MODELLING OF NTC THERMISTOR USING ARTIFICIAL NEURAL NETWORK FOR NON-LINEARITY COMPENSATION

T. D. Dongale[1], R. K. Kamat[2]

[1]Solid State Electronics and Computing Research Laboratory,
School of Nanoscience and Technology,
Shivaji University, Kolhapur
[2]VLSI and Embedded System Research Laboratory
Department of Electronics, Shivaji University, Kolhapur

ABSTRACT

This paper investigates modelling of NTC thermistors using Steinhart-Hart equation for generic model generation and then parsing the same through the linearization algorithm based on Levenberg–Marquart back propagation technique with sigmoid activation function. The entire modelling and scripting of the linearization algorithm has been accomplished in the MATLAB paradigm. The results showcase small linearity error optimal in the chebyshev norms. The reported technique has a potential for linearization of other impedance based non-linear sensors as well. Further work is in progress to integrate the algorithm as a soft IP core in a full custom or semi-custom ASIC wherein thermistors are employed as sensors.

KEYWORDS

ANN, Levenberg–Marquart, Linearization techniques, MATLAB, Thermistors

1. INTRODUCTION

Amongst the leading physical parameters, temperature is the one measured and controlled widely in industrial, domestic and almost all the sector touching day to day human life. Accordingly there exist variety of temperature sensors which have evolved over many years of research and development. One such widely used temperature sensor which is acknowledged for its sensitivity is thermistors. The NTC thermistor has the highest sensitivity, small heat capacity, rapid response, small size, low cost and moderately high-resistance at room temperature [1, 2]. Owing to their cost effectiveness which naturally comes from the basic transition metal oxides forming these sensors, many research groups including ours are striving hard to make these sensors amenable to the state of art microcontrollers and automated instrumentation. Some of these achievements of our research group are as follows. The room temperature resistance of NTC thermistors was customized to get the moderate high value for power optimization and thus to avoid the self heating [3]. Our group has also reported temperature measurement using the pulse width modulation wherein thermistor was placed as sensor. Previously we had also dealt with the non-linearity aspects of these sensors using a non-linear ADC in order to tackle the disproportionate difference between dynamic range, resolution, and measurement accuracy [4].

Thus in nutshell, the international scenario pertaining to NTC thermistors reveals their ever increasing applications [5,6] owing to the deserving attributes except for the non-linearity which is still a major hindrance for the developers. In fact the price of the non-linearity compensation in many such applications is found to be prohibitively high than the application itself. Literature survey [8-20] reveals that the non-linearity compensation techniques are realized either in the hardware domain or in software, however the combination of the above mentioned duo is rarely found in literature [7]. Hardware compensation uses electronic circuits and components for correction, with the schemes such as shunting with the resistive network, nonetheless effective only in a narrow temperature range. The software techniques comprises of various methods that uses fuzzy Logic, look up table method and Artificial Neural Network (ANN). The above mentioned techniques enjoy more popularity then their hardware counterparts owing to their amenability with the state of art microcontrollers and digital processor environment. The software-based linearization methods are addressed by good number of research groups. Recently reported variations in the linearization techniques include LabView [21] and FPGA based instrumentation [22]. , However, a major drawback of these is their off-line compensation which not only poses non-ideal linearization, but also results in time inefficiency in acquiring and processing the sensor data.

In view of the above, the present describes implementation ANN based non-linearity compensation technique which resorts to the online non-linearity compensation thereby providing highest measurement time efficiency. Moreover the technique is suitable to embed as a soft IP core in an ASIC environment which leads to the efficiency in terms of the silicon real estate. The technique used in this paper is based on the Levenberg–Marquart back propagation algorithm fine tuned by employing the sigmoid activation function. The entire implementation depicted in the rest of the paper is under the MATLAB platform. The rest of the paper proceeds as follows. At the outset, the Steinhart-Hart equation is scripted in MATLAB to derive the generic model of the NTC thermistor. After ascertaining the same by comparing with the standard thermistor characteristics, the same is taken as the basis for implementing the non-linearity correction. The paper then describes the implementation of ANN and the corresponding pseudo code as well as discusses the results.

2. IMPLEMENTATION DETAILS

In order to derive the generic model of the NTC thermistor the base model taken up for implementation in MATLAB is based on the Steinhart-Hart equation. The values of resistance and temperature are passed to the Steinhart-Hart equation scripted in MATLAB. The resulting characteristic is as shown in Fig. 1 which confirms the thermistor like characteristics.

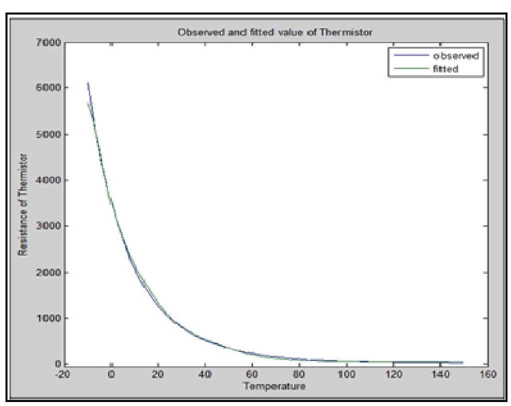

Figure 1: Thermistor ANN Model Test Result

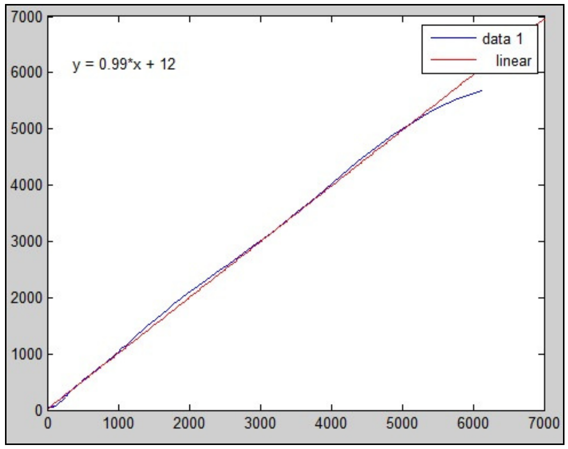

Figure 2: Linearization Curve of Observed Thermistor Characteristics and ANN Model Characteristics

The non-linearity compensation has been developed for the characteristics shown in fig. 1 as the same is generic for any thermistor. The Levenberg–Marquart back propagation technique was then scripted in MATLAB, the pseudo code of which is as shown in table 1. The bias for the above mentioned model is in the form of sigmoid activation function based on the formula. The parameter values for the model developed are as shown in table 2 and figure 3. The table 3 depicts the details of the ANN architecture.

Table 1: Pseudo Code for the Thermistor Model

```
Clear all
        X= [Bias Values First Variable (Temp.)]
        B = [Second Variable (Resistance)]
Declare y in range [0, 1]
Declare learning parameter

Initialization of weights connecting from input unit to hidden unit
Initialization of weights connecting from hidden unit to output unit

Select input randomly
       While
             {
                   Check the error
             }

Update the weight and error values
Loop for training the data

Condition for predicted value using optimal weights
Display graph
```

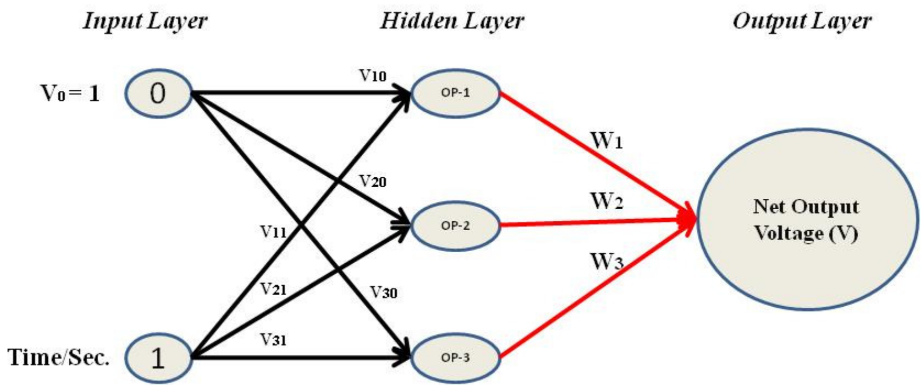

Figure 3: Multilayer Preceptron Model for Thermistor

Table 2: ANN Models Parameters Values

Weights	Values
V_{10}	-2.4972
V_{20}	-1.8626
V_{30}	-4.6656
V_{11}	-0.1860
V_{12}	0.1092
V_{13}	0.0736
W_1	7.7638
W_2	-2.0279
W_3	-3.2968

Table 3: ANN Architecture and Training Parameters

The number of layers	Three
The number of neuron on the layers	Input: 2, Hidden Layer: 3, output: 1
The initial weights and biases	Random
Activation functions	Sigmoid function
Learning rule	Levenberg–Marquart Back propagation

3. RESULTS AND DISCUSSIONS

Fig. 1 reveals the thermistor characteristics obtained through the Steinhart-Hart equation implemented in MATLAB vis-à-vis the non-linearity compensated characteristics. The results are itself indicative that the error values are of the order of 1.51% and thus in the acceptable limits. The curve fitting versions of the above mentioned characteristics are shown in Fig. 2 reveals a small linearity error optimal in the chebyshev norms. This clearly indicates successful non-linearity compensation obtained through the MATLAB implementation of back propagation algorithm finetuned by using the sigmoid activation function. The model consist of three layers an input, output layer and a hidden layer. The results are promising and yields small error as compared to the recent approaches reported in 8, 21 and 22. Work is in progress to embed the reported model as a soft IP core in an ASIC proposed to be developed for a biomedical application.

REFERENCES

[1] Kamat, R.K. and Naik, G.M., (2002)" Thermistors – In search of new applications, manufacturers cultivate advance NTC techniques", Sensor Review, An international journal of sensors and systems, U.K., Vol. 22, No.4, pp. 334-340

[2] Kamat R.K., "Development of High Performance NTC Thermistors", Ph.D. Thesis, Goa University (2003)

[3] R.K. Kamat, G.M. Naik and V.M.S.Verenka, (2001), "Synthesis and Characterization of Nickel Manganese Carboxylate Precursors for Thermistor Applications", Texas Instrument's Analog Application Journal, USA, Volune: 2001:1Q (First Quarter), pp. 52-55.

[4] R.K. Kamat and G.M. Naik, Analogue to Digital Converter With Non-linear Transfer Function for Thermistor Applications, Proceedings of International Measurement Confederation, Retrieved from http://www.imeko.org/publications/tc4-2002/IMEKO-TC4-2002-049.pdf

[5] Andrew J. Skinner and Martin F. Lambert, Log-Antilog Analog Control Circuit for Constant-Power Warm-Thermistor Sensors—Application to Plant Water Status Measurement, IEEE SENSORS JOURNAL, VOL. 9, NO. 9, SEPTEMBER 2009, pp 1049-1057

[6] Deshmukh, M.D. and Panditrao, A., Design and development of thermistor based sensor for spirometry, IEEE Electrical, Electronics and Computer Science (SCEECS), 2012 IEEE , March 2012

[7] Zvezditza P. Nenova and Toshko G. Nenov, Linearization Circuit of the Thermistor Connection, IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 58, NO. 2, FEBRUARY 2009

[8] M. Diamond, "Linearization of resistance thermometers and other transducers," Rev. Sci. Instrum., vol. 41, no. 1, pp. 53–60, Jan. 1970.

[9] Burke, "Linearizing thermistors with a single resistor,Electron" vol. 54, no. 11, pp. 151–154, 1981

[10] Khan and R. Sengupta, "A linear temperature/voltage converterusing thermistor in logarithmic network," IEEE Trans. Instrum. Meas.,vol. IM-33, no. 1, pp. 2–4, Mar. 1984.

[11] Khan, "An improved linear temperature/voltage converter usingthermistor in logarithmic network," IEEE Trans. Instrum. Meas., vol. IM-34, no. 5, pp. 635–638, Dec. 1985.

[12] D. Patranabis, S. Ghosh, and C. Bakshi, "Linearizing transducer characteristics," IEEE Trans. Instrum. Meas., vol. 37, no. 1, pp. 66–69, Mar. 1988.

[13] D. K. Stankovic, "Linearized thermistor multivibrator bridges for temperature measurement," IEEE Trans. Instrum. Meas., vol. IM-23, no. 2,pp. 179–180, Jun. 1974.

[14] D. Stankovic and J. Elazar, "Thermistor multivibrator as thetemperature-to-frequency converter and as a bridge for temperature measurement," IEEE Trans. Instrum. Meas., vol. IM-26, no. 1, pp. 41–46,Mar. 1977.

[15] Sundvist, "Simple, wide-range, linear temperature-to-frequency converters using standard thermistors," J. Phys. E, Sci. Instrum., vol. 16, no. 4,pp. 261–264, Apr. 1983.

[16] R. N. Sengupta, "A widely linear temperature to frequency converter using a thermistor in a pulse generator," IEEE Trans. Instrum. Meas., vol. 37,no. 1, pp. 62–65, Mar. 1988.

[17] S. Natarajan and B. B. Bhattacharyya, "Temperature-to-time converters,"IEEE Trans. Instrum. Meas., vol. IM-26, no. 1, pp. 77–79, Mar. 1977.

[18] W. T. Bolk, "A general digital linearizingmethod for transducers," J. Phys.E, Sci. Instrum., vol. 18, pp. 61–64, 1985.

[19] W. Balzer, "Sensorkennlinien linearizieren," Feinwerktechnik und Messtechnik, no. 6, pp. 221–226, 1992

[20] Flammini, D. Marioli, and A. Taroni, "Application of an optimal lookup table to sensor data processing," IEEE Trans. Instrum. Meas., vol. 48,no. 4, pp. 813–816, Aug. 1999.

[21] Chin-Fu Tsai , Lung-Tsai Li ; Chin-Hao Li ; Ming-Shing Young, Implementation of Thermistor Linearization Using LabVIEW, IEEE Conference on Intelligent Information Hiding and Multimedia Signal Processing, 2009.

[22] Sonowal, D. and Bhuyan, M. FPGA implementation of neural network for linearization of thermistor characteristics, IEEE Conference on Devices, Circuits and Systems (ICDCS), 2012, March 2012.

Author Bibliography

Mr. T. D. Dongale was born in 1989, India. He did his Bachelors and Masters in Electronics specialized in Embedded Systems. He is Assistant Professor in School of Nanoscience and Technology, Shivaji University, Kolhapur. He also qualified the State Eligibility Test for Lectureship (SET) and National Eligibility Test for Lectureship with Junior Research Fellowship (NET-JRF) during his second year of Masters itself. He has been awarded 'Merit Scholarship' of the Shivaji University, Kolhapur for securing the first rank in his graduation and post graduation studies. Moreover he is also a recipient of the 'Eklavya Scholarship' for supporting his Masters studies. He has to his credit 18 research papers published in reputed international journals and author of three book 'The Treatise on sensor interfacing' (Germany, Lap- Lambert, 2012)', 'Annals of Scholarly Research in Electronic', (Germany, Lap- Lambert, 2012)', 'ZigBee and RFID Based System Design', (Germany, Lap- Lambert, 2012)'. His current research interests are Soft Computing, Feedback Control System, Power Electronics, Computational Electronics, Chaos and Memristor.

Dr. Rajanish K. Kamat was born in India in 1971. He received B.Sc. in Electronics, M. Sc. in Electronics both in distinction in 1991 and 1993 respectively. Further he completed M.Phil in Electronics in 1994 and qualified the State Eligibility Test (in 1995), which is mandatory for faculty positions in India. He pursued his Ph.D. in Electronics specialized in 'Smart Temperature Sensors' at Goa University and completed the same in 2003. He was awarded merit scholarship during the Masters programme.

Dr. Kamat is currently a Professor with the Department of Electronics, Shivaji University, Kolhapur, India. Prior to joining Shivaji University, he was working for Goa University and on short term deputation under various faculty improvement programmes to Indian Institute of Science, Bangalore and IIT Kanpur. He has successfully guided five students for Ph.D. in the area of VLSI Design. His research interests include Smart Sensors, Embedded Systems, VLSI Design and Information and Communication Technology. He is recipient of the Young Scientist Fellowship under the fast track scheme of Department of Science and Technology, Government of India and extensively worked on Open Source Soft IP cores. One of his research papers won 4th place in the international paper contest organized by American Society for Information Science and Technology [ASIST, USA] for the year 2008. He has published over 50 research papers, presented over 60 papers in conferences and authored eight books: Harnessing VLSI System Design with EDA Tools (U.K., Springer, 2011), Unleash the System On Chip using FPGAs and Handel C (U.K., Springer, 2009), Practical Aspects of Embedded System Design using Microcontrollers C (U.K., Springer, 2008), Exploring C for Microcontrollers: A Hands on approach (U.K., Springer, 2007), A Monogram on Design & Implementation of: Spatially and Temporally Efficient Visualization Algorithms for Manufacturing Industries (Germany, Lap Lambert, 2012), 'The Treatise on sensor interfacing' (Germany, Lap- Lambert, 2012)', 'Annals of Scholarly Research in Electronic', (Germany, Lap- Lambert, 2012)', 'ZigBee and RFID Based System Design', (Germany, Lap- Lambert, 2012)'.

Dr. Kamat is a Member of IEEE and also a life member of Society of Advancement of Computing. He has been listed in the Marquis Who's Who in the World, USA.