The Development of a Low Cost Instrument for Temperature and Relative Humidity Measurement Calibrated using Least Square Regression Method

Pongpun Rerkkumsup

Department of Mechatronics Engineering, Faculty of Engineering, Pathumwan Institute of Technology

833 Rama1 Rd., Wangmai, Pathumwan, Bangkok 10330 Thailand

Tel. 0-2219-3833 Ext. 244 , Fax. 0-2219-3855

E-mail: pongpun@ptwit.ac.th, rerkkumsup@hotmail.com

Abstract

In this paper, the development of an instrument for temperature and relative humidity measurement using a low cost pre-calibrated sensor with calibration technique based on least square regression method is described. The instrument consists of 5 main parts i.e. a microcontroller unit, a sensing unit, a real time clock unit, a display unit and a data storage unit. The PIC C compiler is used to develop the operating software with the standard coefficients provided by manufacturer of the sensor. The discrete data of the temperature measurement using original coefficients are used to calculate the new coefficients needed for calibration. The results show that temperature measurement using modified coefficients based on least square method can reduce the true percent relative error more than 10 times. The new coefficients used for temperature conversion is involved to compensate for the measurement of relative humidity. By combining the modified coefficients of temperature conversion with the calibration method for relative humidity measurement, the true percent relative error is reduced more than one-third.

1. Introduction

The ambient environmental conditions, especially, temperature and relative humidity play important role in nanometer scale research i.e. the research that using scanning tunneling microscope (STM) [1] and laser interferometer [2,3]. Although the STM can be used to image the sample surface in air [4], the temperature fluctuation in the order of sub-degree Celsius can deform the STM image [5-7]. Moreover, temperature and relative humidity have high influence for the refractive index of air [8-10] used in the length measurement method based on light source instrument [11]. The water layer condensed in high relative humidity environment on sample surface cause the deformed STM image due to the stick-slip phenomenon [12]. Therefore, measurement of these parameters is useful in compensation for the experimental conditions. The commercial precision instrument for temperature and relative humidity measurement is still expensive and it needs extra expense for annual calibration service to maintain its performance. The aim of this paper is to propose the development of an instrument for temperature and relative humidity measurement using a low cost pre-calibrated sensor product with the calibration technique based on curve fitting method.

2. Apparatus

As the diagram shown in Fig. 1, the developed instrument consists of 5 main parts i.e. a microcontroller unit, a Real Time Clock (RTC) unit, a sensing unit, a

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data storage unit and a display unit. A PIC® 16F877A [13] chip with 20 MHz operating frequency is employed as the central processor. A certified pre-calibrated sensor SHT15 [14] is used in the sensing unit to measure the temperature and relative humidity. The raw digital data of temperature and

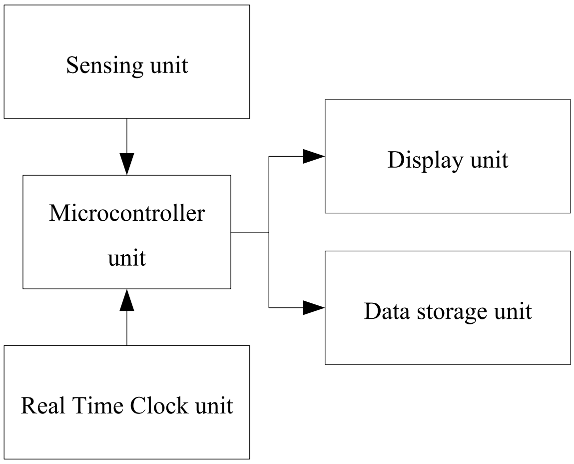

Figure 1 Main units of the developed instrument.

relative humidity from SHT15 are sent to the microcontroller via RB4 and RB5 pins. In order to perform time stamping on the acquired data, the RTC data from DS1307 is sent to the microcontroller via RC3 and RC4 pins. The imported digital readout of temperature data SO_T is converted to temperature value T using

$$T = d_1 + d_2 SO_T \tag{1}$$

where the standard coefficients d_1 and d_2 for our case of 5 V supply voltage with 14 bits resolution are of -40.1 and 0.01, respectively. Since the digital readout of relative humidity data SO_{RH} is nonlinearity, the linearization must be performed to convert the raw data using

$$RH_{linear} = c_1 + c_2 SO_{RH} + c_3 SO_{RH}^2 \tag{2}$$

where coefficients c_1, c_2 and c_3 for our case of 12 bits resolution are of -4.0, 0.0405 and -2.8×10^{-6}, respectively. Moreover, for the temperature significantly different from 25 °C, the calculated linear relative humidity should be compensated using

$$RH_{true} = (T - 25)(t_1 + t_2 SO_{RH})c_1 + RH_{linear} \tag{3}$$

where coefficients t_1 and t_2 for 12 bits resolution are of 0.01 and 0.00008, respectively. Both calculated

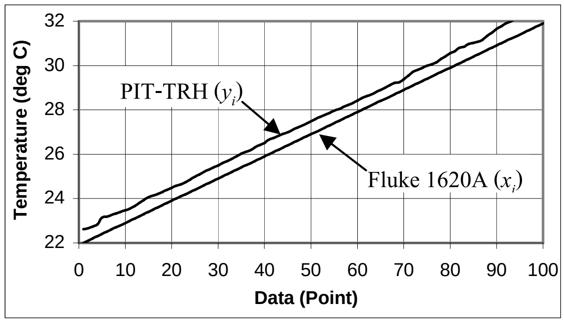

Figure 2 A hundred of discrete data points of temperature measured by the developed instrument compared with ones measured by Fluke 1620A.

temperature and relative humidity data with time stamping will be sent to a display unit and a data storage unit, simultaneously. The secure digital memory module is employed to store the measurement data in the format in which the general text editor or spreadsheet software can read. The CCS PIC MCU® C compiler [15] is used to develop the operating software of the instrument. It includes 4 main parts. The 16F877A.h header file is included to support the controller programming with special instruction. A ds1307.c is included to support the operation with RTC unit. An lcd_lib2.c is included to support the data monitoring via liquid crystal display on the display unit. The main.c which included all previous necessary files is programmed to perform data communication with other units and calculation.

3. Measurement and calibration

The precision instrument for temperature and relative humidity measurement Fluke 1620A [16] is used as a reference to calibrate the developed instrument in our experimental room. In order to avoid the different temperature between sensors of the two instruments, both sensors are kept as close as possible and shielded together

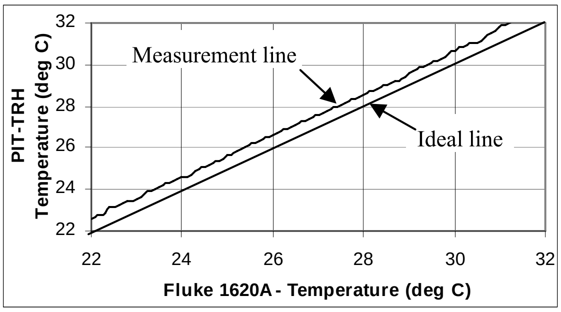

Figure 3 The temperature measured by the developed instrument with respective to ones measured by Fluke 1620A as the reference.

with aluminum foil. A hundred of discrete data points measured over the temperature range of 22.0 to 31.9 °C are plotted as shown in Fig. 2. Visual inspection in the graphical method indicates that temperature measured by the developed instrument (PIT-TRH) compared with the one measured by Fluke 1620A has satisfied linearity with small positive offset occurred. The calculated average true error and true percent relative error of the developed instrument compared with Fluke 1620A are of 0.6092 °C and 2.2778%, respectively. As illustrated in Fig. 3, plotting of discrete data measured by the PIT-TRH with respect to ones measured by Fluke 1620A and compared with the ideal line, the least square regression can be applied to evaluate the numerical characteristic of the experimental results using

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left(y_i - a_0 - a_1 x_i \right)^2 \quad (4)$$

The slope a_1 and offset a_0 of linear least square regression can be determined using

$$a_1 = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i \right)^2} \quad (5)$$

$$a_0 = \bar{y} - a_1 \bar{x} \quad (6)$$

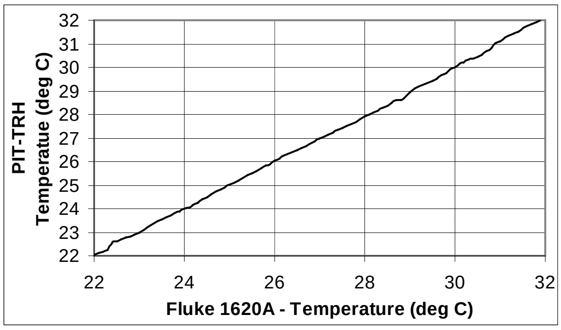

Figure 4 The temperature measured by the developed instrument with modified coefficients with respective to ones measured by Fluke 1620A.

The analytical results using Eq. (5) and (6) show that the measurement line has the slope a_1 and offset a_0 of 1.0093 and 0.3575, respectively. These values are used to compensate the coefficients provided by manufacturer and substituted in Eq. (1) by

$$d_{2\_new} = \frac{d_{2\_old}}{a_1} \quad (7)$$

$$d_{1\_new} = \frac{d_{1\_old}}{a_1} - a_0 \quad (8)$$

Fig. 4 shows the experimental result of temperature measurement using the developed instrument with the modified coefficients proposed in Eq. (7) and (8) with respective to one measured by Fluke 1620A. The result shows that the least square calibration method by modification of coefficients in programming of the algorithm can reduce the measurement error effectively. The average true error and true percent relative error for the measured data after calibrated are evaluated of

0.0033 °C and 0.2009%, respectively. The modified coefficients used in temperature conversion are involved in Eq. (3) to compensate for the measurement of relative humidity in our humidity controlled cabinet. Fig. 5 shows the experimental results of relative humidity measurement

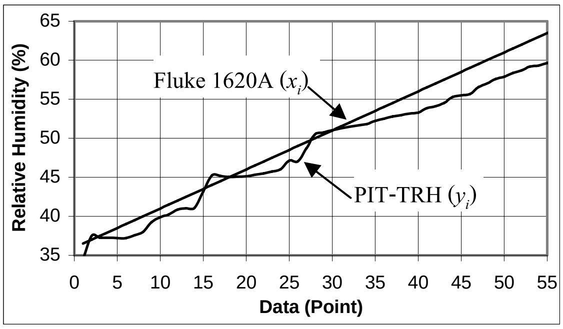

Figure 5 Discrete data points of the relative humidity measured by the developed instrument compared with ones measured by Fluke 1620A.

using the developed instrument with new modified coefficients for temperature conversion compared with one measured by Fluke 1620A. Although the coefficients used in algorithm for temperature conversion were calibrated, the average true error and true percent relative error of 1.7685% and 3.3788%, respectively, are observed. Since conversion of digital readout SO_{RH} to relative humidity required algorithm for linearity and algorithm for temperature compensation, our calibration method, for this case, avoid those too much coefficient. The a_1 and a_0 calculated based on least square method for the discrete data shown in Fig. 5 of 0.8397 and 3.6895, respectively, are used to insert the compensation algorithm as a soft-signal conditioner using

$$RH_{comp} = \frac{RH_{true} - a_0}{a_1} \tag{9}$$

Where RH_{comp} is the compensated true relative humidity value that send to a display unit and a data storage unit. Fig. 6 shows the relative humidity measured using the developed instrument with fully calibrated for temperature and relative humidity with respect to ones of Fluke 1620A. The experimental data is used to evaluate the performance of the

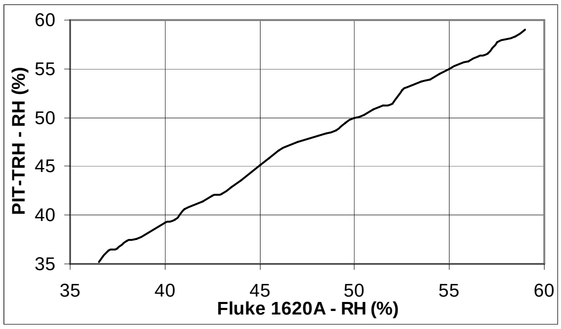

Figure 6 Discrete data points of the relative humidity measured by the calibrated instrument compared with ones measured by Fluke 1620A.

proposed calibration method based on least square regression. We found that the average true error and true percent relative error are reduced to be 0.25% and 0.9533%, respectively.

4. Conclusion

The developed instrument for temperature and relative humidity measurement consists of 5 main parts i.e. a microcontroller unit, a sensing unit, a real time clock unit, a display unit and a data storage unit. The PIC MCU® C compiler was used to develop the operating software with the standard coefficients provided by manufacturer of the sensor SHT15. The discrete data of the temperature measurement using original coefficients were used to calculate the new coefficients needed for calibration. The results of temperature measurement using modified coefficient based on least square method can reduce the true percent relative error to be 0.2009%. The new proposed coefficient used for temperature conversion was involved to compensate for the measurement of relative humidity. By combining the modified coefficients of temperature conversion with the calibration method for relative humidity measurement, the true percent relative error was reduced to 0.9533%. With these experimental results, we can conclude that the developed instrument has high cost performance ratio and capable to perform self calibration. It can be developed and constructed to use in a local laboratory instead of purchase the expensive commercial instrument.

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