity.

Thus, if a failure occurrs in the process of sensors survey, then the model from the knowledge base of IHS is automatically selected, by which pasty material humidity is determined with an acceptable error. As a result of the adaptive algorithm work IHS is a fault-tolerant system. The adaptive operation algorithm of IHS is shown in Figure.

An IHS during a pasty material drying in a drum-tape dryer implemented at JSC "Pigment" (Tambov); its use has allowed increasing the production of quality products.

Thus, a technical task of rapid assessment of a moving pasty material humidity during its drying in real time is reached in order to ensure the quality of the resulting material.

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Адаптивный алгоритм функционирования интеллектуального датчика влажности

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Ключевые слова: адаптивный алгоритм; интеллектуальный датчик; нейронная сеть; отказ датчика.

Аннотация: Приведен адаптивный алгоритм функционирования интеллектуального датчика влажности, позволяющий в случае отказа компонентов устройства с приемлемой погрешностью определять влагосодержание пастообразного материала.

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Adaptiver Algorithmus des Funktionierens des intellektuellen Feuchtigkeitsensors

Zusammenfassung: Es ist den adaptiven Algorithmus des Funktionierens des intellektuellen Feuchtigkeitsensors, der im Fall des Versagens von den Anlagekomponenten mit dem annehmbaren Fehler den Feuchtegehalt zu bestimmen erlaubt, angeführt.

L'algorithme adaptatif du fonctionnement de la sonde intellectuelle d'humidité

Résumé: Est donné un algorithme adaptatif du fonctionnement de la sonde intellectuelle d'humidité permettant en cas de défaillance des composants de l'appareil de déterminer la teneur en eau de la matière pâteuse avec une précision acceptable.

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