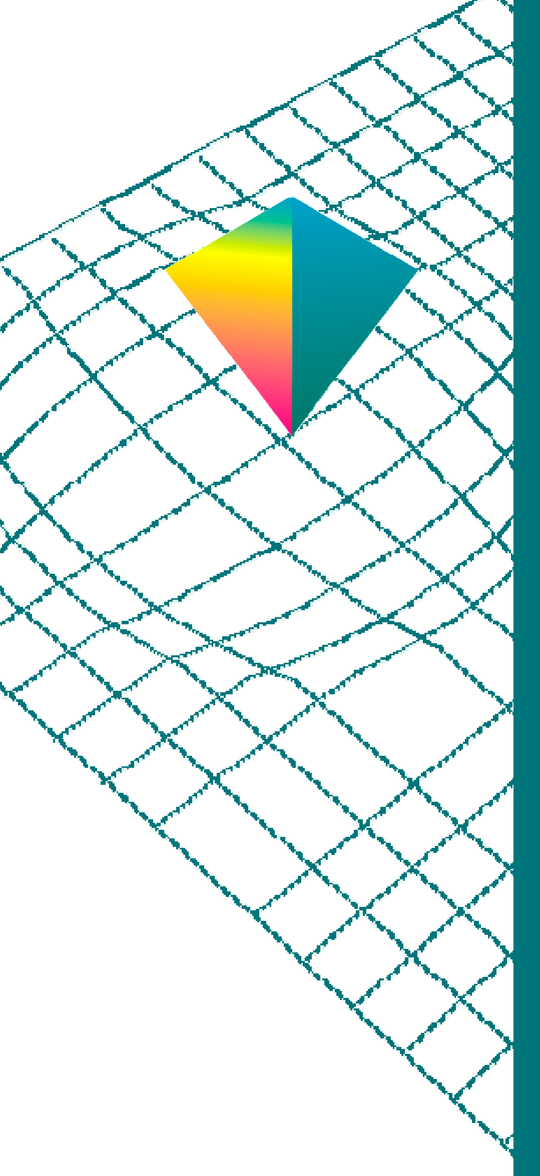
50. Internationales Wissenschaftliches Kolloquium

September, 19-23, 2005



Maschinenbau von Makro bis Nano / Mechanical Engineering from Macro to Nano

Proceedings

Fakultät für Maschinenbau /
Faculty of Mechanical Engineering

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

Impressum

Herausgeber:	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Peter Scharff
Redaktion:	Referat Marketing und Studentische Angelegenheiten Andrea Schneider
	Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurtz, Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte, Univ.-Prof. Dr.-Ing. habil. Gerhard Linß, Dr.-Ing. Beate Schlütter, Dipl.-Biol. Danja Voges, Dipl.-Ing. Jörg Mämpel, Dipl.-Ing. Susanne Töpfer, Dipl.-Ing. Silke Stauche
Redaktionsschluss: (CD-Rom-Ausgabe)	31. August 2005
Technische Realisierung: (CD-Rom-Ausgabe)	Institut für Medientechnik an der TU Ilmenau Dipl.-Ing. Christian Weigel Dipl.-Ing. Helge Drumm Dipl.-Ing. Marco Albrecht
Technische Realisierung: (Online-Ausgabe)	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau
Verlag:	isle Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16 98693 Ilmenau

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ISBN (Druckausgabe):	3-932633-98-9	(978-3-932633-98-0)
ISBN (CD-Rom-Ausgabe):	3-932633-99-7	(978-3-932633-99-7)

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
19.-23. September 2005

George Nikolov / Boyanka Nikolova / Marin Marinov / Siegmar Hecht

Resistance Temperature Detector Calibration In LabVIEW Environment

ABSTRACT

In the present paper the calibration and linearization methods based on capability offered by virtual instrumentation concept are proposed. The two-point calibration method is suggested and explained in details. The main difference between suggested method and these described in literature references is that the resistors with precise known values are used instead very precise known temperatures. Since it is much easier to obtain high precision resistors than temperature references (as is offered in more of publications) the accuracy can be set to a higher level. Other benefit of presented method is the ability of use more efficiently the ADC's full scale. By using LabVIEW considerable decrease the effort of calibration procedure as coefficients are obtained in one environment by software at once. The other great LabVIEW opportunity – build in mathematical and statistical function are applied to achieve accurate measurement results by averaging and high-order linearization.

INTRODUCTION

The most widely measured phenomena in the process control environment is temperature. Common elements, such as Resistance Temperature Detectors (RTDs), thermistors, thermocouples or diodes are used to sense absolute temperatures, as well as changes in temperature. Of these technologies, the platinum RTD temperature sensing element is the most accurate and stable over time and temperature. These types of detectors are commonly used in temperature measurement systems because of their high stability, repeatability, and accuracy. The linear relation between resistance and temperature of the RTD simplifies the implementation of signal conditioning circuitry, which greatly streamlines voltage-to-temperature conversion.

Beyond the initial element errors represented in manufacturer's data sheets, there are other sources of error that affect the overall accuracy of the temperature sensor. These sources of error are considered from various aspects in references [1, 2, 3, 4, 5, 6]. These considerations can be summarized as: - Linearization error; Signal conditioning errors and Self-heating error.

Linearization errors can be eliminating by using the transfer function and appropriate linearization techniques [1, 2].

The signal conditioning errors are due to electrical design used to condition, gain and digitize the RTD output. In addition factors that affect the accuracy of an ADC measurement including the

noise, offset, gain error, reference voltage accuracy, and integral non-linearity must be considered. More of these inaccuracies can essentially be removed through calibration techniques [1]. To remove the error contribution of the lead wires the 3-wire and 4-wire configuration is used. Noise can be reduced through averaging and other filtering techniques [6]. The remaining errors that cannot be compensated for or removed, and which are a major concern for high-resolution systems, are the reference voltage errors. In order to eliminate this error, recently the so-called "ratiometric" measurements are treated with grow popularity [1, 3, 4, 5, 6]. In contrast of absolute measurement a ratiometric measurement provides a result that is the ratio of the reference voltage. This is accomplished by using the reference voltage as a source of excitation for the analog input source – fig.1. If the measurement of a voltage is actually being used to measure another quantity such as resistance as the cases of RTD measurements, then the measurement can be set up to read the resistance more directly as a ratio to a reference resistor. By putting the same current through both the sensor resistance and the reference resistor, the ADC result will be a measure of the ratio of the two resistors:

$$D_{ADC} = \frac{(V_{IN+} - V_{IN-})}{(V_{REF+} - V_{REF-})}\left(2^n - 1\right), \tag{1}$$

$$D_{ADC} = \frac{V_{IN+}}{V_{REF+}}\left(2^n - 1\right) = \frac{I_{EXC} R_{RTD}}{I_{EXC} R_{REF}}\left(2^n - 1\right) = \frac{R_{RTD}}{R_{REF}}\left(2^n - 1\right). \tag{2}$$

The last mentioned of these sources of errors is the self heating of the RTD element that results from the required current excitation [7]. A current excitation is used to convert the resistance of the RTD into a voltage. It is desirable to have a high excitation current through the resistive sensing element in order to keep the output voltage above the system noise levels. A negative side to this design approach is that the element will self-heat as a result of the higher current. The combination

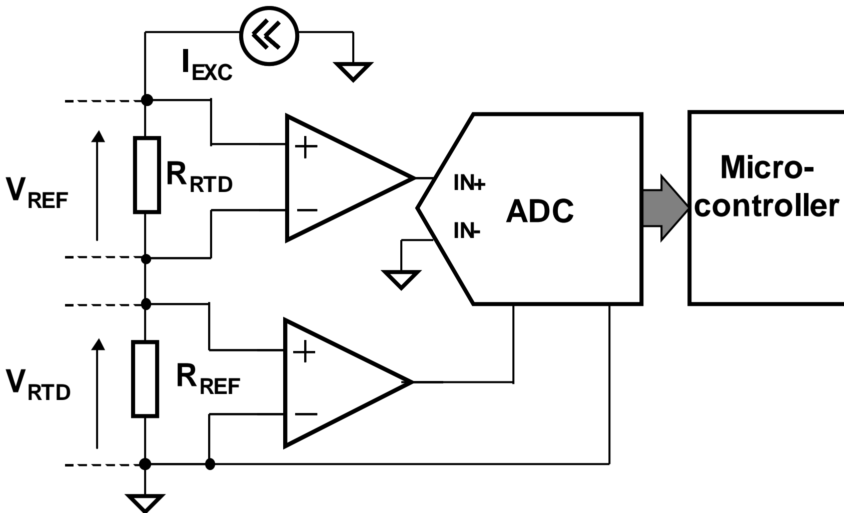


Fig.1. RTD ratiometric measurement.

of current and resistance create power and in turn the by-product of heat. The heat generated by the power dissipation of the element artificially increases the resistance of the RTD. The error contribution of the heat generated by the element's power dissipation is easily calculated given the package thermal resistance (R_{THp}), the magnitude of the current excitation (I) and the value of the RTD resistance R_{RTD}):

$$\Delta^0 C = I^2 R_{RTD} T_{THp} \quad . \tag{3}$$

The described advanced approaches of RTD measurement is considered to some extent by various sensor and analog microcontroller manufacturers such as Analog Devices, Texas Instruments, Maxim, Crystal etc [1, 4, 5, 7]. The drawbacks of explained in pointed references methods, however are the limited memory space of the microcontrollers and respectively limited computing capability. In addition the microcontrollers can't operate with coefficients (for fifth-order equation) represented by extended-precision floating-points digits (128 bits). Another drawback is the lack of detailed practical and theoretical guidance to achieve full-scale performance of the ADC for ratiometric configuration.

To solve these problems in next pages the authors proposed a calibration and linearization methods based on capability offered by concept of virtual instrumentation.

THE BENEFITS OF VIRTUAL INSTRUMENTATION

In last few yeas the concept of virtual instrumentation plays a critical role in a measurement and automation software framework. With this concept, the system developers design and integrate the system that takes measurements, controls processes, implements calibration and linearization routines, displays information to the end user or connects with other applications. In addition it is imperative that the virtual instruments provide high-level, intuitive development paradigms so that a wide variety of users can rapidly build measurement and control systems. They include comprehensive statistical and numerical analysis functions, as well as high-performance signal processing and control algorithms common in measurement applications including functions such logic control, noise reduction, spectral measurements, digital filtering, signal detection, numerical integration and differentiation, curve fitting, fractional-octave analysis, and order analysis.

It is well known that National Instruments LabVIEW is one of an industry-leading application development environment for designing and implementing virtual instruments and systems [8]. It provides an easy-to-use application development environment designed specifically for the needs of engineers and scientists. LabVIEW offers powerful features that make is easy to connect to a wide variety of hardware and other software.

One of the most powerful features that LabVIEW offers is its graphical programming environment.

With LabVIEW, it is easy to design custom virtual instruments by creating a graphical user interface on the computer screen through which the user can:

- Operate the instrumentation program;
- Control selected hardware;
- Reconfigure measurement node for acquiring various measurement data;
- Easy implement calibration and linearization techniques;
- Manipulate and analyze acquired data;
- Display and publish results.

Although LabVIEW provides the tools required for most applications, LabVIEW also is an open development environment. This mean that the developers can easy upgrade or create new applications without discontinue the working programs.

In order to put into practice the pointed LabVIEW advantages, a measurement system based on analog microcontroller was created. The system was developed so that the microcontroller converts the incoming signals into digital signals and sent it to the computer. The hardware device does not compute or calculates the final measurement. That task is left to the software that resides in the computer. The same devices can perform a multitude of measurements by simply changing the software application that is reading the data. So in addition to controlling, measuring and displaying the data the user application for an LabVIEW based microcontroller system also play the role of the firmware that would exist inside in special purpose measurement system.

As with LabVIEW, engineers interface with real-world signals, analyze data for meaningful information, and share results and applications, than the environment can be observed as be composed of three base parts. The first one is for data acquisition, second for data manipulation and analyzing, and the last one for data presentation and publishing. Following this division the developed application development environment for analog microcontrollers just like is divided in three parts:

- Downloader consisting of number of programs and functions that controls data acquisition;
- Library consisting of Virtual Instruments (VI) and subVI for data manipulation. Some of these VIs are build-in LabVIEW libraries of functions and some for their particularity are created additionally. LabVIEW has more than four hundred build-in function designing specifically for extracting useful information from set of acquired data. Examples include mathematics, frequency analyses, peak detection, curve fitting, statistics, and many more. It is obvious that developer after acquiring data from analog microcontroller as decimal (or hexadecimal) digits has a great number of opportunities to scale data as necessity. He can be involve calibration coefficients, make linearization by polynomial curve fitting, establish optimization procedures, etc.

- Number of top level VI for data representation, which encompasses data visualization, user interface design, web-publishing, report generation and data management. Because LabVIEW was designed specifically for engineers and scientists, the user can take advantage of measurement-specific interface design tools.

RTD CALIBRATION METHOD

The main advantage of suggested calibration method compare to described in reference [1] is that the resistors with precise known values are easier to obtain than temperature references consequently accuracy can be set to a higher level. Additionally if a 4-wire RTD is used the offset cancellation is not needed. Other benefit of presented method is the ability of use more efficiently the ADC's full scale. Creating virtual calibration module in LabVIEW considerable decrease the effort of calibration procedure as coefficients are obtained in one environment by software at once. The other great virtual instrumentation opportunity are build in mathematical and statistical function applied to achieve accurate measurement results by averaging and high-order linearization.
To illustrate the calibration method the temperature measuring module based on Analog Devices' ADuC834 Microconvertor is created. As temperature sensing element the Heraeus's Pt100 type W-SZK (O) is used – fig. 2. The performed calculations are shown in brackets.

The calibration procedure consists of following main topics:

- ADC full scale selection;
- ADC resistance resolution calculation;
- RTD measuring;
- RTD linearization and averaging.

ADC full scale selection is maintained as follows:

1. Obtaining the temperature range of interest (for example from –20 ^{0}C to +100 ^{0}C).
2. Calculating the minimal and maximal value of R_{RTD} for the temperature range (90Ω – 140Ω).
3. Choice of reference resistance R_{REF}. The value of R_{REF} must be as close as possible to the maximal value of R_{RTD} (R_{REF} = 2.5 kΩ - minimal possible according ADuC 834 data sheet).
4. Determining the amplification needed to cover full scale of ADC $A = \frac{R_{REF}}{R_{RTD\,max}}$ (A ≈ 17).
5. Calculating the maximum value of the measured voltage $V_{max} = \frac{V_{REF}}{A}$ (V_{max} = 147 mV) .

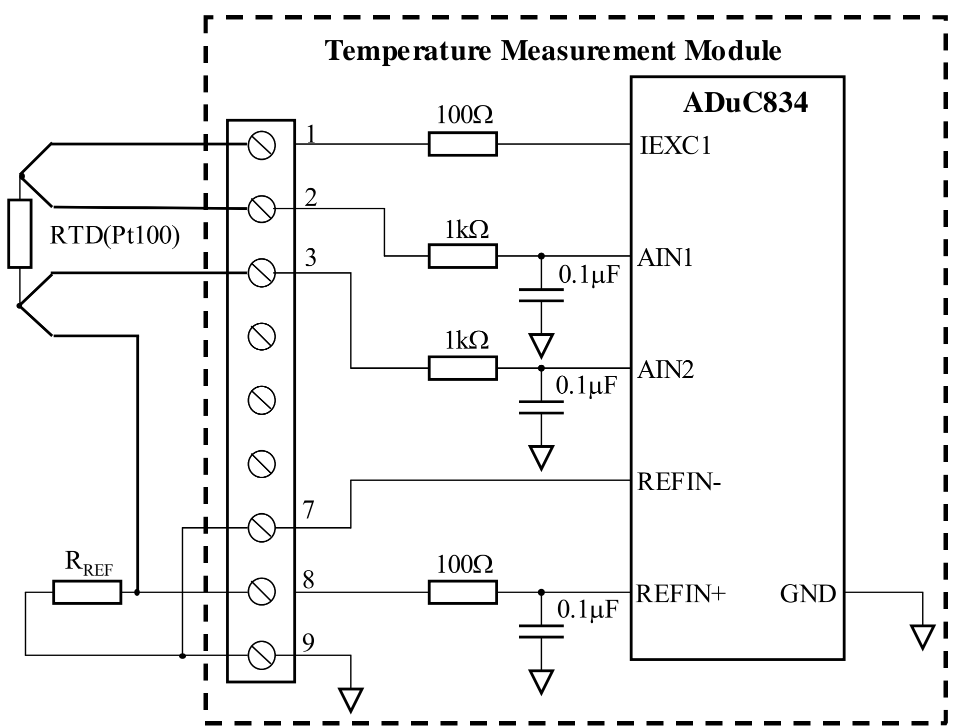


Fig.2. The experimental circuit for temperature measuring.

6. Choice of the possible signal conditioning scale of ADC according to the value of V_{max} (160mV according ADuC 834 data sheet).

ADC resistance resolution calculation is performs by replacing RTD with calibration resistors (fig. 2). Procedure sequences are:

1. Selection of the precise calibration resistors. To achieve more accuracy it is necessary to cover all ADC range. For this reason the value of the calibration resistors must be as close as possible to the minimal and maximal values of the R_{RTD} accordingly. (R_1 =85.38Ω, R_2=109.573Ω. The exact values are determined by HP3478 DMM)

2. Calculation of ADC resistance resolution LSB_R is accomplished by the equation:

$$LSB_R = \frac{R_2 - R_1}{D_2 - D_1}, \quad (4)$$

where D_2 and D_1 are digital codes produced by ADC for R_2 and R_1 accordingly ($LSB_R = 1.33198951 \times 10^{-6}\Omega$).

To facilitate the procedure the particular LabVIEW virtual instrument was created which front panel and block diagram are considered later.

RTD measuring. The value of the R_{RTD} corresponding to the measured temperature is obtained by simply multiplication of the digital code D to the previously calculated LSB_R –

$$R_{RTD}(T) = D(T).\ LSB_R. \quad (5)$$

RTD linearization and averaging. As is mentioned the linearization in LabVIEW environment can be achieved easily. The most precise direct mathematical method can be used [1] by simply fill in the transfer function in LabVIEW's formula node. Sinse for different standards (DIN43760, ITS-90, and American [2]) the Callendar-Van Dusen coefficients take a different values it is good idea to select the coefficients through the front panel.

LABVIEW VI FOR RTD CALIBRATION

The core of presented RTD calibration method is virtual instrument created by graphical programming language LabVIEW.

The user interface or so called in virtual instrumentation's terminology front panel of the application is shown in fig. 3. The interface that appears when the user executes the calibration procedure consists from three main parts.

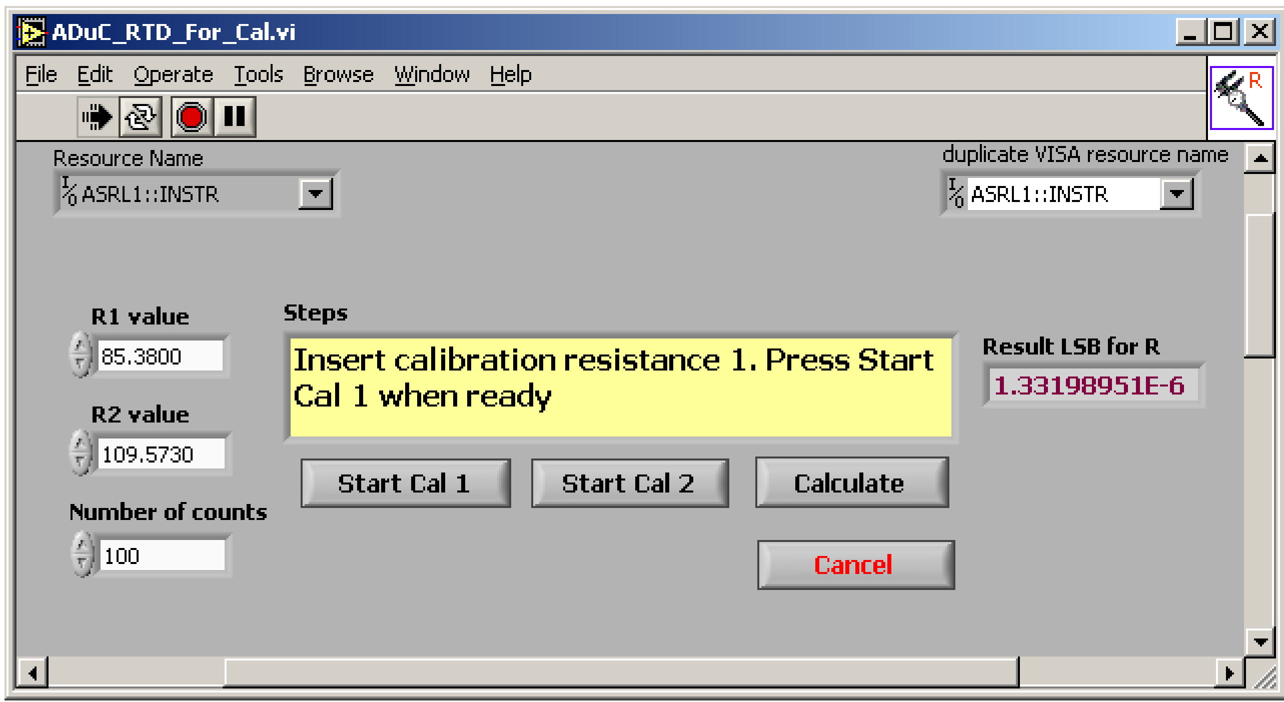


Fig.3. The front panel of the VI for RTD calibration.

The digital controls when the user must subscribe exact values of calibration resistors R1 and R2 are located in left part of the front panel. It is necessary to note that the value must be entered before starting the calibration. In the center as dialog box, a guidanse for manipulation that must be accomplished by the user is positioned. The result obtained after successive calibration appears in right part of the front panel.

The corresponding block diagram of the virtual instrument can be seen on fig. 4. The three state machines are used. First and second one are served for calibration resistors measurement. Last one

calculates the final result for ADC resistance resolution.

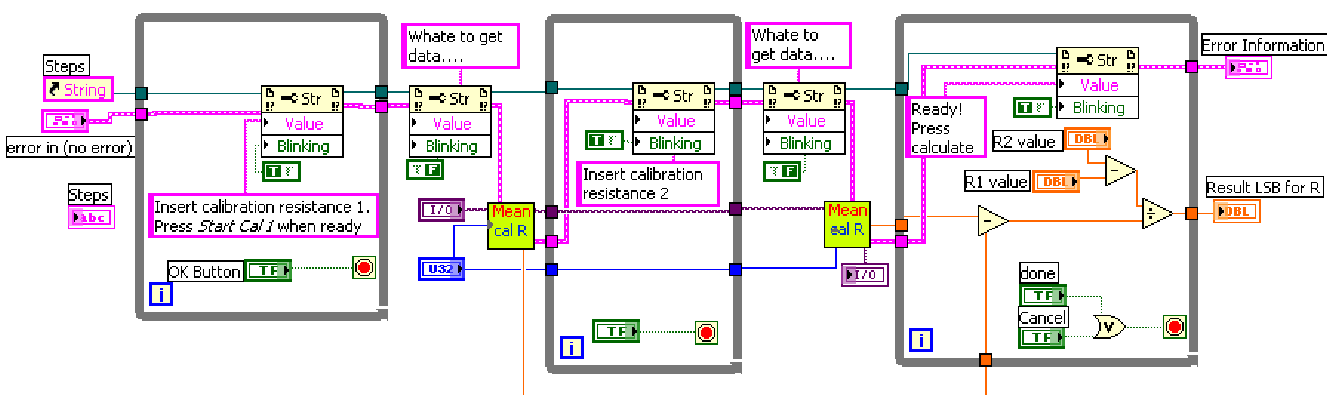


Fig.4. The block diagram of the VI for RTD calibration.

The described software application consists of three sub-Virtual Instruments (subVIs) witch hierarchy is shown in fig. 5. The brief description of each subVI is listed in table 1.

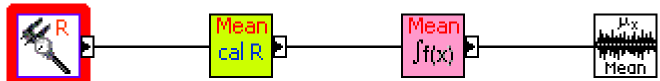
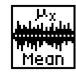


Fig.5. The hierarchy of the VI.

ADuC_RTD_For_Cal.vi
This VI can be used to calibrate ratiometric measurements. It take the mean results from ADC (in absolute digits) for two reference resistances and calculate the LSB for resistance in Ohms.

ADuC_RTD_Calib_Sub.vi
This subVI is used to return mean value of n ADC iteration in Absolute Digital value.

ADuC_RTD_R_Mean.vi
This subVI Read n-number of data and calculate mean. It is removed the null values.



Mean.vi
Computes the mean (average) (μ) of the values in the input sequence X. Build-in function.

Table 1.

CONCLUSION

In this paper the RTD calibration method is presented. The prposed method is established by analyzing the important considerations and error sources of a temperature measurement system. In order to accomplish calibration procedure it is necessary to integrate the temperature measurement node and application development environment in one software framework. In the present paper the appropriate graphical application development environment is explained. This virtual environment is based on Analog Devices' MicroConvertor ADuC834 and National Instruments' LabVIEW. As temperature detector for experimental work the Heraeus's Pt100 is used. The presented approach can be used also for other resistance type detectors if its maximal resistance is less than ten kiloohms. Finally the authors suggest how by applying conception of virtual instrumentation it is possible to easily implement a cost-effective, high-performance solution with unique features of an analog microcontrollers.

References

[1] King, G., Fukushima, T., „ RTD Interfacing and Linearization Using an ADuC8xx MicroConverter“, AN709, Analog Devices, 2004
[2] National Instruments "Measuring Temperature with an RTD or Thermistor", Application Note 046, 2003
[3] Anderson, R., „Understanding Ratiometric Conversions“, Texas Instruments, Data Acquisition Group, SBAA110 – March 2004
[4] Schreiber,R., " Integrating an RTD and an A/D Converter for Accurate Temperature Measurement",Sensors Express, JANUARY 2002
[5] Johnston, J., "Precision Temperature Measurement using RTDs with the CS5516 and CS5520 Bridge Transducer A/D Converters'; Crystal Semiconductor Corporation, AN28, 1996
[6] Loewenstein, E., B., "Reducing the Effects of Noise in a Data Acquisition System by Averaging", National Instruments, AN152, April 2000
[7] Bonnie Baker, B., „Temperature Sensing Technologies“, Microchip Technology, AN679, 1998
[8] National Instruments, "Measurement and Automation Catalog", 2005

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