ISSN 1726-5479

SENSORS & TRANSDUCERS

12/12 vol. 147

Sensor Market Trends

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 147, Issue 12
December 2012

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).

Sensors & Transducers Journal

Contents

Volume 147
Issue 12
December 2012

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal’s webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

International Frequency Sensor Association (IFSA).


IARIA
The Fourth International Conference on Sensor Device Technologies and Applications
SENSORDEVICES 2013
25 - 31 August 2013 - Barcelona, Spain
Tracks: Sensor devices - Ultrasonic and Piezosensors - Photonics - Infrared - Gas Sensors - Geosensors - Sensor device technologies - Sensors signal conditioning and interfacing circuits - Medical devices and sensors applications - Sensors domain-oriented devices, technologies, and applications - Sensor-based localization and tracking technologies - Sensors and Transducers for Non-Destructive Testing
Deadline for papers: 30 March 2013
http://www.iaria.org/conferences2013/SENSORDEVICES13.html


IARIA
The Seventh International Conference on Sensor Technologies and Applications
Deadline for papers: 30 March 2013
SENSORCOMM 2013
25 - 31 August 2013 - Barcelona, Spain
Tracks: Architectures, protocols and algorithms of sensor networks - Energy, management and control of sensor networks - Resource allocation, services, QoS and fault tolerance in sensor networks - Performance, simulation and modelling of sensor networks - Security and monitoring of sensor networks - Sensor circuits and sensor devices - Radio issues in wireless sensor networks - Software, applications and programming of sensor networks - Data allocation and information in sensor networks - Deployments and implementations of sensor networks - Under water sensors and systems - Energy optimization in wireless sensor networks
http://www.iaria.org/conferences2013/SENSORCOMM13.html


IARIA
The Sixth International Conference on Advances in Circuits, Electronics and Micro-electronics
CENICS 2013
25 - 31 August 2013 - Barcelona, Spain
Deadline for papers: 30 March 2013
Tracks: Semiconductors and applications - Design, models and languages - Signal processing circuits - Arithmetic computational circuits - Microelectronics - Electronics technologies - Special circuits - Consumer electronics - Application-oriented electronics
http://www.iaria.org/conferences2013/CENICS13.html

Sensors & Transducers Journal, Vol. 147, Issue 12, December 2012, pp. 6-14

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

An Intelligent Temperature Measurement Technique Using J Type Thermocouple with an Optimal Neural Network

Santhosh K. V., B. K. Roy
Department of Electrical Engineering
National Institute of Technology, Silchar
E-mail: kv.santhu@gmail.com, bkr_nits@yahoo.co.in

Received: 22 February 2012 /Accepted: 18 December 2012 /Published: 31 December 2012

Abstract: This paper aims at designing an intelligent temperature measurement technique using J type thermocouple with an optimized neural network model. The objectives of this work are to (i) extend the linearity range of measurement to 100 % of the full scale, (ii) make the measurement system adaptive of variation in temperature coefficients and (iii) to achieve (i) and (ii) using optimal neural network. The output of thermocouple is in mV range. A suitable data conversion circuit is used to convert mV to voltage and to overcome the problem of interference of noise and open thermocouple detection. A suitable optimal Artificial Neural Network (ANN) block is added in cascade to data conversion unit. This arrangement helps to linearise the overall system and make it adaptive of variations in temperature coefficients. Since, the proposed intelligent temperature measurement technique produces adaptive of variation in physical properties of thermocouple. It avoids the requirement of repeated calibrations every time the thermocouple is replaced. Simulation results show that proposed measurement technique satisfies the objectives. *Copyright © 2012 IFSA.*

Keywords: Artificial neural networks, Thermocouple, Sensor modelling.

---

1. Introduction

Attempts of standardized temperature measurement have been reported as early as 170 AD by Claudius Galenus. The modern scientific field has its origins in the works by Florentine scientists in the 17th century. Temperature is one of the most frequently used process measurements. Almost all chemical processes and reactions are temperature dependent. In chemical plants, temperature is frequently the only indication of the progress of a process. Where the temperature is critical to the reaction, a considerable loss of product may results from incorrect measurement of temperatures. In some cases, loss of control of temperature can results in catastrophic plant failure with consequent damages and possible loss of life. There are many other areas of industry in which temperature measurement is essential. Such applications include steam raising and electricity generation, plastics manufacture and moulding, milk and dairy products, and many other areas of the food industries. Thus, an accurate and precise measurement of temperature is very important.

Many methods have been developed for measuring temperature. Most of these rely on measuring some physical property of a working material that varies with temperature. Thermocouple is one such sensor which finds a wide application in a process industry because of its characteristics like accuracy and precision. However in the thermocouple the problem of non linearity has restricted its applications. To solve the problem of linearizing a sensor, there are in general two methods, the first one requires nonlinear analog circuit and the second uses numerical methods that are computed by microprocessor or personal computer [1]. The first method has a few practical drawbacks. Further, the whole circuitry may be altered or replaced when there is need to change thermocouple to achieve wide range, different sensitivity, cost etc. This increases the time and effective cost of the instrument. The last method is preferred because computer is used today for data acquisition and also it has the advantage of linearization on taking into account the effect of disturbing variables.

Artificial neural networks are broadly useful in a wide range of applications such as signal and image processing, pattern recognition [2], control systems [3] and recently instrumentation [4]. Because of their nonlinear characteristics, they are very useful in solving complex problems more accurately than linear techniques. So a method has been proposed in this paper using the concept of ANN. The ANN model is added in cascade to an amplifier circuit which will be trained to produce the linear relation between the input temperature and output of ANN. Further it’s also made intelligent so as to produce results adaptive of the variation in physical parameters of the thermocouple so that no action is to be taken even though there is a change in thermocouple.

Literature survey reveals that linearization of temperature measurement using thermocouple has been attempted by many researchers using various techniques. Neural networks are used for this purpose by [5-7]. Linearization is achieved by analog circuits in [8, 9]. Linearization of level measurement using capacitance level sensor and making it independent of permittivity of the measuring liquid is discussed in [10]. Temperature measurement is presented in [11] using thermistor. Linearization of such temperature measurement and making it independent of temperature coefficient s of thermistor is reported.

The paper is organized as follows: after introduction in Section-1, a brief description on thermocouple is given in Section-2. The output of the thermocouple is mV; a brief discussion on signal conditioning unit i.e. an amplifier and compensator is discussed in Section-3. Section-4 deals with the problem statement followed by proposed solution in Section-5. Finally, result and conclusion is given in Section-6.

2. Thermocouple

A thermocouple is a temperature-voltage transducer. It is a device made by two different wires joined at one end, called junction end or measuring end. The two wires are called thermo elements or legs of the thermocouple. The two thermo elements are distinguished as positive and negative ones. The other end of the thermocouple is called tail end or reference end as shown in Fig. 1. The junction end is immersed in the environment whose temperature T_2 is to be measured, while the tail end is held at a different temperature T_1.

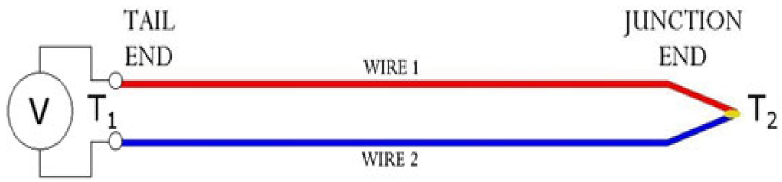

Fig. 1. Schematic diagram of a thermocouple.

Because of the difference in temperature between junction end and tail end, a voltage is measured between two thermo elements at tail end.

Approximately 300 different types of temperature measuring thermocouples have been identified and studied [12]-[14]. But, only a few types having the more favorable characteristics are used in general. There are eight types of thermocouples that have been standardized. Table 1 shows the list of standard thermocouples with its materials and ranges.

Table. 1. Types of standard thermocouple

No.	Type	Materials	Typical Range °C
1.	T	Copper (Cu) vs. Constantan	-270 to 400
2.	J	Iron (Fe) vs. Constantan	-210 to 1200
3.	K	Chromel vs. Alumel	-270 to 1370
4.	E	Chromel vs. Constantan	-270 to 1000
5.	S	(Pt-10%Rh) vs. Pt	-50 to 1768
6.	B	(Pt-13% Rh) vs. (Pt-6% Rh)	0 to 1820
7.	R	(Pt-13%Rh) vs. Pt	-50 to 1768
8.	N	(Ni-Cr-Si) vs. (Ni-Si-Mg)	-270 to 1300

Equation 1 illustrates the power series model used for J type thermocouples [5, 6]

$$V = C_1(T_2 - T_1) + C_2((T_2 - 273)^2 - (T_1 - 273)^2)\ \mu V, \tag{1}$$

where: T_2 – Hot junction temperature of thermocouple in ^oC;
T_1 – Cold junction temperature of thermocouple in ^oC;
C_1 & C_2 – Coefficients depending on the materials used.

3. Data Conversion Unit

The block diagram representation of the proposed measurement technique is given in Fig. 2.

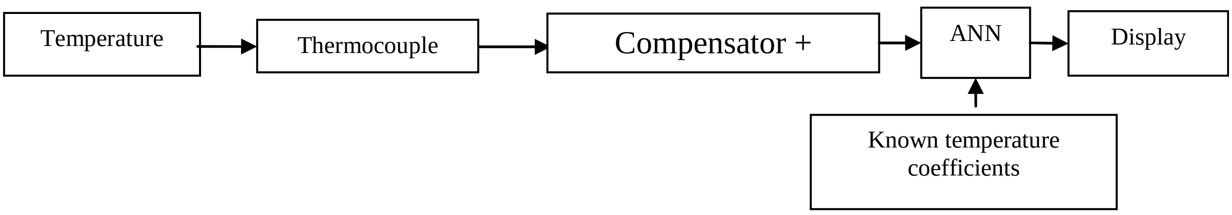

Fig. 2. Block diagram of the proposed temperature measurement technique.

3.1. Compensator and Amplifier

The tail end is maintained at ambient temperature by cold junction compensator. The temperature fluctuations between two legs at the tail end are tolerated. Thermocouple produces a voltage proportional to (T_2-T_1) and hence the voltage proportional to T_2 is not generated. An additional voltage equal to the voltage produced by thermocouple for the temperature difference of 0 ^oC to T ^oC is added with the voltage at tail end so that the total voltage is proportional to T_2 ^oC. [12-15].

A sketch of a thermocouple with cold junction compensation is shown in Fig. 3.

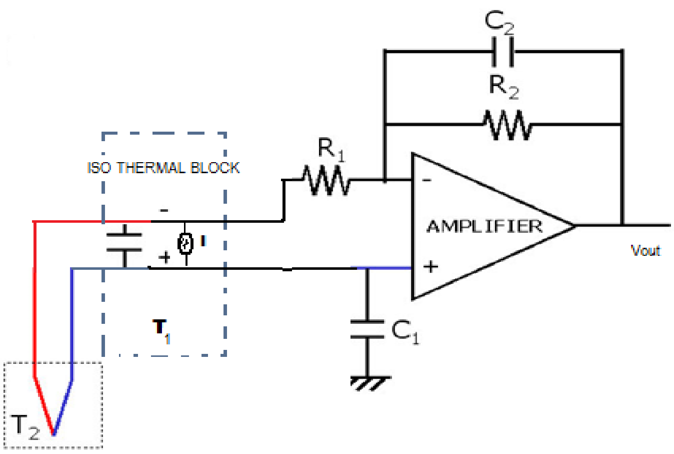

Fig. 3. A Cold Junction Compensation circuit.

The output of thermocouple ranges in the mV. Which make it very difficult to handle such signal. So, an amplifier is used to amplify the signal as shown in Fig. 3. The ratio of R_2 and R_1 will decide the amplification factor. Because thermocouples generate a relatively small voltage, noise is always an issue. The most common source of noise is the utility power lines (50 or 60 Hz). Thermocouple bandwidth is lower than 50 Hz, so a simple filter in each channel can reduce the interfering ac line noise. Common filters include resistors and capacitors and active filters built around op amps. Detecting open thermocouples easily and quickly is especially critical in systems with numerous channels. Thermocouples tend to break or increase in resistance when exposed to vibration, poor handling, and long service time. A simple open thermocouple detection circuit comprises a small capacitor placed across the thermocouple leads and driven with a low level current. The low impedance of the intact thermocouple presents a virtual short circuit across the capacitor so it cannot charge. But when a thermocouple opens or significantly changes resistance, the capacitor charges and drives the input to one of the voltage rails, which positively indicates a defective thermocouple.

4. Problem Statement

In this section characteristics of thermocouple are simulated to understand the difficulties associated with the available measurement technique. For this purpose, simulation is carried out using J type thermocouple. The equation (1) is used to find the output voltage of thermocouple with respect to various values of input temperatures considering a particular value of temperature coefficients. These output voltages are used as input to compensator and amplifier circuit and the final voltage is produced.

The MATLAB environment is used and the following are shown in Fig. 4 and Fig. 5.

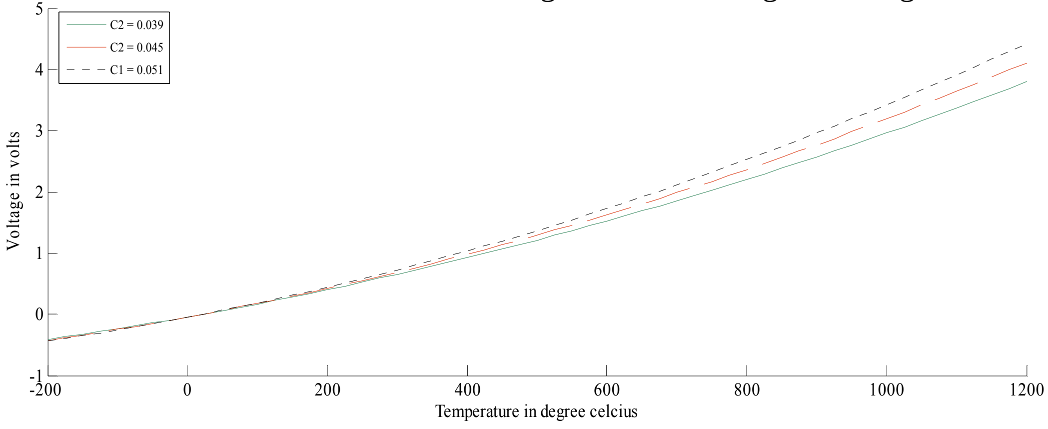

Fig. 4. Data converter outputs for variation of temperature with C_2 and C_1 = 60.

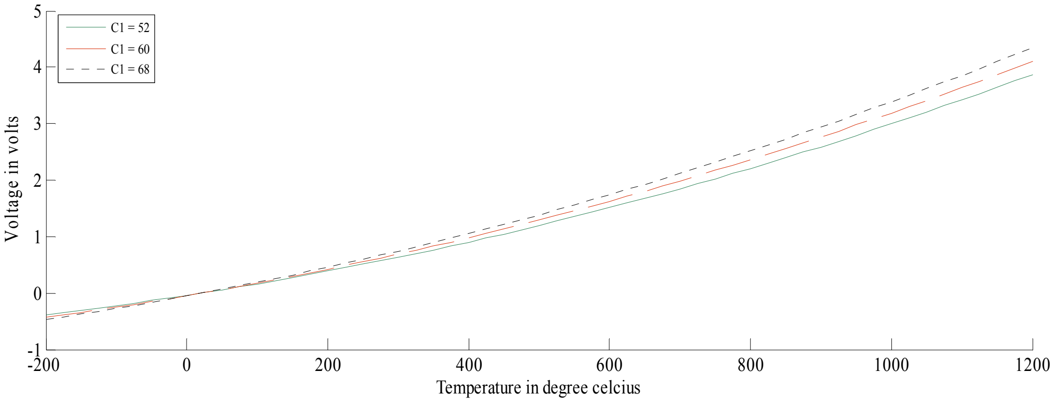

Fig. 5. Data converter outputs for variation of temperature with C_1 and C_2 = 0.045.

Fig. 4 and Fig. 5 show the variation of voltage with the change in input temperature for different values of coefficients.

It has been observed from the above graphs (Fig. 4 and Fig. 5) that the output from the data converter circuit has a non linear relation. Datasheet of thermocouple suggests that the input range of 10 % to 70% of full scale is used in practice as linear range. The output voltage also varies with the changes in coefficients. These are the reasons which have made the user to go for calibration techniques using some circuits. The conventional techniques have a drawback that its time consuming and need to be calibrated every time a thermocouple is replaced in the system. Further, the use is restricted only to a portion of full scale.

To overcome these drawbacks, this paper makes an attempt to design a temperature measurement technique incorporating intelligence to produce linear output and to make the system adaptive of variations in temperature coefficients using a suitable optimized artificial neural network.

5. Problem Solution

The drawbacks discussed in the earlier section are overcome by introducing an optimized ANN model is cascaded after data converter unit. This model is designed using the neural network toolbox of MATLAB.

The first step in developing a neural network is to create a database. The output voltage of the system for a particular change in temperature and coefficients C_1 and C_2 is stored as row of input data matrix various such combinations of input temperature, C_1, C_2 and their corresponding output voltages are used to form the other rows of input data matrix. The output matrix would be the target matrix consisting of data having a linear relation with the temperature and adaptive of variation in C_1 and C_2 all other parameters as shown in Fig. 6.

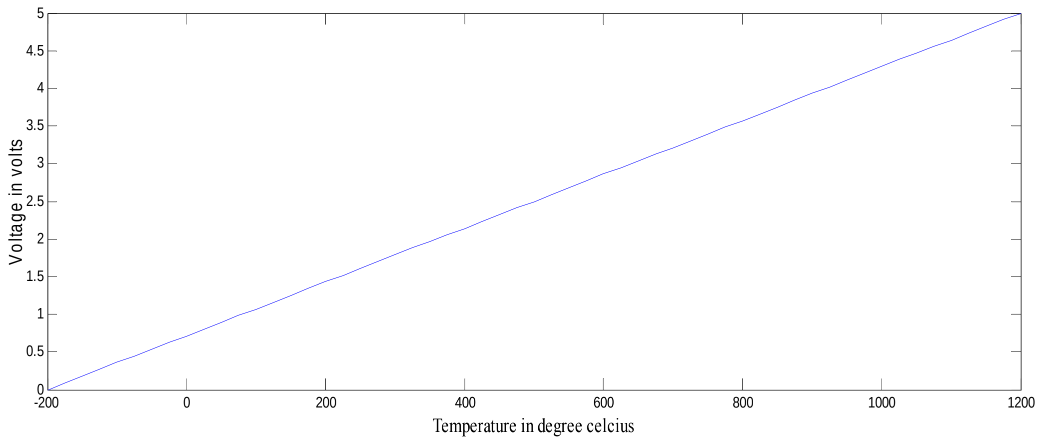

Fig. 6. Target graph for ANN.

5.1. Training

The process of finding the weights to achieve the desire output is called training. The optimized ANN is found by considering different algorithms with varying hidden layer as shown in Table. 2. Mean Squared Error (MSE) is the average squared difference between outputs and targets. Lower values of MSE are better. Zero means no error. Regression (R) measure the correlation between output and target. Regression equal to 1 means a close relationship and 0 means a random relationship. With these details the network is trained to achieve its desired target. The details of the neural network are given in Table 2.

Table. 2. Comparison of Algorithm and Hidden layers.

Hidden layers		GNA	LMA	BP trained by ACO	RBF trained by ACO
1.	MSE	3.256E-2	3.516E-2	1.11E-2	2.325E-3
	R	0.7992	0.889999	0.92353	0.9568
2.	MSE	7.3658E-3	1.986E-3	5.83E-4	3.658E-5
	R	0.8659512	0.91456	0.99875	0.9992
3.	MSE	3.465E-5	9.264E-5	1.32E-6	3.658E-7
	R	0.998856	0.9994513	0.9999235	0.99998265
4.	MSE	6.78E-7	2.585E-7	1.993E-9	6.847E-10
	R	0.9999321	0.999992	0.99999940	0.999999

Four different schemes and algorithms are used to find the optimized ANN. These are Gauss-Newton Algorithm (GNA) [16, 17], Levenberg-Marquardt algorithm (LMA) [16, 18], Back Propagation neural network (BP) trained by Ant Colony Optimization (ACO) [19-21] and Radial Basis Function (RBF) trained by ACO [22-24]. Training of ANN is first done assuming only one hidden layer. MSE and R values are noted. Hidden layer is increased to 2 and training is repeated. This process is continued up to 4 hidden layers. In all cases MSE and R are noted and shown in Table 2. MSE's and R's corresponding to different algorithm and hidden layers are shown in Fig. 7 and Fig. 8. From Table 2, Fig. 7 and Fig. 8 its very clear that RBF trained by ACO yields most accurate results. RBF trained by ACO with 3 layers is considered as the most optimized ANN for better accuracy of result.

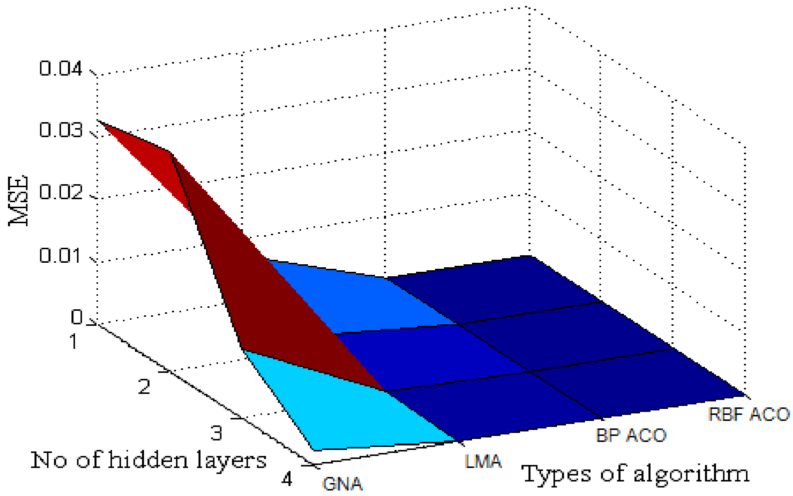

Fig. 7. Graph showing the MSE corresponding to different ANN models.

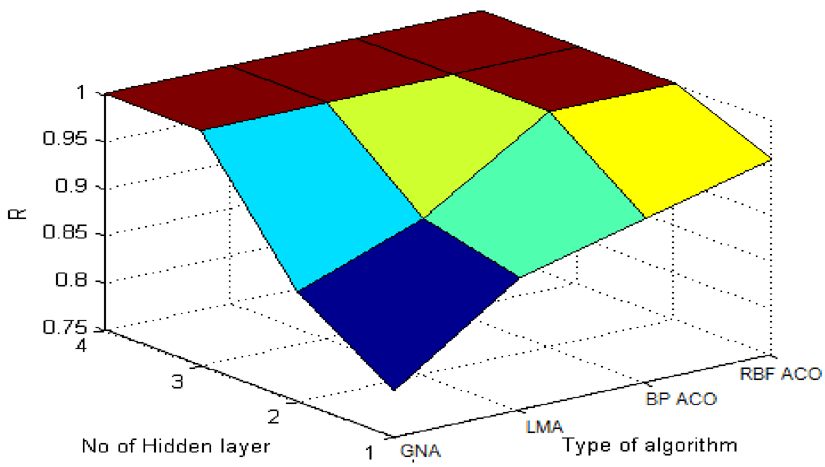

Fig. 8. Graph showing the R corresponding to different ANN models.

6. Result and Conclusion

As discussed, ANN is trained, validated and tested with simulated data. Once the training is over, the proposed measurement system as shown in Fig. 2 is subjected to various test inputs corresponding to different combinations of temperature, C_1 and C_2, all within the range given in Table. 3. For testing purposes the range of temperature is considered from -210 ^{o}C (63 K) to 1200 ^{o}C (1473 K). The range of coefficient C_1 is 50 to 70 and range of coefficient C_2 is 0.039 to 0.051. The output voltages and of system are noted corresponding to various combination of input temperature coefficients C_1 and C_2, within the range. The input temperatures and the corresponding output voltages are plotted and are shown in Fig. 9. The output graph is matching the target graph as shown in Fig. 6.

Table 3. Summarizes the require data for training.

Optimized parameters of the neural networks model				
Database		Training base (70 %)		98
		Validation base (15 %)		21
		Test base (15 %)		21
No of neurons in		1^{st} layer		7
		2^{nd} layer		7
		3^{rd} layer		8
Transfer function of		1^{st} layer		tansig
		2^{nd} layer		tansig
		3^{rd} layer		tansig
		Output layer		linear
Input		Temperature	C_1	C_2
	min	-210 °C (63 K)	50	0.039
	max	1200 °C (1473 K)	70	0.051

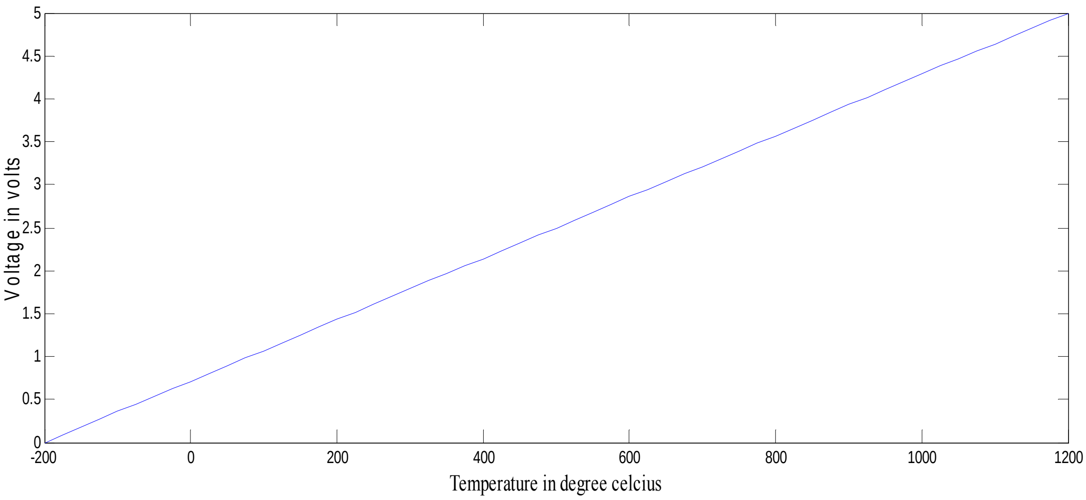

Fig. 9. Response of the system for change in temperature and temperature within the range.

It is evident from the Fig. 9, that the proposed measurement technique has incorporated intelligence to the thermocouple. It has increased the linearity range of the thermocouple to 100 % of full scale of input range and the output is made adaptive of variation in coefficients C_1 and C_2. Thus if a thermocouple is replaced by another having different values of temperature coefficients, the proposed measurement technique does not require any calibration.

Available reported works have discussed different techniques used for calibration of thermocouple, but these are not adaptive of variations in temperature coefficients. Hence, repeated calibration is requested for any change of thermocouple. Some time the calibration circuit may itself be replaced which is a time consuming and tedious procedure. Further, some reported works don't utilize the full scale of measurement. In comparison to these, the proposed measuring technique achieves linear input output characteristics for full input range and also makes the output adaptive of variations in the coefficients. So, proposed technique avoids repeated calibration every time a thermocouple is replaced. An optimized ANN is used by comparing various scheme, algorithms and hidden layers to achieve the objectives in comparison to an arbitrary ANN in most of the reported works. Similarly technique may be incorporated for other different types of thermocouples.

References

[1]. M. Attari, Methods For Linearization of Non-Linear Sensors, *Proc. of the 4th Maghrebin Conference on Numerical Methods of Engineering, CMMNI-4*, Algiers (Algeria), Vol. 1, pp. 344-350, November 1993.

[2]. J. A. Freeman, Neural Networks: Algorithms, Applications, and Programming Techniques, *Addison-Wesley*, Massachusetts, 1992.

[3]. M. E. Aggoune, F. Boudjema, A. Bensenouci, A. Hellal, S. V. Vadari, M. R. El Mesai, Design of an adaptive-structure voltage regulator using artificial neural networks, in *Proc. of the 2nd IEEE Conference on Control Applications*, Vancouver, Canada, September 1993, pp. 337-343.

[4]. L. F. Pau and F. S. Johansen, Neural Network Signal Understanding for Instrumentation, *IEEE Transactions on Instrumentation & Measurement*, Vo1. 39, No. 4, Aug. 1990, pp. 558-564.

[5]. Dia wen, Lin Qing, Lu Qiang, Calibration system of thermocouple application based on technology of virtual instrument and neural network, in *Proc. of the IEEE Conference on Electronic Measurements and Instruments*, 2007, pp. 268-273.

[6]. N J Medrano-Marques, B Martin-del-Brio, A General Method for Sensor Linearization based on Neural Networks, in *Proc. of the IEEE International Symposium on Circuits and Systems*, Geneva, Switzerland, May 2000.

[7]. Guo Li-Hui, Wang Wu, Jiao Xiao-Bo, Thermocouple signal conditioning with genetic optimizing RBF neural networks, in *Proc. of the IEEE Conference on Communication Software and Networks*, Xian 2011.

[8]. Jim Williams, *Thermocouple Measurement*, Linear Technology, Application note no 28, 1998.

[9]. J. Francis, T. M. Yau, On Radiant Network Models of Thermocouple Error in Pre and Past Flashover Compartment Fires, *Journal on Fire Technology*, Vol. 40, 2004, pp. 277-294.

[10].B. K. Roy, Santhosh K. V., An Intelligent Instrument for Measuring Liquid Level, in *Proc. of the IEEE Conference Process Automation Control and Computing (PACC' 2011)*, Coimbatore, India, July 2011.

[11].Santhosh K V, B K Roy, A Smart Temperature Measuring Technique Using Thermistor, *International Journal of Engineering Science and Management*, Vol. I, No 2, 2011.

[12].Kinzie, P. A., Thermocouple Temperature Measurement, *John Wiley Publication*, New York, 1973.

[13].Bela G. Liptak, Instrument Engineers Handbook-Process Measurement and Analysis, 4th Edition, *CRC Press*, 2003.

[14].John P. Bentley, Principle of Measurement Systems, 3rd Edition, *Pearson Education Publication*, India, 2003.

[15].Ramon Pallas-Areny, John G. Webster, Sensors and Signal Conditioning, 2nd Edition, *A Wiley-Interscience Publication*, 2001.

[16].Björck A., Numerical methods for least squares problems, *SIAM Publications*, Philadelphia, 1996.

[17].Fletcher, Roger, Practical methods of optimization, 2nd Edition, *John Wiley & Sons*, New York, 1987.

[18].Fernando Morgado Dias, Ana Antunes, José Vieira, Alexandre Manuel Mota, Implementing the Levenberg-Marquardt Algorithm on-line: a sliding window approach with early stopping, in *Proc. of the Int. Conf. Proc. IFAC*, USA, 2004.

[19].Jeng-Bin Li, Yun-Kung Chung, A Novel Back propagation Neural Network Training Algorithm Designed by an Ant Colony Optimization, in *Proc. of the IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian*, China, 2005.

[20].L. Bianchi, L. M. Gambardella, M. Dorigo, An ant colony optimization approach to the probabilistic travelling salesman problem, in *Proc. of the 7th International Conference on Parallel Problem Solving from Nature PPSN-VII,*, Berlin, Germany, 2002.

[21].Stuart Russell and Peter Norvig, Artificial Intelligence A Modern Approach, 3rd Edition, *Prentice Hall*, New York, 2009.

[22].Park J., Sandberg J. W., Universal Approach Using Radial Basis Function Network, *Neural Computation*, Vol. 3, 1991, pp. 246-257.

[23].T. Poggio, F. Girosi, Networks for approximation and learning, *Proc. IEEE*, 78, 9, 1990, pp. 1484-1487.

[24].Paul Yee V and Simon Haykin, Regularized Radial Basis Function Networks: Theory and Applications, *John Wiley*, 2001.

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2012.pdf