# Computer-based System for Calibration of Temperature Transmitter using RTD

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*Abstract*— **Using the temperature calibration instrument, the purpose of this paper is to design the uncertainty calculation system. The test was conducted using Resistance Temperature Detector (RTD) sensor, transmitter, and repeated for three times. The data acquisition (DAQ) card is used to interface the temperature instrument and the computer. In order to determine the uncertainty of the temperature measurement, graphical user interface (GUI) software has been developed in Visual Basic(VB) programming language. The developed software shows that the uncertainty of the temperature transmitter measurement can be calculated by interfacing the instrument to the computer through DAQ card. The study focuses on manual temperature measurement and concentrates only on RTD temperature sensor. The results provide the confidence limits of five-point calibration of temperature transmitter that could improve the teaching techniques using computer-based system of the temperature measurement.**

*Keywords-calibration, uncertainty, confidence limits, temperature transmitter*

## I. INTRODUCTION

Technological advancements in process monitoring, control and industrial automation over the past decades have contributed greatly to improve the productivity of virtually all manufacturing industries throughout the world. A temperature measurement method in multiple points situated on turning around axis bodies shows it still requires performing equipment, supplied from voltage source on moving part with some strict to reduce disturbances. Besides, it is a necessity to calibrate the system after it was assembled, which could be done by the implementation of computer, data acquisitions board to process the signal from the instruments [1]. Nowadays, calculation of measurement uncertainty can be incorporated in virtual instruments; unfortunately so far there are very few mechanisms incorporated in software offered by software products. [2]. Uncertainty of measurement is the doubt that exists about the result of any measurement. By quantifying the possible spread of measurements, the confident of the result can be determined. In many cases results of temperature measurements have to be presented together with the uncertainty of these measurements. Uncertainty calculation has been presented by Korczynski in virtual instruments using the DAQ card, Analog to Digital Converter (ADC) and front-end elements [2]. The detailed procedure for uncertainty calculation enable an evaluation of temperature measurement of electronic microcircuits, but it shows that the camera and emissivity have the largest influence on uncertainty [3]. An error evaluation of temperature measurement system has also been proposed by using temperature sensor based on thermocouples, with controlled profile of temperature field along electrodes [4]. The best measurement capabilities in temperature calibrations by comparison strongly relate to some particular and some typical uncertainty contributions. The repeatability, uncertainty of a calibration bath or furnace, uncertainty of a reference thermometer and uncertainty of measuring devices are the main contributions of the uncertainties in calibration of thermometers based on comparison [5]. The performance benefits such as reduced measurement uncertainty, increased robustness and failure prediction and detection has been implemented through a smart thermocouple system. Optical temperature measurement has been calibrated based on pixel-wise and the accuracy of the measurement has been calculated. However, the accuracy of the measurement reveals more compared to the need for pixel-wise for the calibration process [6]. The calibration of high accuracy and industrial grade which flexible for all type thermostats and RTDs has been proposed using semiautomatic method based on the comparison, reducing the influence of slow temperature drift and optimizing time [7].

This paper is organized as follows. In Section II, a brief description of the temperature calibration instrument is performed. Section III describes the uncertainty calculation that would be used in the development of the software using VB while the interfacing technique via DAQ card is discussed in Section IV. In Section V, simulation studies on temperature monitoring for five-point calibration and uncertainty calculation are presented. Conclusions are made in Section VI.

## II. TEMPERATURE CALIBRATION INSTRUMENT

For the Five-point calibration of the RTD as considered in this study is shown in Fig. 1. The span of the Unit Under Test (UUT) is divided into five equal parts with the first point at the Lower Range Value (LRV) and the top point at the Upper Range Value (URV).
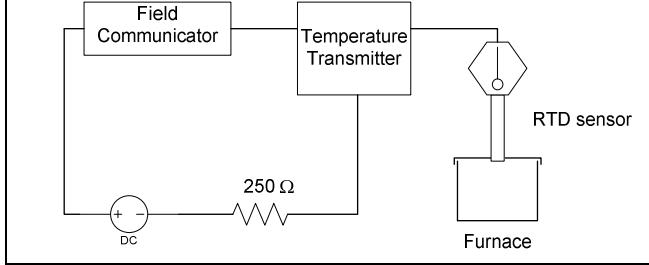


Figure 1. Temperature Calibration Instrument

For example the RTD has the calibration range of 50 – 200 °C. Therefore the span is 200 – 50 = 150 °C. Dividing the span by four will be 37.5 °C. Hence the five equal points are 50, 87.5, 125, 162.5 and 200 °C based. The desired output is calculated based on the 50 – 200 °C range using (1);

$$Desired\ output = \frac{x}{100}(URV - LRV) + LRV \qquad (1)$$

where;

| | |
|---|---|
| $x$ | = $i$th point (0,25,50,75,100%) |
| URV | = Upper range value |
| LRV | = Lower range value |

## III. UNCERTAINTY CALCULATION

Standard uncertainty (2) is an uncertainty of the result of a measurement expressed as a standard deviation based on the three repeated measurement.

$$s(x_k) = \sqrt{\frac{1}{(n-1)}\sum_{j=1}^{k}(x_k - \bar{x})^2} \qquad (2)$$

Type A evaluation (of uncertainty) is a method of evaluation of uncertainty by the statistical analysis of series of observations, due to the repeatability or spread of measurement of the experiment, $u_1$ (3).

$$u_1 = \frac{s(x_k)_{highest/worst\ case}}{\sqrt{n}} \qquad (3)$$

$$Degree\ of\ freedom = \gamma_1 = n-1$$

Uncertainty Contribution Due to Master Standard Unit (MSU) Error, $u_2$ (4).

$$u_2 = \frac{MSU}{\sqrt{3}} \qquad (4)$$

The degree of freedom for this uncertainty is assumed to be $\infty$ since the manufacturer is expected to provide the error data after a large number of tests.

$$Degree\ of\ freedom = \gamma_2 = \infty$$

Type B evaluation (of uncertainty) is a method of evaluation of uncertainty by means other than the statistical analysis of series of observations. Uncertainty due to Unit Under Test (UUT) resolution, $u_3$ (5).

$$u_3 = \frac{resolution\ of\ MSU\ or\ resolution\ of\ UUT}{\sqrt{3}} \qquad (5)$$

The degree of freedom for this uncertainty is consider as $\infty$.

The combined standard uncertainty, $u_c$ (6) is a standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariance of these other quantities weighted according to how the measurement result varies with changes in these quantities.

$$u_c = \sqrt{(u_1^2 + u_2^2 + u_3^2)} \qquad (6)$$

Expanded uncertainty is a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurement. To obtain the lower and upper confidence limits (7) about the measurements,

$$u = u_c k \qquad (7)$$

where $k$ is coverage factor , the numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty. $K$ is determined from the t-distribution table found using the effective degrees of freedom $v_e$, given by (8).

$$v_e = \frac{u_c^4}{\dfrac{u_1^4}{\gamma_1} + \dfrac{u_2^4}{\gamma_2} + \dfrac{u_3^4}{\gamma_3}} \qquad (8)$$

## IV. THE INTERFACING TECHNIQUE VIA DAQ CARD

Interfacing technique between temperature instrument and developed software is achieved by using USB-4716 DAQ Card which is manufactured by Advantech. USB-4716 DAQ Card use Universal Serial Bus (USB) to connect to computer. The Advantech Data Acquisition driver is designed to support programming language such as Visual Basic. Fig. 2 shows the DAQ card that used in this project. This DAQ card has analog input, analog output, digital input and digital output channel.
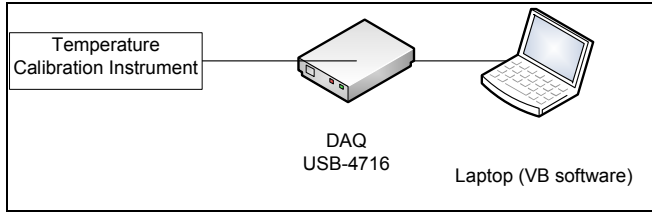
Figure 2. Interfacing Technique

TABLE 2. MEAN, STANDARD DEVIATION & ERROR OF TEMPERATURE TRANSMITTER

| Point(%) | Mean | Standard Deviation | Error (%) |
|---|---|---|---|
| 0 | 4.0103 | 0 | 0.257 |
| 25 | 8.005 | 0.0003 | 0.062 |
| 50 | 12.0972 | 0.0335 | 0.8098 |
| 75 | 15.9896 | 0.0037 | -0.0651 |
| 100 | 19.9947 | 0.0003 | -0.0264 |

## V.    IMPLEMENTATION & RESULT

An instrumentation software was develop and the user interfacing for uncertainty and confidence limits of five-point calibration are presented in Fig. 3 to determine the uncertainty contribution due to repeatability of the experiment as in Table 1.
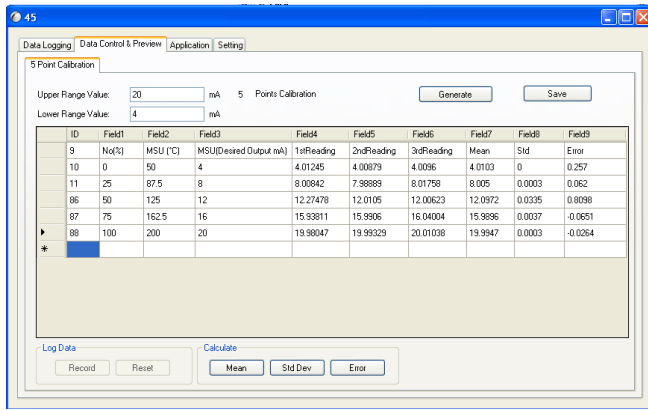


Figure 3. Five-point calibration of RTD

TABLE 1. FIVE-POINT CALIBRATION OF TEMPERATURE TRANSMITTER

| Point (%) | MSU (°C) | MSU (mA) | $UUT_1$ (mA) | $UUT_2$ (mA) | $UUT_3$ (mA) |
|---|---|---|---|---|---|
| 0 | 50 | 4 | 4.01245 | 4.00879 | 4.0096 |
| 25 | 87.5 | 8 | 8.00842 | 7.98889 | 8.01758 |
| 50 | 125 | 12 | 12.27478 | 12.0105 | 12.00623 |
| 75 | 162.5 | 16 | 15.93811 | 15.9906 | 16.04004 |
| 100 | 200 | 20 | 19.98047 | 19.99329 | 20.01038 |

Implementations results in Table 2 show that the highest standard deviation is 0.1542 and produce an error of 0.143%. Standard deviation shows how much the recorded value deviate from desired value. The highest standard deviation recorded will be used to calculate $u_1$ as shown in Fig. 4.

The combined standard uncertainty, $u_c$ (Fig. 7) is determined from the individual uncertainties, $u_1$, $u_2$, and $u_3$ as shown in Fig, 4, Fig. 5 and Fig. 6 respectively.
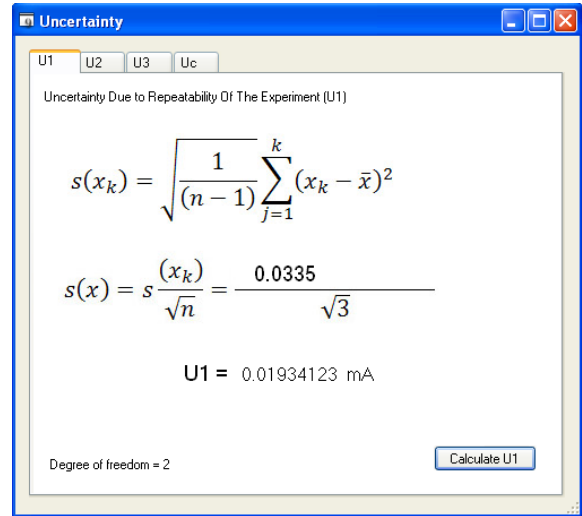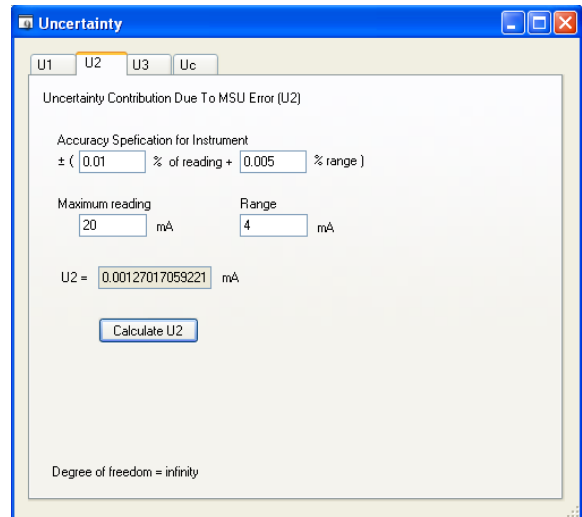


Figure 4. Type A evaluation, $u_1$



Figure 5. Uncertainty Contribution Due to Master Standard Unit (MSU) Error, $u_2$
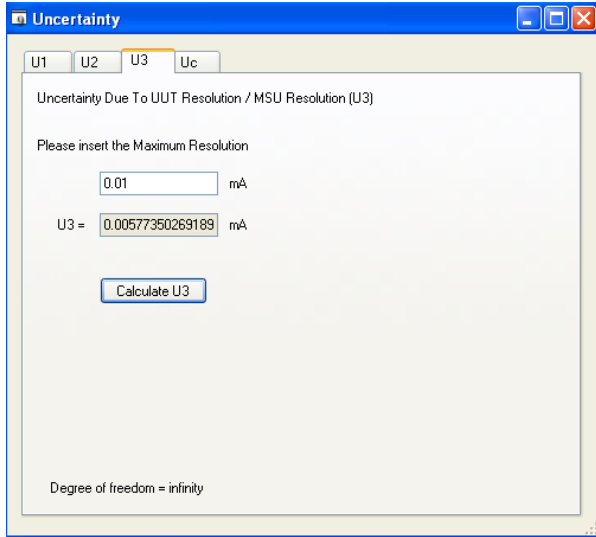
Figure 6. Type A evaluation, $u_3$



Figure 8. Combined standard uncertainty, $u_c$, effective degree of freedom and confidence limit of 99%

For the effective degrees of freedom 6.92653 ≈ 6, the coverage factor, $k = 2.52$ for 95.45% (Fig 7) and $k = 3.71$ for 99% (Fig. 8) confidence level is determine from the t-distribution table. The temperature transmitter using RTD confidence limits of 95.45% and 99% are 0.07 mA and 0.10 mA respectively.
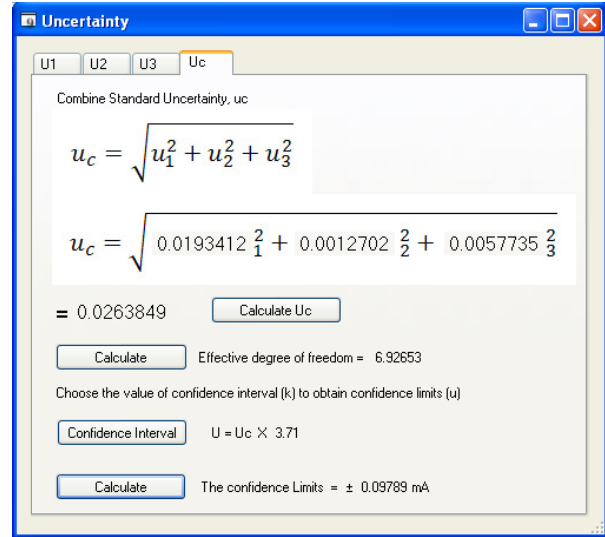
The five-points calibration curve and error curve of temperature transmitter are shown in Fig. 9 and Fig 10 respectively.



Figure 9. Calibration curve
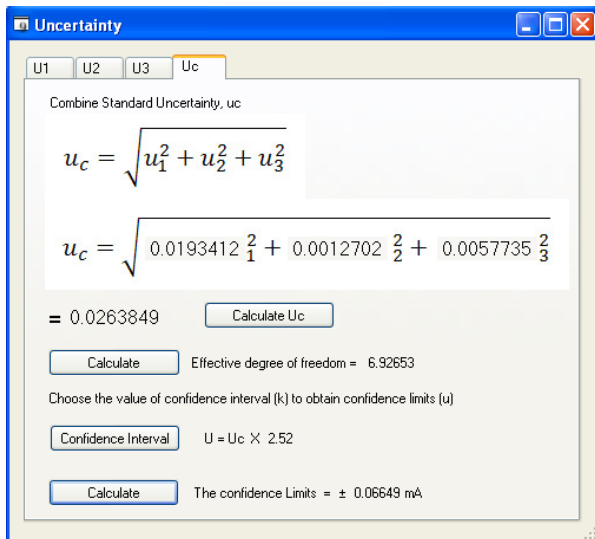


Figure 7. Combined standard uncertainty, $u_c$, effective degree of freedom and confidence limit of 95.45%
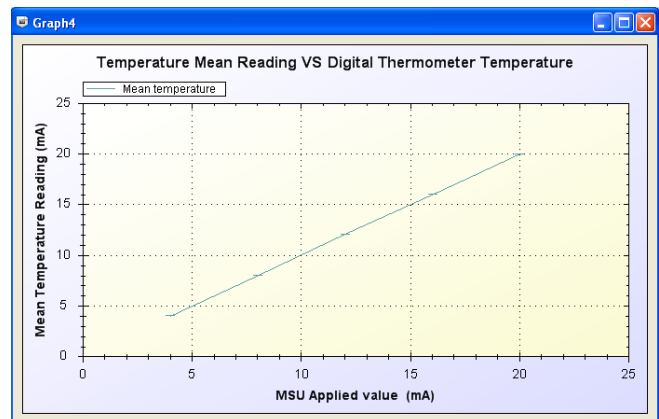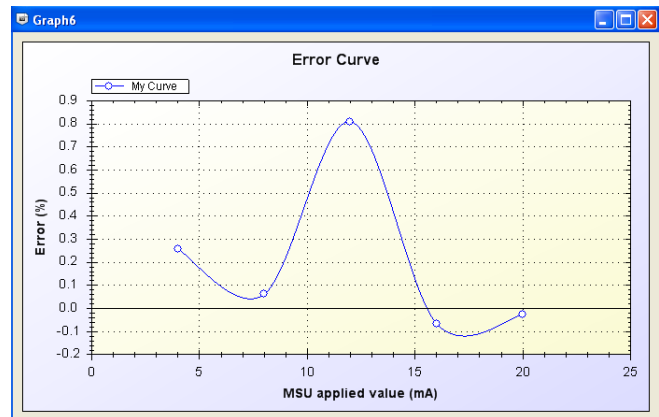


Figure 10. Percentage error curve

## VI. Conclusion

The uncertainties calculation and confidence limits of temperature transmitter calibration is presented. The sample taken in this study, $n = 3$ should also be considered in calculation, because if more samples are taken, the lower uncertainty value will be achieve and if fewer samples are taken, the uncertainty value will increase. The uncertainties will be higher for the higher standard deviation. The data should be recorded in noise free environment by removing the Hart Communicator to reduce the error percentage. The noise occurs when the temperature instrumentation is connecting to Hart Communicator parallel with temperature transmitter. This causes, the current produced by temperature transmitter diverted to 2 junctions, therefore decreasing the actual current value. When the current changed, the voltage is also changed according to ohm's law and this causes the instability to the system. Nevertheless, by using the developed software, the uncertainties and confidence limits of type-k thermocouple for five-point calibration was determined manually. It is concluded that the developed software is capable for computerized calibration and could be improved for automatic computerized calibration.

## Acknowledgment

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