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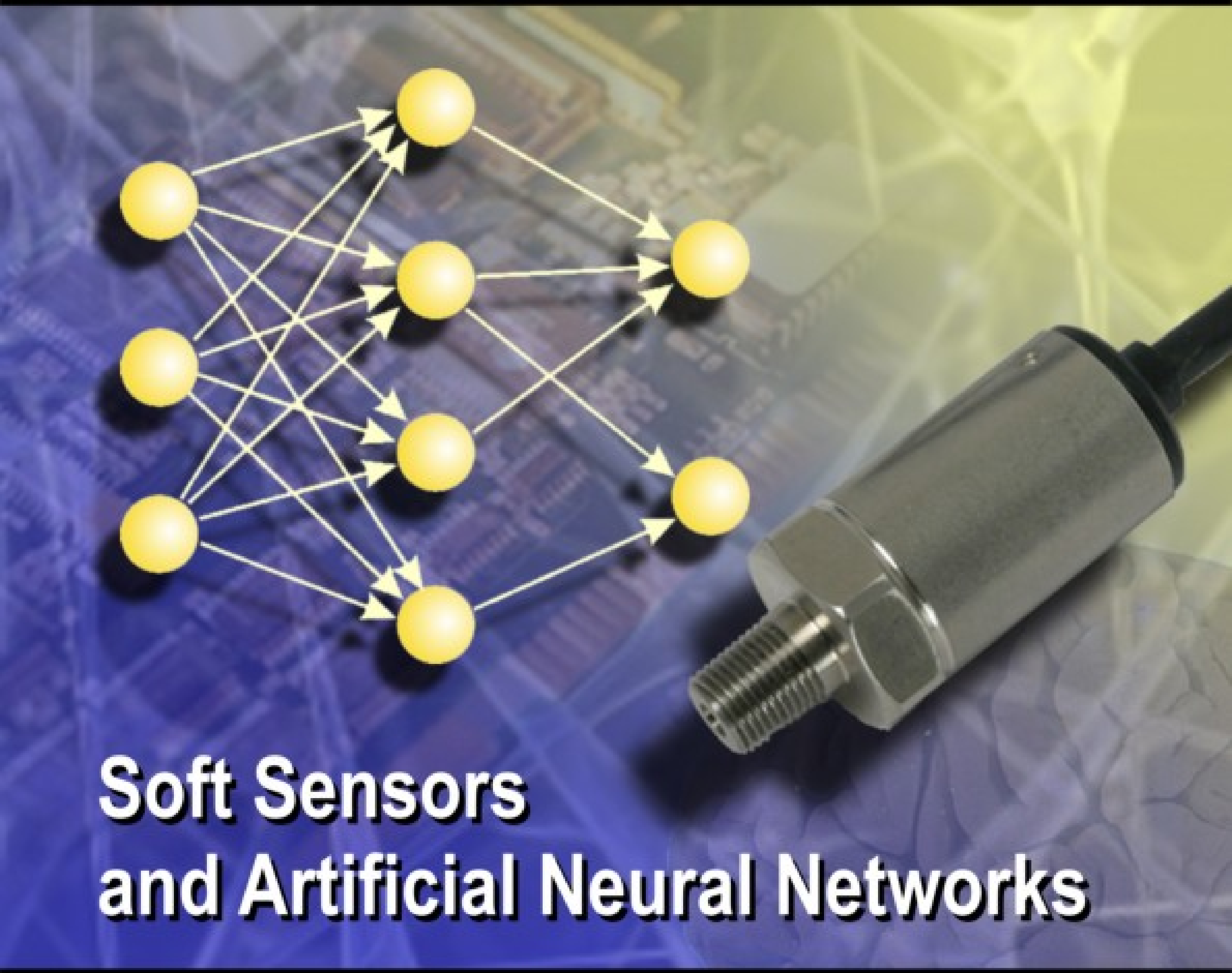

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An Artificial Neural Network Based System for Measurement of Humidity and Temperature Using Capacitive Humidity Sensor and Thermistor

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Abstract: The present paper reported a system for simultaneous measurement of humidity and temperature, employing a capacitive humidity sensor and a thermistor placed in a 555 linear circuit operating in the astable multivibrator mode. The output of the circuit, after further conditioning, is processed by an appropriately trained artificial neutral network (ANN) to yield the % relative humidity and temperature values. The efficiency of the system has been tested by numerical simulation studies. The versatility of the arrangement from the point of view of accuracy and cost-effectiveness has been established by comparison with other reported schemes for humidity and temperature measurement. *Copyright © 2008 IFSA.*

Keywords: Capacitive humidity sensor, Thermistor, Artificial neutral network, 555 timer

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1. Introduction

Knowledge of humidity is not only important for weather-related measurements but also for the operation and/or automatic control of many industrial process and a few domestic appliances as well. The domain extends from pharmaceutical food processing industries to the humidity control mechanisms for microwave ovens, tumble dryers and humidifiers. Many of such applications require the simultaneous sensing of temperature and humidity.

Earlier, mechanical hydrometers were extensively used for measurement of humidity. [1] However with the rapid development of electronic instrumentation systems, and also with the spurt in the sensing related to humidity control applications, mechanical hygrometers could not evade the all-pervading on-slaught of electronics. People started looking for electronic sensors which are both inexpensive and reliable. This triggered the development of a bunch of parametric humidity sensors over decades, ranging from variants of resistive sensors and capacitive sensors [2-9] also commonly referred to as humistors. An electronic version of the dry and wet bulb hygrometer was also developed [10], which employed quartz crystal as temperature sensors and utilized an EPROM based look-up table to yield the relative humidity from the dry and wet temperatures. On the other hand, recent advances in soft-computing methods have resulted in their successful applications in different fields of engineering. One of the important applications of these techniques is in single or multidimensional nonlinear mathematical fitting for pattern classification or function approximation. In particular, artificial neutral networks (ANN) have been quite successful in this area. ANNs can therefore be conveniently utilized also in the realm of sensor signal processing. As the simplest example, the output of the transducer may be processed by a properly trained ANN to yield the value of the physical variable under measurement. Since in this application, the incorporation of the trained neutral network effectively results in system with quasi-linear transfer characteristic, it is often referred to as the linearizer.

The present paper proposes a novel scheme for simultaneous measurement of relative humidity and temperature by employing a capacitive humistor and a theirmistor with negative temperature coefficient (NTC) placed in a 555 timer circuit working in the astable mode. The circuit output, after further conditioning, is processed by an ANN. It is can be easily programmed in a microcontroller and the arrangement is thus within the means of common users. The performances of the arrangement has been assessed by numerical simulation and compared with that of a novel low-cost ANN based psychrometer already reported by the authors.

2. Capacitive Humidity Sensor – an Overview

The capacitive humidity sensor (often known by the acronym humistor) consists of a dielectric that has the ability to absorb water and the permittivity is dependent on humidity [4, 5, 9, 11]. The dielectrics that are usually used are aluminium oxide or special type of polymer. One or both of the electrodes consist of a metal which is permeable to water vapour. In one variety, the dielectric is coated on both sides with gold, so as to form a parallel plate capacitor and the configuration is housed in a perforated plastic case. In another variety, one electrode is a layer of tantalum deposited on glass substrate and the other is a thin layer of chromium under high tensile stress, so that it takes into a fine mosaic. In both cases, water molecules pass into the dielectric through the perforated electrodes, and capacitance becomes a function of the humidity of the environment to which the sensor is exposed. As humidity increases the capacitance also increases, but not in a linear manner. Revolutionary advancements in thin film technology and advent of highly efficient software for optimizing sensor geometries have enabled the manufacturers to come up with capacitive humistors with considerably reduced nonlinearity of the transfer characteristics.

The capacitive sensors for humidity measurement are characterized by high stability and most air pollutants, except some solvents e.g. acetone, alcohol, benzene and ethyl alcohol etc, have almost no effect on their performance. However, for such sensors, temperature is an important interfering physical variable, which calls for appropriate compensation techniques. The capacitance value increases with increase in temperature.

3. The Proposed Scheme

3.1. Underlying Principle

The 555 timer is a multipurpose but low cost IC which serves as the basic building block for wide variety of circuits. In the present application, the IC is used in the astable multivibrator mode [12, 13] and the circuit for such operation is shown in Fig. 1.

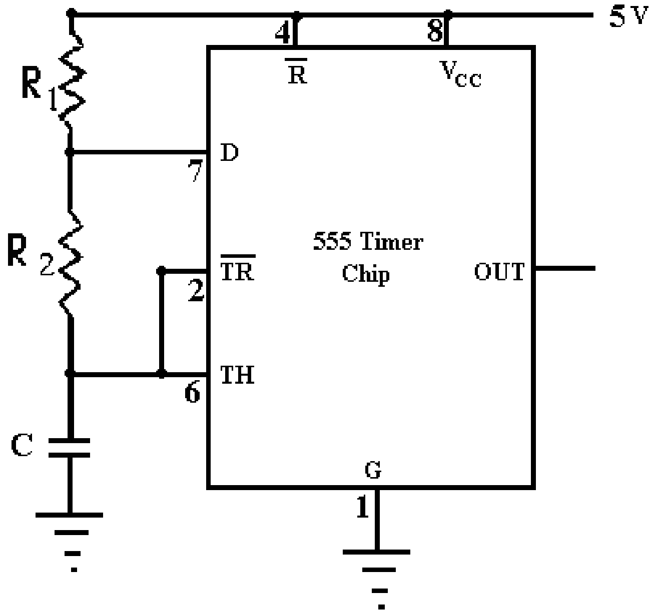

Fig. 1. 555 Timer in Astable mode

The frequency or the repetition rate of the output pulses from 555 timer circuit in astable mode is determined by the values of the two resistors R_1 and R_2 and by that of the timing capacitor C. The frequency is approximately,

$$f = 1.44 / [(R_1+R_2)\, C] \tag{1}$$

The duration T_1 of the HIGH level (ON time) and duration T_2 of the LOW level (OFF time) of the pulse train as indicated in Fig. 2, are approximately given by,

$$T_1 = 0.69\, (R_1+R_2)\, C \tag{2}$$

and

$$T_2 = 0.69\, R_2C \tag{3}$$

The capacitive humistor Cs forms the timing capacitor C and an NTC thermistor (Th_1) forms the resistor R_1. The ambient temperature sensed by the thermistor is one of the measurands, and it is also utilized for compensating the temperature–dependence of the humistor capacitance. R_2 is a fixed resistance, appropriately chosen, so that the frequency of output pulse train of the astable circuit lies within the operating frequency range of the 555 timer IC.

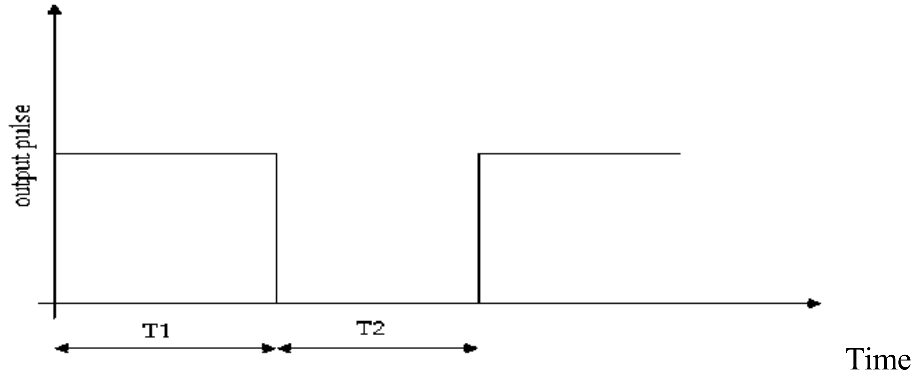

Fig. 2. Output Waveform from 555 timer Output Pin.

Here, since R_2 is fixed, the measured values of 'ON TIME' and 'OFF TIME' have direct dependence on the values of C and R_1 and hence on humidity and temperature. The values of T1 and T2 are extracted by appropriate means and they are processed by a multilayered ANN to yield the relative humidity and temperature of the ambient. In the present case, since the humidity sensor of even a cheap variety has a transfer characteristic with reasonably decent linearity, and the nonlinear psychrometric curves are dispensed with the task of neural computation is easier, the only other nonlinearity being that of the thermistor characteristic. Thus in this work a much simple error-compensated and unified measurement arrangement has been developed involving the humidity and temperature sensors, the resulting in a low-cost and compact transducer for simultaneous measurement of humidity and temperature.

3.2. The Complete Measurement System

Block diagram representations of two possible realizations of the complete measurement set-up are shown in Fig. 3.

The implementation depicted in Fig. 3(a) assumes that the 'ON' time and 'OFF' time values of the astable multivibrator output are obtained using digital hardware (referred to as the signal conditioning circuit) and these values are processed by the ANN linearizer programmed in an ANN chip. The circuit for time duration measurement usually utilizes a known high frequency pulse train and calculates the time interval under measurement by counting the number of high frequency pulses accommodated within such interval [14, 15].

In the alternative shown in Fig. 3(b) it is intended that the output of the astable circuit will be taken to microcontroller or PC based system. Here, a software module will determine the values of T_1 and T_2 which will be utilized as before, by an ANN linearizer for further processing.

In both the cases considered, linearization by artificial neural network utilizes the ability of such networks to learn during the calibration phase, the complex relation between a set of input variables and a set of output variables (measurands) and thereby to predict the unknown values of measurands corresponding to known values of the input variables [16]. Here the measurands are the ambient temperatures (T_d) and the % Relative Humidity, while the input variables are the 'ON' time (T_1) and 'OFF' time (T_2) determined either by hardware or by software technique. Thus one possibility is to have the astable multivibrator circuit comprising the sensors followed by the hardware arrangement for measuring T_1 and T_2 and subsequently by an ANN algorithm programmed in an ANN chip, constituting a complete system. Another option is to combine the multivibrator with the sensors and the preprocessing software (for obtaining T_1 and T_2) and ANN processing algorithm programmed in a microcontroller, to form a ready-to-use system. The third and simplest alternative is to only have the astable circuit containing the sensors as the hardware unit and relevant software for the neural linearizer. The users of this product may then couple this hardware unit to their own computer or microcontroller, where the program for the neural signal processing should also be loaded.

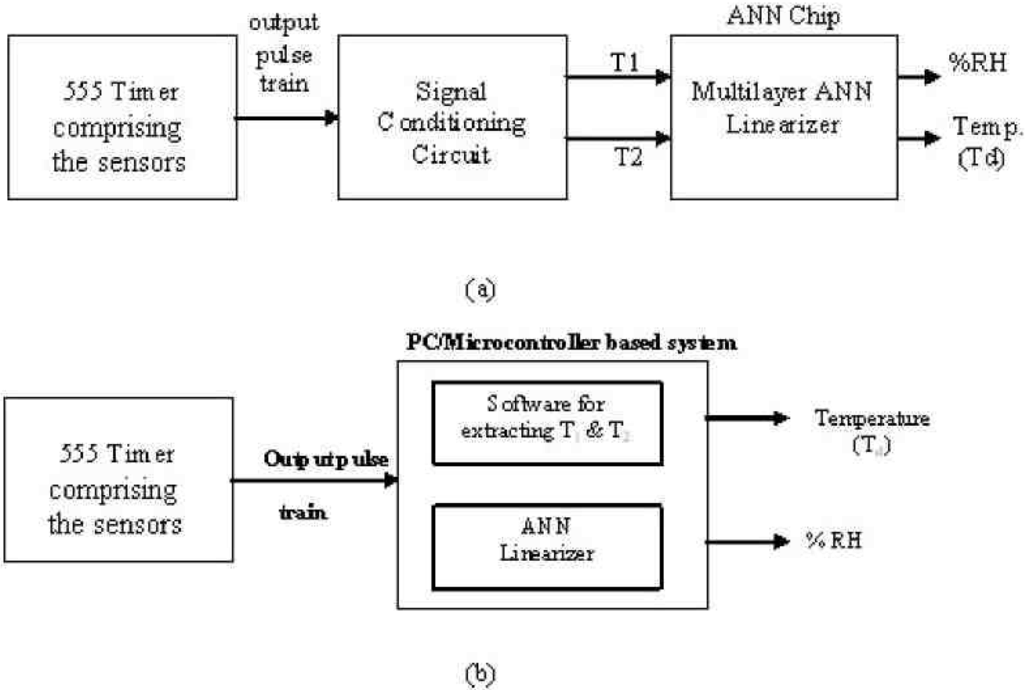

Fig. 3. Block Diagram Representations of the Proposed Scheme.

4. ANN Linearizer

Artificial neural networks (ANN) are processing elements based on the principle of work of human brain [17, 18]. An ANN consists of a set of artificial neurons or processing units and their connections which are called weights and biases. ANN learns i.e. adjusts its weights and biases from input-output data called examples. As ANNs are model-free estimators, it is not necessary to presume a model function that relates the input-output data pairs. Artificial neural networks are extensively useful in a wide spectrum of applications such as signal and image processing, pattern recognition [19], control systems [20] and instrumentation also [21]. As ANNs possess nonlinear characteristics, they are very useful in solving complex and nonlinear problems. They provide better and more accurate results as compared to linear techniques.

In both the schemes in the present work a multi-layered (2-20-2) feed forward neural network has been considered. It has input layer with two input node, a hidden layer ANN with twenty nodes and output layer with two nodes. Each hidden node multiplies every input by its weight and sums the product and then passes the sum through the sigmoid function. The outputs from the output layer of the neural network are compared to the target value of the training data function to calculate the error.

5. Algorithm for Training the Artificial Neural Network

It is evident that adjusting the weights and biases during the training of an ANN is a problem of optimization. The training algorithm optimizes the weight and bias values of the network such that it understands the underlying relation of the input and output data pattern. So any local or global optimization technique can be applied for the training of a feed forward neural network. But the problem with local optimization methods lie in the fact that, if the error surface is highly corrugated i.e. there exists many local minima, then the local optimization methods can converge to a local solution. Therefore the quality of training i.e. how good the trained network will perform depends on several factors, like dimensionality of the objective function, nature of the error surface for a given problem and network structure [22]. If gradient information of error surface is available gradient based algorithms can be successfully used. The most popular one among these is the gradient based back propagation algorithms. If gradient information is not available and also the function of the error surface is non-differentiable then some different approach, like stochastic algorithms may be applied. Simulated annealing is used for networks with non differentiable transfer functions in [23]. An alternative way is to use evolutionary algorithm based global optimization techniques such as Differential Evolution (DE) [24] for this purpose. The differential evolution based training method is successfully applied and discussed in [25] and a generalized approach using evolutionary methods for evolving neural networks is investigated in [26]. For large feed forward neural networks the most popular training methods like back propagation etc, become inefficient because of local minima and also for a very large computational load that increase execution time and memory usage. On the other hand stochastic algorithms posses slow convergence characteristics. As a solution hybrid of gradient based optimization methods and evolutionary algorithms is studied in [27, 28]. Better initialization of the gradient based algorithms may also be a solution. In this work evolutionary algorithm based Differential Evolution (DE) algorithm is used for ANN training. Thus the weights and biases of the network are initialized with DE and thereafter this initialized network is again trained with the help of Levenberg-Marquadt algorithm.

6. A Novel ANN Based Psychrometer

The author have already reported [29] an intelligent psychrometer for humidity and temperature measurement, which is a variant of the present scheme. The core of the psychrometer is the same 555 IC based astable multivibrator. R_1 and R_2 are two NTC thermistors for sensing dry temperature (t_d) and wet temperature (t_w) respectively. A timing capacitor C of suitable value is used. On variation of humidity and temperature, R_1 and R_2 and consequently T_1 and T_2 will change. Thus on measuring T_1 and T_2, the thermistor resistances R_1 and R_2 can be calculated and a prior-knowledge of the resistance-temperature data of the thermistors will subsequently give t_d and t_w respectively. From standard psychrometric data, the relative humidity can then be obtained the relative humidity and ambient temperature (t_d) values. The ANN used in the psychrometer is exactly similar is structure to the ANN used in the present work and identical training methodology has been deployed.

7. Simulation and Results

The simulation and testing of the schemes have been carried out using SIMULINK and Neural Network Toolbox of MATLAB 6.5 in a Pentium 4 processor based PC. *UUA 33J4* thermistors of Omega Engineering have been considered as temperature sensors and their resistance-temperature data obtained from the manufacturer [30] have been utilized for simulation.

Capacitive humidity sensor *2322 691 90001* of PHILIPS has been considered here [6]. The capacitance vs. %RH characteristic of the sensor has a certain amount of nonlinearity, but not to a great extent as shown in the Fig. 4. The transfer curve of the sensor considered here is far more nonlinear compared to the other variants of capacitive humistors which are more costly. The pleasure of using a cheaper humistor could be afforded since the linearity of the transfer relation sacrificed as a consequence, does not pose any appreciable problem, because neural computation is used to predict the humidity.

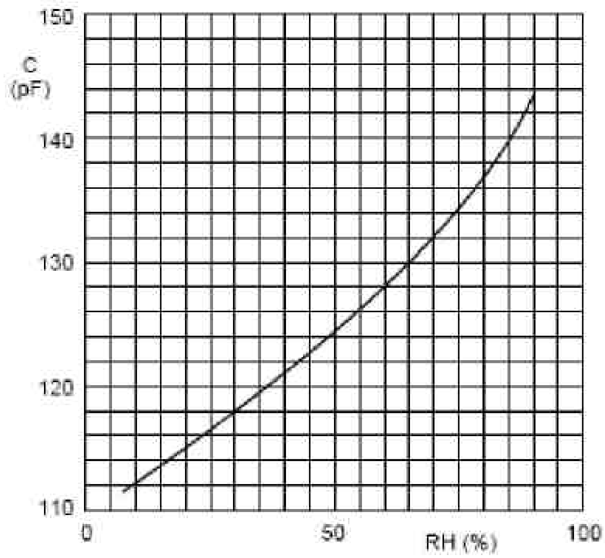

Fig. 4. Transfer Characteristic of *2322 691 90001*(PHILIPS) Capacitive Humidity Sensor.

The capacitance of the humistor and the humidity are related by the equation

$$C_s/C_s(12\%) = 0.985 + 0.34(H_{rel} / 100)^{1.4},$$

where H_{rel} is the percentage relative humidity (%RH); C_s is the capacitance value of the sensor; $C_s(12\%)$ is the capacitance value of the sensor at 12% RH(H_{rel}=12%).

The capacitance value has a temperature coefficient of 0.1%/K. During training of the ANN in both the schemes100 epochs (iterations) are used for initialization of the weights and biases of the network by DE algorithm and the initialized network is then trained using 350 epochs (iterations) with Levenberg-Marquadt algorithm.

The errors in the measured (i.e. predicted by the ANN) values of ambient temperature and relative humidity have been expressed as percentage of the full scale values of the measurands. The error curves for the proposed scheme are given in Figs. 5 and 6. The percentage full scale errors in %RH and Temperature for both the schemes are compared in Table 1 and in Table 2 respectively.

As revealed by the results tabulated in Table-1, the performance of the proposed capacitive humistor based scheme, with respect to humidity measurement, is much superior to than that of the psychrometer reported by the authors. This is not contrary to expectation, since the capacitive humistor has a transfer characteristic with decent linearity while the psychrometer uses two NTC thermistors which have highly nonlinear resistance-temperature characteristics. However, the performances of both the arrangements as regards temperature measurement are almost same.

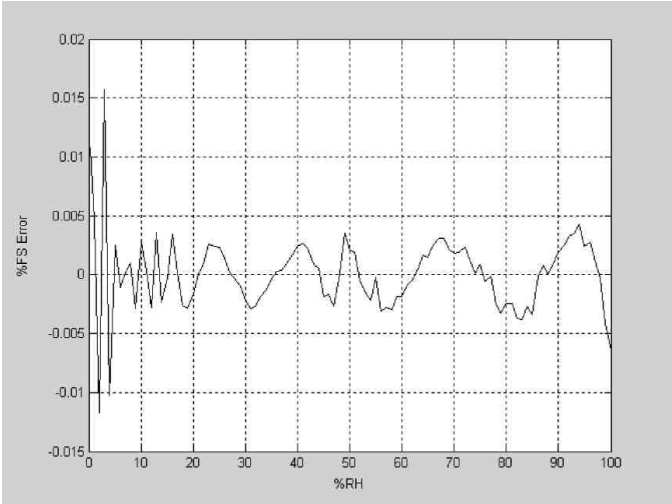

Fig. 5. Percentage Full-scale Error variation with % RH for present scheme.

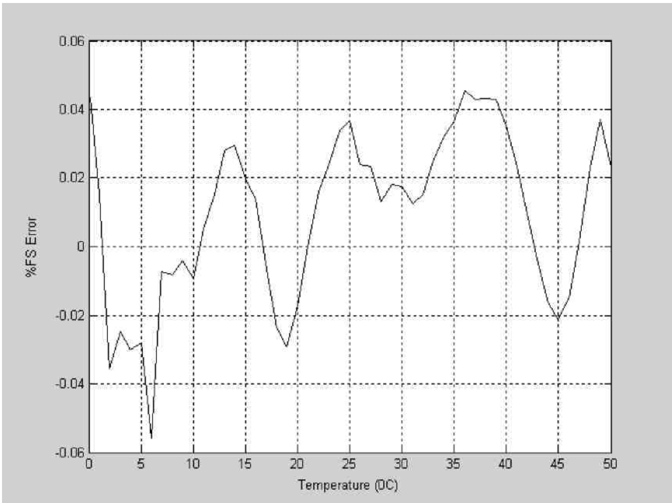

Fig. 6. Percentage Full-scale Error variation with Temperature for present scheme.

Table 1. Comparison between full scale errors of the measurement schemes for %RH.

%Full Scale Error in the measured value of %Relative Humidity		
	Present Scheme	**Intelligent Psychrometer**
Max Error (positive)	0.0157	0.07
Max. Error (negative)	-0.0115	-0.09
RMS Error	0.0033	0.023

Table 2. Comparison between full scale errors of the measurement schemes for Temperature.

%Full Scale Error in the measured value of Temperature		
	Present Scheme	**Intelligent Psychrometer**
Max Error (positive)	0.046	0.063
Max Error (negative)	-0.057	-0.083
RMS Error	0.0258	0.0198

8. Conclusions

In this work a simple scheme for measurement of relative humidity and temperature has been devised and its performance has been tested by simulation. It can be easily appreciated that the scheme is not only practically feasible but can also be expected to be manufactured commercially because of its case of implementation and low cost. The assessed errors have been substantially low, thereby guaranteeing fairly accurate measurements. The humidity measurement is much more accurate compared to that by author novel, low cost system developed by the authors, while the temperature measurement errors are comparable. However the cost of the system in this paper is higher. In another work by A. Chatterjee *et al* [16] the RMS (% full scale) error in humidity measurement is 0.0576, while in the present scheme it is only 0.0033. Finally it is worthy to mention that though a system for simultaneous measurement of humidity and temperature with lower error had been reported [7] such a system is much costly than its proposed system. Thus the efficacy of the system presented in this paper is evident.

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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 it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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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:

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- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
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