Using Artificial Neural Network for Compensation of Semiconductor Thermistor Nonlinearity

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***Abstract* — A method for correcting the transformation function of a semiconductor thermistor using a nonlinearity compensator based on a three-layer perceptron is proposed. Using of computer simulation, the operability of the proposed method has been investigated, a comparative analysis has been carried out with polynomial compensators of nonlinearity.**

Keywords* — *artificial neural network, perceptron, learning, compensation of nonlinearity.

I. Introduction

The primary transducers such as semiconductor thermistors or thermistors are often used in the practice of temperature measurements. They are widely used in various measuring circuits, temperature relays, climate control systems, heat meters. The advantages of these sensors include a large range of temperature measurement, vibration strength, compactness, low inertia and high sensitivity. In a wide temperature range, the dependence of semiconductor resistance R_{sc} on temperature t is complex and nonlinear. So, it is impossible to express the dependence $R_{sc}(t)$ by a simple formula that would allow graduation with high precision. Typically, the entire temperature interval is divided into individual sections, in which the dependence $R_{sc}(t)$ is described by its interpolation formula.

To reduce the error of temperature measurement, the nonlinear conversion function of thermistor leads to a linear form by change of variables. Then determine the parameters of this function using the least squares method [1]. But in this case it is necessary to have a priori information about the form of this nonlinear function or, in other words, know the structure of the mathematical model of the measuring instrument. The justified choice of the general form of a nonlinear conversion function is a rather complicated task that is difficult to formalize.

A universal method to reduce the influence of the nonlinearity of the conversion function on the error of the measurement result is an algorithmic correction of the conversion function with the help of an additional compensator device that implements the dependence opposite to the conversion function. An additional condition is the invariance of such a converter to the form of nonlinear dependence, which it needs to correct, that is, the possibility of adaptation to an arbitrary type of conversion function.

Thus, the essence of the problem considered here is that with the help of an additional adaptive device for processing the measuring signal, the correction of the conversion function of the semiconductor thermistor is performed and its linearity is ensured in the working temperature range.

II. Theoretical Relationships

As a device-compensator, it is most expedient to use an artificial neural network. The rationale for this choice is that artificial neural networks are nonlinear in nature, have good approximating properties and do not require specially developed design methods, they can be synthesized through training.

The block diagram of an adaptive non-linear compensation system for the conversion function of a semiconductor thermistor is presented on fig. 1. The resistance of the thermistor R_{sc} is converted by the measuring device into a digital code R_d , which is fed to the input of the neural network-compensator. As a result of the adaptation process, the synaptic weights of the neural network, which in this case is the inverse model of a semiconductor thermistor, are adjusted so that its output signal T_N is the best approximation of the input signal T .

The neural network-compensator is a three-layer perceptron, the structure of which is shown in fig. 2.

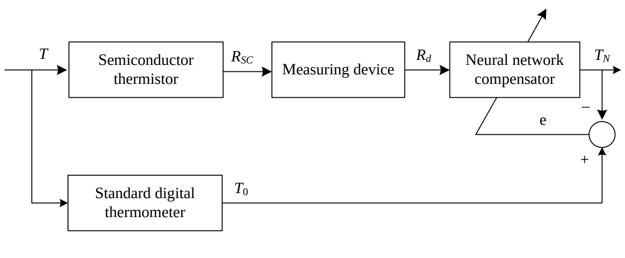

Fig. 1. The structure of the adaptive system for compensation of the semiconductor thermistor conversion function nonlinearity.

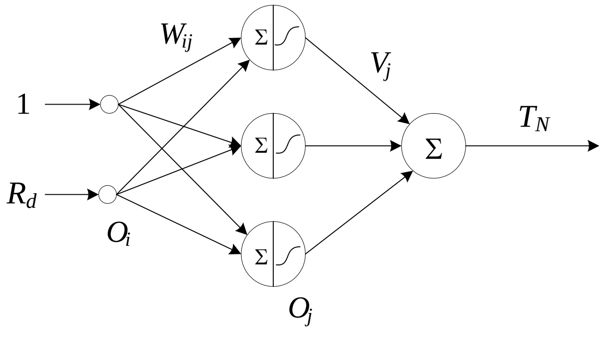

Fig. 2. Three-layer perceptron.

The output layer of the perceptron is formed by a single neuron, which forms a signal T_N as a weighted sum of the output signals of the neurons of the hidden layer

$$T_N = \sum_{j=1}^{n} V_j O_j \ , \qquad (1)$$

where O_j – output of the j-th neuron of the hidden layer; V_j – synaptic weight of the j-th input of the neuron of the output layer; n – the number of neurons in the hidden layer.

The hidden layer is formed by neurons with sigmoidal activation functions. Each neuron of this layer is described by the following equations

$$O_j = \frac{1}{1+e^{-S_j}}, \qquad S_j = \sum_{i=1}^{m} W_{ij} O_i, \qquad (2)$$

where O_i – output signal of the i-th neuron of the input layer; W_{ij} – synaptic weight of the i-го input of the input of the j-th in the hidden layer; m – number of neurons in the input layer.

The input layer of neurons is formed by the input signals of the neural network. In the framework of this task, the input signals of the neural network are the output signal of the measuring device R_d and a constant signal equal to one, which is introduced to describe the constant offset.

Adjusting the synaptic weights of the perceptron V_j and W_{ij} will be done using the learning algorithm of Levenberg-Marquardt [4-6], which has the maximum convergence rate in the class of gradient procedures. The optimality criterion is the average square of the error of estimation

$$E(k) = \frac{1}{2} e^2(k) = \frac{1}{2}\left(T_0(k) - T_N(k)\right)^2 . \qquad (3)$$

The training sample for the training procedure of the neural network compensator consists of pairs of values $< R_{di}, T_{Oi} >$ obtained during the calibration of the measuring system.

Note that the calibration must be carried out in the operating temperature range of the semiconductor thermistor. This will allow you to get the most reliable data for training the artificial neural network and provide a minimum of measurement error.

III. Results and Their Discussion

To obtain an experimental calibration characteristic of a thermistor in the temperature range of 20 ° C ... 80 ° C (Fig. 3), a measurement system was used consisting of a temperature chamber MC-71, a semiconductor and reference thermistors, digital voltmeters B7-16A (for measuring R_{sc}) and B7-27A/1 (for measuring t). A set of points of the obtained characteristic was used as a training sequence for a neurocompensator.

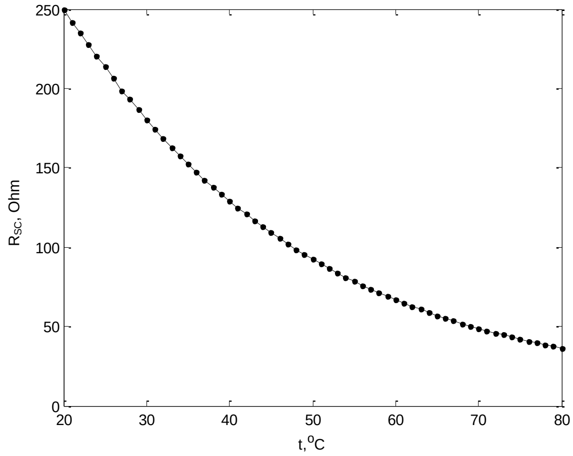

Fig.3. Thermistor calibration characteristic.

The investigation of the properties and characteristics of the proposed system for the correction of the conversion function of a semiconductor thermistor was carried out using a computer simulation method. For that purpose, a program in the MATLAB language was developed, using the functions of designing and modeling artificial neural networks of the library Neural Network Toolbox [7].

Nonlinearity was compensated using the proposed neural network device based on a three-layer perceptron, as well as using 3rd, 4th and 5th degree polynomials. Coefficients of polynomials were calculated by the least squares method.

The main indicator of the quality of the adaptive nonlinearity compensation system for each experiment was the mean square of the temperature measurement error in the specified range. The maximum absolute error of temperature measurement for each type of compensator was calculated additionally.

Transfer functions and temperature measurement errors without compensation of nonlinearity, as well as using various types of compensators are shown in Fig. 4–13.

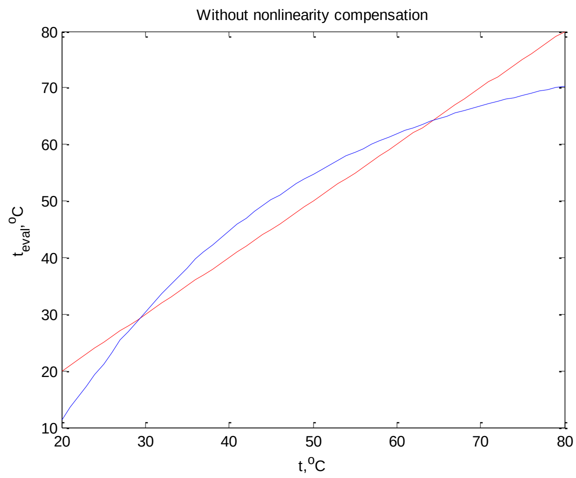

Fig. 4. Transfer function of measurement device without nonlinearity compensation.

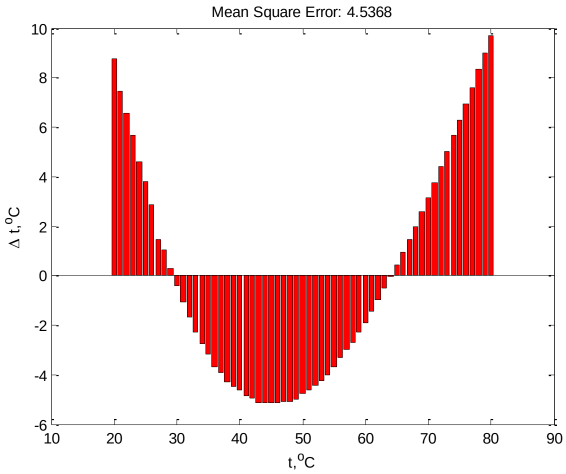

Fig. 5. Absolute error of temperature measurement without nonlinearity compensation.

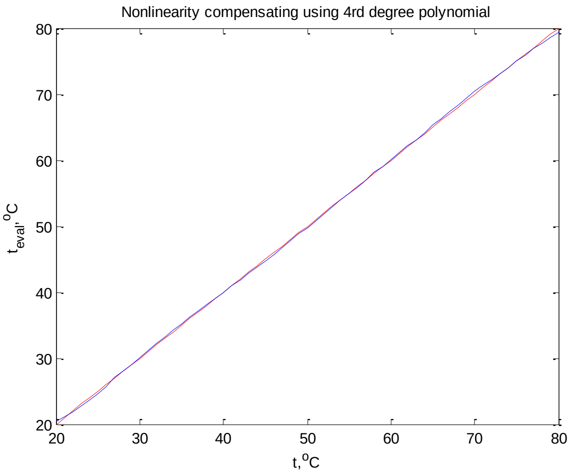

Fig. 8. Transfer function of measurement device when nonlinearity compensating using 4rd degree polynomial.

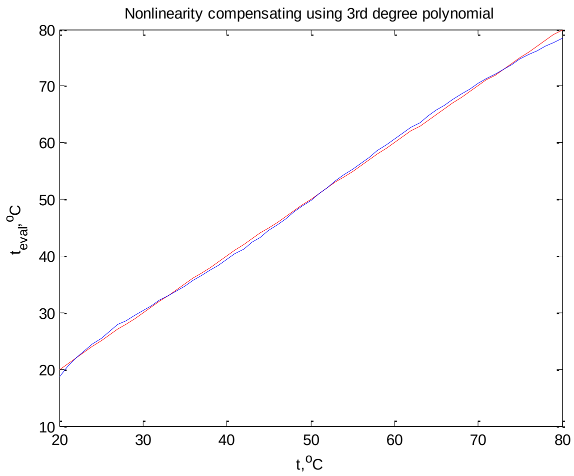

Fig. 6. Transfer function of measurement device when nonlinearity compensating using 3rd degree polynomial.

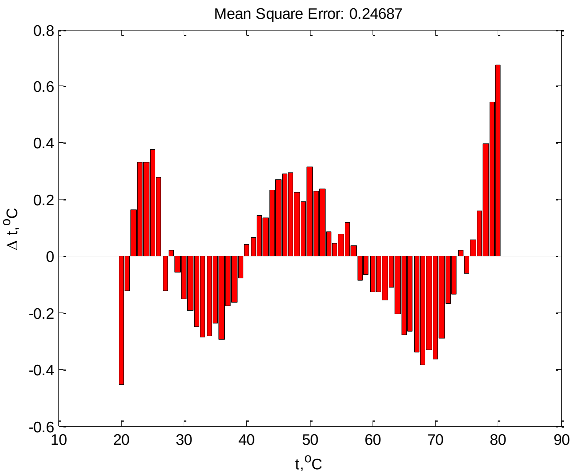

Fig. 9. Absolute error of temperature measurement when nonlinearity compensating using 4rd degree polynomial.

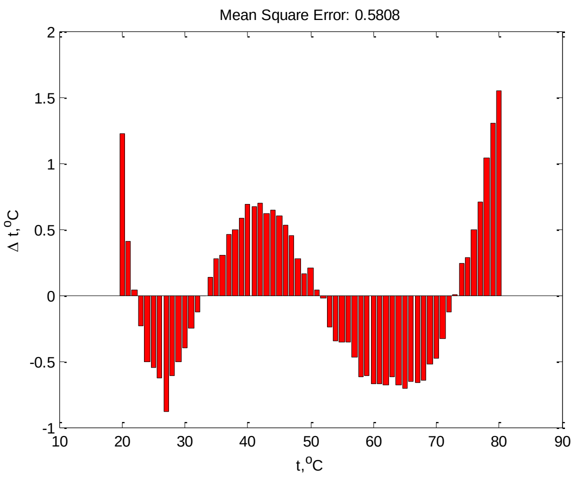

Fig. 7. Absolute error of temperature measurement when nonlinearity compensating using 3rd degree polynomial.

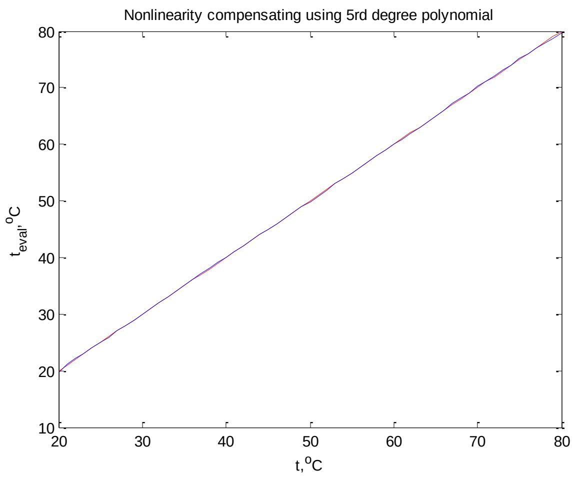

Fig. 10. Transfer function of measurement device when nonlinearity compensating using 5rd degree polynomial.

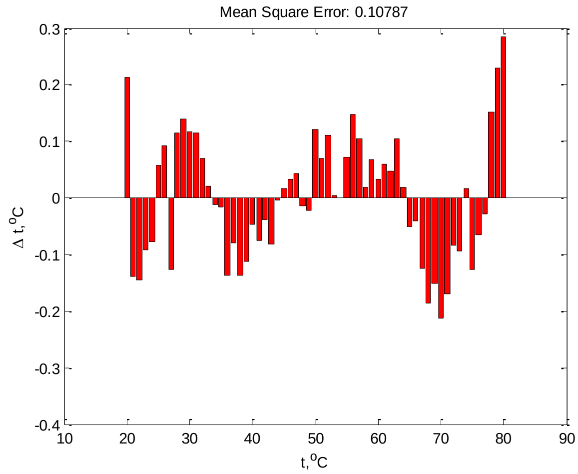

Fig. 11. Absolute error of temperature measurement when nonlinearity compensating using 5rd degree polynomial.

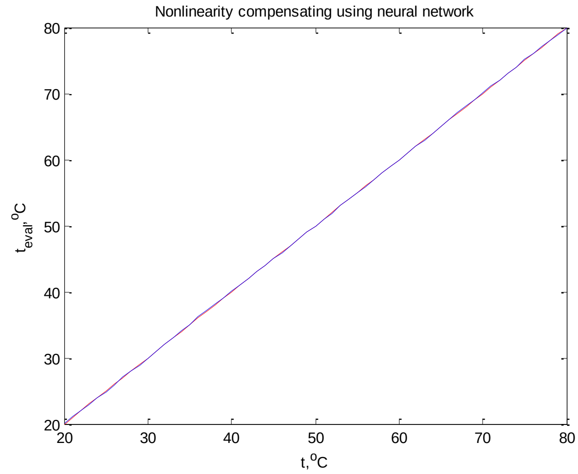

Fig. 12. Transfer function of measurement device when nonlinearity compensating using neural network.

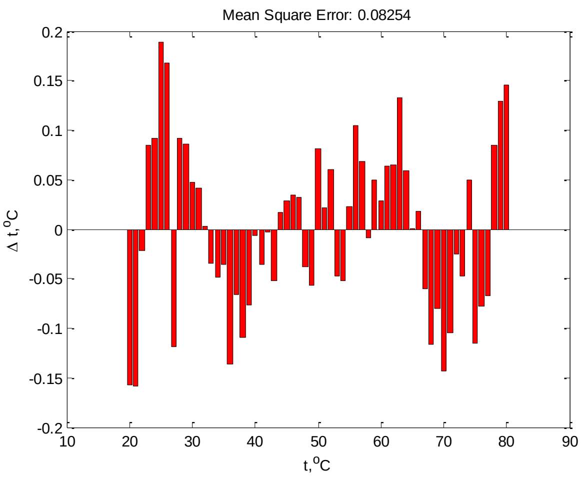

Fig. 13. Absolute error of temperature measurement when nonlinearity compensating using neural network.

The values of the standard and maximum error of temperature measurement for each type of compensator are shown in Table 1.

TABLE I. RESEARCH RESULTS FOR VARIOUS TYPES OF NONLINEARITY COMPENSATION

Index	**Type of compensator**	**Standard error** $\sigma_t, ^oC$	**Maximum error** Δ_t max, ^oC
1	Without compensator	4,5368	9,7125
2	3rd degree polynomial	0,5808	1,5487
3	4rd degree polynomial	0,2469	0,6752
4	5rd degree polynomial	0,1079	0,2855
5	Three-layer perceptron	0,0825	0,1915

CONCLUSIONS

In general, the results of simulation modelling fully confirm the efficiency of the considered system of automatic correction of the conversion function of a semiconductor thermistor and are consistent with the theoretical treatment. A comparative analysis of the functioning of the proposed system and a similar system that uses a compensator based on a polynomial approximator showed that the standard error of the correction of the transformation function by the neural network device is less than the error of correction by the 5th degree polynomial.

The advantage of the proposed approach is the invariance of the neural network compensator to the type of nonlinear characteristics of a semiconductor thermistor and the ability to synthesize such a system through training, without involving complex design methods. The use of the proposed adaptive corrector will significantly reduce the systematic measurement error caused by the mismatch between the nominal and real conversion functions of the measuring device.

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