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Digital Sensors and Sensor Systems: Practical Design

Sergey Y. Yurish



The goal of this book is to help the practicians achieve the best metrological and technical performances of digital sensors and sensor systems at low cost, and significantly to reduce time-to-market. It should be also useful for students, lectures and professors to provide a solid background of the novel concepts and design approach.

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Digital Sensors and Sensor Systems: Practical Design will greatly benefit undergraduate and at PhD students, engineers, scientists and researchers in both industry and academia. It is especially suited as a reference guide for practicians, working for Original Equipment Manufacturers (OEM) electronics market (electronics/hardware), sensor industry, and using commercial-off-the-shelf components

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Conference Announcement



Topic E2: Transportation & Mobility

The Euromat conference series, organised by the Federation of European Materials Societies (FEMS), is one of the largest events of its kind in Europe, covering the full width of materials science and technology. We would like to direct your attention to the following Symposia which are focussing specifically on transport applications:

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E2.III: **Energy absorbing and protective materials and structures**
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Temperature Measurement and Control Based on LabVIEW and SMS

D. Mercy, Ashok M., Karthick N., Rajamanickam M.

Department of Electronics and Instrumentation Engineering, M.A.M College of Engineering, Siruganur, Tiruchirappalli-621105, TamilNadu, India
Tel.: +91 9842270067
E-mail: mercyprabhu06@gmail.com

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Abstract: Remote applications are becoming widely used in various fields such as industry, education and security. This paper presents a low cost system to monitor and control the temperature remotely by Short Message Service (SMS). The system has been designed using LabVIEW. In this process there is no need of manual operation, the temperature can be controlled automatically from anywhere using Bluetooth mobile phones. The system was successfully tested locally and remotely in a temperature measurement procedure. *Copyright © 2012 IFSA.*

Keywords: LabVIEW, SMS, Bluetooth.

1. Introduction

The advancement of remote monitoring and control systems in recent years is closely related to the outstanding advance in electronics and instrumentation techniques. In every distinct area it is possible to evince different advantages and applications when using remote systems. To exemplify the industrial field, a remote data acquisition may be used to monitor and control the temperature where it is difficult to access or to use wired data acquisition systems. Addressing now the main focus of this project, the Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is a graphical programming environment from National Instruments that deserves attention not only on remote systems, but in a wide range of applications.

In this project Temperature is monitor and controlled using Virtual Instrumentation. Virtual Instrumentation is the combination of Data acquisition hardware and LabVIEW software. The DAQ hardware used here is the universal DAQ and the LabVIEW software is installed in the PC. The DAQ hardware is connected to the PC through Universal Serial Bus. First the temperature is measured using thermocouple and it is connected to the DAQ. The DAQ hardware consists of Analog to Digital converter and the analog input acquire is converted to a digital form that is compatible with PC. In PC LabVIEW based temperature monitoring coding is performed. By using the Front Panel of the LabVIEW temperature can be monitored & based on the set points temperature can be controlled [1].

2. Block Diagram

The block diagram describes the working of complete temperature process (Fig. 1). First the temperature is measured using thermocouple and it is connected to the DAQ. The DAQ hardware consists of Analog to Digital converter and the analog input temperature is converted to a digital form that is compatible with PC. In PC LabVIEW software is installed and in the LabVIEW block diagram temperature monitor coding is performed. By using the Front Panel of the LabVIEW temperature can be monitored and controlled based on the coding. The set point is set in the front panel when the temperature reaches the set point "SET POINT REACHED" command is send as a SMS to the mobile phone or PC using Bluetooth [5]. When the set point reaches the desire level the temperature process will be stopped.

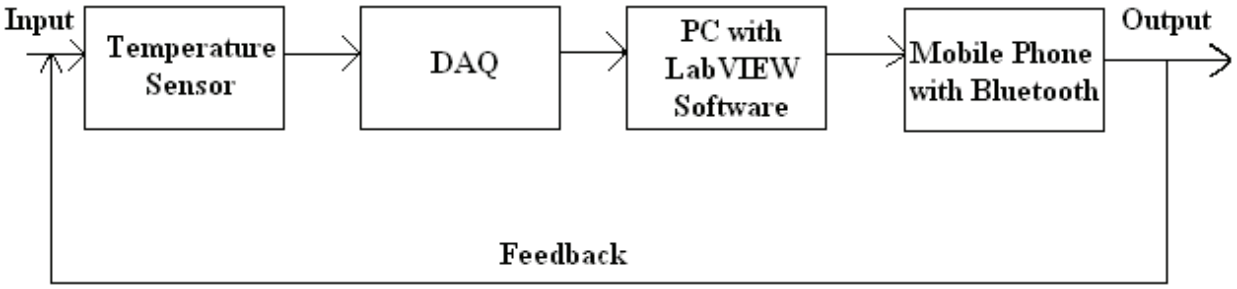


Fig. 1. Block Diagram.

3. Hardware Description

3.1. Temperature Sensor

Thermocouples are the most popular temperature sensors. A thermocouple is a device consisting of two different conductors (usually metal alloys) that produce a voltage, proportional to a temperature difference, between either end of the two conductors. Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert a temperature gradient into electricity. They are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external form of excitation. The main limitation with thermocouples is accuracy and system errors of less than one degree Celsius (C) can be difficult to achieve. Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage [2].

Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are among the easiest temperature sensors to use and obtain and are widely used in science and industry. They are based on the Seeback Effect or Thermoelectric Effect that occurs in electrical conductors that experience a temperature gradient along their length. They are simple, rugged; need no batteries, measure over very wide temperature ranges and more. Thermocouples are available in different combinations of metals or calibrations.

3.1.1. Thermocouple Types

Thermocouples are available in different combinations of metals or calibrations. The four most common calibrations are J, K, T and E. Each calibration has a different temperature range and environment, although the maximum temperature varies with the diameter of the wire used in the thermocouple. Some of the thermocouple types have standardized with calibration tables, color codes and assigned letter-designations [2].

There are four "classes" of thermocouples:
- The home body class (called base metal);
- The upper crust class (called rare metal or precious metal);
- The rarified class (refractory metals);
- The exotic class (standards and developmental devices).

The home bodies are the Types E, J, K, N and T. The upper crust is types B, S, and R, platinum all to varying percentages. The exotic class includes several tungsten alloy thermocouples usually designated as Type W. In this project, we use J-Type thermocouple as temperature sensor (Fig. 2). Type J (iron–constantan) has a more restricted range than type K (−40 to +750 °C), but higher sensitivity of about 55 μV/°C. The Curie point of the iron (770 °C) causes an abrupt change in the characteristic, which determines the upper temperature limit [2].

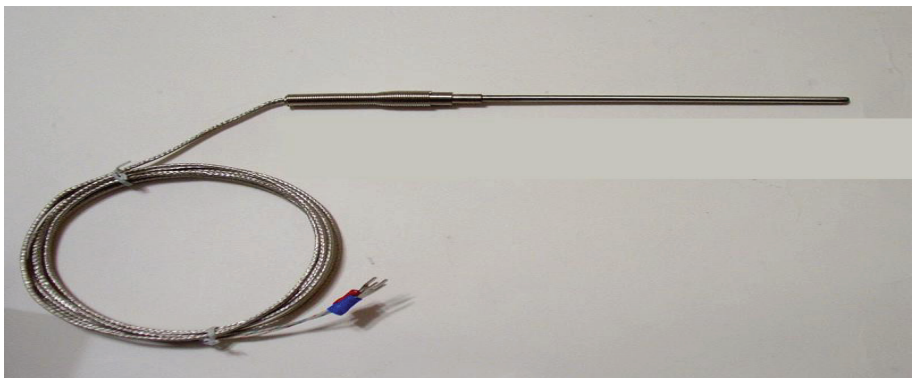


Fig. 2. J-Type thermocouple.

3.1.2. Principle of Working

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice-versa. A thermoelectric device creates a voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated; hence inducing a thermal

current. This effect can be used to generate electricity, measure temperature or change the temperature of objects. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices are efficient temperature controllers.

The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect and Thomson effect. Textbooks may refer to it as the Peltier–Seebeck effect. This separation derives from the independent discoveries of French physicist Jean Charles Athanase Peltier and Estonian-German physicist Thomas Johann Seebeck. Joule heating, the heat that is generated whenever a voltage is applied across a resistive material, is related though it is not generally termed a thermoelectric effect. The Peltier–Seebeck and Thomson effects are thermodynamically reversible, whereas Joule heating is not.

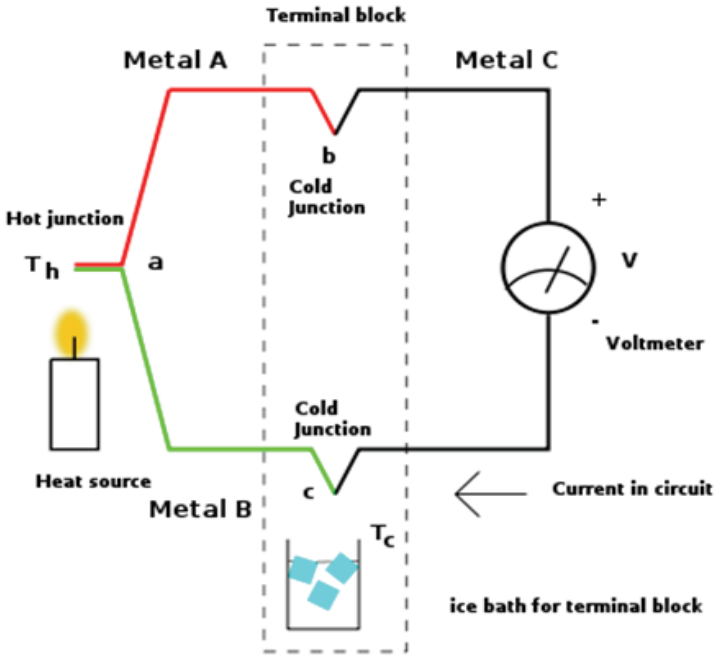


Fig. 3. Thermocouple measuring circuit.

The working principle of thermocouple is based on three effects, discovered by Seebeck, Peltier and Thomson.

Seebeck effect: The Seebeck effect states that when two different or unlike metals are joined together at two junctions, an electromotive force (emf) is generated at the two junctions. The amount of emf generated is different for different combinations of the metals (Figure 4).

The Seebeck effect is the conversion of temperature differences directly into electricity and is named for German physicist Thomas Johann Seebeck, who, in 1821 discovered that a compass needle would be deflected by a closed loop formed by two metals joined in two places, with a temperature difference between the junctions. This was because the metals responded differently to the temperature difference, creating a current loop and a magnetic field. Seebeck did not recognize there was an electric current involved, so he called the phenomenon the thermomagnetic effect. Danish physicist Hans Christian rectified the mistake and coined the term "thermoelectricity". The voltage created by this effect is of the order of several microvolts per Kelvin difference. One such combination, copper-constantan, has a Seebeck coefficient of 41 microvolts per Kelvin at room temperature [2].

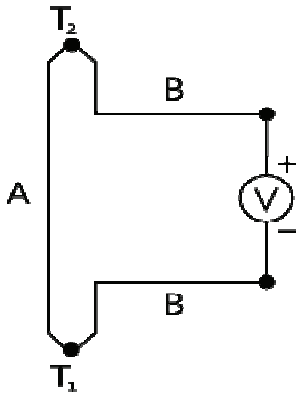


Fig. 4. Seebeck Effect.

The voltage V developed can be derived from:

$$V = \int_{T_1}^{T_2} \left(S_B(T) - S_A(T)\right) dT,$$

Where S_A and S_B are the thermopowers (Seebeck coefficient) of metals A and B as a function of temperature and T_1 and T_2 are the temperatures of the two junctions. The Seebeck coefficients are non-linear as a function of temperature, and depend on the conductors' absolute temperature, material, and molecular structure. If the Seebeck coefficients are effectively constant for the measured temperature range, the above formula can be approximated as:

$$V = \left(S_B - S_A\right) \cdot \left(T_2 - T_1\right)$$

The Seebeck effect is used in the thermocouple to measure a temperature difference; absolute temperature may be found by setting one end to a known temperature. A metal of unknown composition can be classified by its thermoelectric effect if a metallic probe of known composition, kept at a constant temperature, is held in contact with it. Industrial quality control instruments use this as thermoelectric alloy sorting to identify metal alloys. Thermocouples in series form a thermopile, sometimes constructed in order to increase the output voltage, since the voltage induced over each individual couple is small. Thermoelectric generators are used for creating power from heat differentials and exploit this effect [2]. Based on the Seebeck effect the water bath temperature is measured & it is given to the DAQ.

3.1.3. Thermocouple Applications

Thermocouples are suitable for measuring over a large temperature range, up to 2300 °C. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0–100 °C with 0.1 °C accuracy. For such applications thermistors, silicon band gap temperature sensors and resistance temperature detectors are more suitable. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. The Seebeck effect is used in the thermoelectric generator, which functions like a heat engine, but is less bulky, has no moving parts, and is typically more expensive and less efficient. These have a use in power plants for converting waste heat into additional power (a form of energy recycling), and in automobiles as automotive thermoelectric generators (ATGs) for increasing fuel

efficiency. Space probes often use radioisotope thermoelectric generators with the same mechanism but using radioisotopes to generate the required heat difference [2].

3.2. DAQ Hardware

A data acquisition system is devices designed to measure and log some parameters. The purpose of the data acquisition system is generally the analysis of the logged data and the improvement of the object of measurements. The data acquisition system is normally electronics based, and it is made of hardware and software. The hardware part is made of sensors, cables and electronics components. The software part is made of the data acquisition logic and the analysis software. An example: Data logging, carried out by a data acquisition system (DAS), can be used to measure parameters such as temperature and humidity in storage facilities with perishable products; the measurement data is then stored for analysis to improve quality assurance.

A data acquisition system (DAQ) is a collection of sensors and communication links to sample or collect and then return data to a central location for further processing, display, or archiving. Data acquisition is the process of extracting, transforming, and transporting data from the source systems and external data sources to the host processing system to be displayed, analyzed, and stored. A data acquisition system (DAQ) typically consist of transducers for asserting and measuring electrical signals, signal conditioning logic to perform amplification, isolation, and filtering, and other hardware for receiving analog signals and providing them to a processing system, such as a personal computer. A data acquisition system may be used to obtain, and possibly record, information about an environment. Information obtained from the environment by the data acquisition system may be used to adjust a system operating in or controlling that environment. Digital data processing systems are employed in many applications, including a variety of laboratory process control, real time data analysis, and real time data reduction operations, process monitoring and control, data logging, analytical chemistry, tests and analysis of physical phenomena, and control of mechanical or electrical machinery. Data recorders are used in a wide variety of applications for imprinting various types of forms, and documents. Data collection systems or data loggers generally include memory chips or strip charts for electronic recording, probes or sensors which measure product environmental parameters and are connected to the data logger. Hand-held portable data collection systems permit in field data collection for up-to-date information processing [1, 2].

A data acquisition system (DAQ) is a combination of computer hardware and software that gathers, stores or processes data in order to control or monitor some sort of physical process. A typical data acquisition system comprises a computer system with DAQ hardware, wherein the DAQ hardware is typically plugged into one of the I/O slots of the computer system. The DAQ hardware is configured and controlled by DAQ software executing on the computer system. A data acquisition system mostly includes transducers, sensors, amplifiers and other means for provision of the signal representation by their measurement and/or monitoring. These components provide field electrical signals representing a process, physical phenomena, equipment being monitored or measured, etc. The transducers or other detecting means convert the physical phenomena being measured into electrical signals, such as voltage or current, measurable by the DAQ hardware. A data collection system for providing a controller with data typically comprises a sensor, including a sensing element and an electronic circuit for converting the output of the sensing element into electric signal, and a readout device for analyzing the output of the electronic circuit of the sensor. In data acquisition systems, information about a plurality of parameters is often obtained by simultaneously deploying numerous sensors. Data acquisition involves interfacing an analog sensor with a recording or display device to measure and record some value of interest over a period of time. A signal generated by the one or more sensors may need to be amplified and/or filtered by the data acquisition system for proper operation. Sensors are

commercially available which can produce environmental information in the form of an electrical or optical signal about the local area in which the sensor is situated.

The advent of the information age has been made possible by computer technology. Information processing and handling had been performed by hand on paper. Computers provide an effective and efficient way for humans to manage, locate, peruse and manipulate data or objects. A personal computer may be configured by software programs and by plug-in peripheral equipment to perform a wide variety of special purpose tasks, including data reduction or computation, data acquisition and control. In the particular area of data acquisition, peripheral devices for performing measurements of physical phenomena and converting such measurements to digital signals conventionally are attached to a personal computer through an expansion bus. Messages are transmitted through the expansion bus to issue commands to instruments and to receive data back in return. Computer systems have been indispensable in reducing the amount of menial labor surrounding data acquisition and record keeping. Computer systems can maintain large databases associated with a particular organizations operation. Typical commercially-available data acquisition systems sample the voltage signal from a sensor in discrete time interval. Generally, this analog voltage must be converted to a digital signal that the computer can process and store. This analog-to-digital conversion is typically done with specialized data acquisition hardware and software which must be installed in a user's computer.

All data acquisition systems generally operate in a similar fashion. They receive an external input from some type of sensing device, condition and/or convert the input to a format suitable for transmission, and transmit it a computer. In data acquisition systems, it is necessary to convert one or several analog signals into one or several digital signals capable of being stored in a digital memory and processed by a digital processor. Analog signals must be digitized before they can be used by a computer as a basis for supporting computations. An analog to digital converter is an electrical device that converts an analog signal to a digital signal. When the analog signal has been converted to a digital signal it can be processed and stored by computer systems. An analog to digital converter is often fabricated on a single integrated circuit. Data acquisition systems for generating digital data for the purposes of computation may receive analog input signals from a plurality of sensors. There are numerous applications where digital data from analog to digital converters is gathered, stored, and analyzed. Data and information are constantly being transferred from one location to another.

DAQ act as an interfacing between thermocouple and PC. In thermocouple two leads are there. One is positive lead and another lead is negative lead. Both that positive and negative leads are connected to channel-0 at port number 4, 5 in DAQ. The data acquisition hardware is connected to pc through USB port. The NI cDAQ-9174 is a four-slot NI Compact DAQ chassis designed for small, portable, mixed-measurement test systems. Combine the cDAQ-9174with up to four NI C Series I/O modules for a custom analog input, analog output, digital I/O, and counter/timer measurement system [1, 2].

3.3. Bluetooth Connectivity

Bluetooth is a connectivity device used to transfer the data from one device to another. We can transfer images, audio, files etc., Main goal of our work was to learn things around Bluetooth and to learn to work with Bluetooth application. In our day to day life we are widely make use of Bluetooth device. Bluetooth technology was designed primarily to support simple wireless networking of personal consumer devices and peripherals, including cell phones, PDAs, note books, PCs, printers and wireless headsets. Wireless signals transmitted with Bluetooth cover short distances, typically up to 30 feet (10 meters). Bluetooth devices generally communicate at less than 1 Mbps. Here we use Bluetooth as a main device for both server and client. The PC act as a server and mobile phone as a client. To transfer the data from PC to mobile both the devices should be in pair [5]. For that we have to know the Bluetooth address of the both devices.

For PC:

Bluetooth name : ASHOK-PC

Bluetooth address:90:4c:e5:d1:82:ab

For mobile:

Bluetooth name: Nokia5233

Bluetooth address:10:f9:ee:9d:04:19

4. Software Details

4.1. LabVIEW

Virtual instrumentation is defined as combining hardware and software with industry-standard computer technologies to create user-defined instrumentation solutions. Virtual Instrumentation is the use of customizable software and modular measurement hardware to create user-defined measurement systems, called virtual instruments. A computer-based instrument using digital data acquisition or generation combined with software algorithms to create the functionality of an instrument. LabVIEW is a Laboratory Virtual Instrument Engineering Workbench and is a development environment based on graphical programming. A LabVIEW virtual instrument (VI) roughly equivalent to a subroutine. A VI has both a diagram (and program) and a front panel (user interface). LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications. In contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution [2, 3].

LabVIEW is an integral part of virtual instrumentation because it provides an easy-to-use application development environment designed specifically for engineers and scientists. LabVIEW offers powerful features that make is easy to connect to a wide variety of hardware and other software. This ease of use and these features deliver the required flexibility for a virtual instrumentation software development environment. The result is a user-defined interface and user-defined application functionality. One of the most powerful features that LabVIEW offers is its graphical programming paradigm [2, 3].

LabVIEW is programmed with set of icons that represents controls and functions, available in the menu of the software. The user interface which is called a VI consists of two parts- a front panel and a block diagram. This is similar to that of an instrument where a front panel is used for an input, output controls, and to display the data whereas the circuit resides on the circuit board. Similarly you can bring the buttons, indicators and graphing and display functions on the front panel. Here we use LabVIEW 2009 software [2, 3].

One benefit of LabVIEW over other development environments is the extensive support for accessing instrumentation hardware. Drivers and abstraction layers for many different types of instruments and buses are included or are available for inclusion. These present themselves as graphical nodes. The abstraction layers offer standard software interfaces to communicate with hardware devices. The provided driver interfaces save program development time. The sales pitch of National Instruments is, therefore, that even people with limited coding experience can write programs and deploy test solutions in a reduced time frame when compared to more conventional or competing systems.

5. Results and Discussion

The LabVIEW coding is performed for measuring the temperature using block diagram window and the measured temperature is monitored using the front panel window. The block diagram and front panel are shown in Fig. 5 and Fig. 6 respectively.

5.1. Block Diagram

Block diagram contains the graphical source code that defines the functionality of the VI Block diagram is build using the graphical programming language. Nodes are objects on the block diagram that have inputs and/or outputs and perform operations when a VI runs. They are analogous to statements, operators, functions, and subroutines in text-based programming languages. The block diagram of temperature process is shown in Fig. 5.

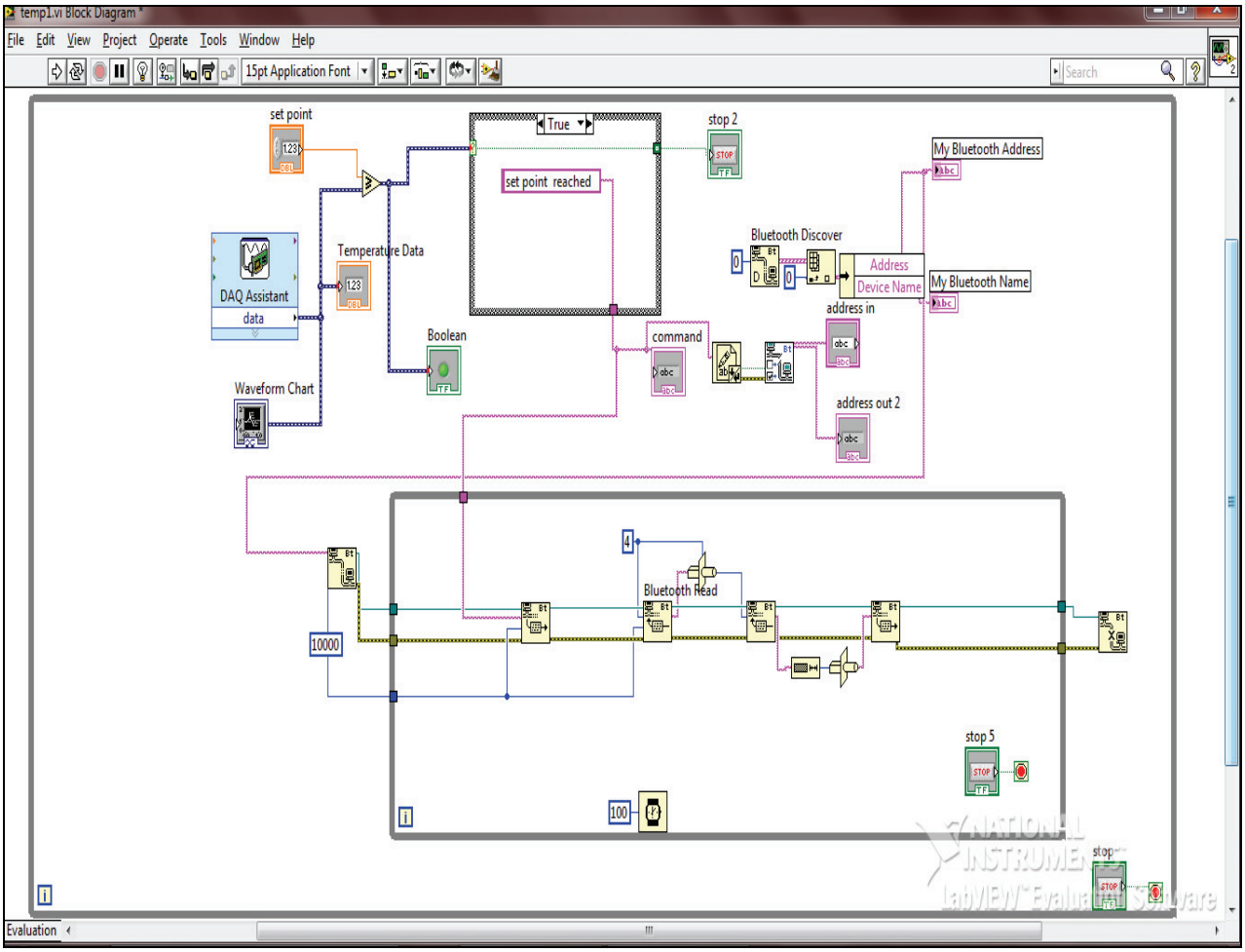


Fig. 5. Block Diagram Window.

5.2. Front Panel

The front panel is the user interface of a VI. Generally, the front panel is designed first, and then the block diagram is designed to perform tasks on the inputs and outputs. It is used to set the input value and viewing the output from the Virtual Instrumentation block diagram. The front panel is built with controls and indicators, which are the interactive input and output terminals of the VI, respectively.

Inputs are called controls and the outputs are called indicators. Controls are knobs, push buttons, dials, and other input devices. Indicators are graphs, LEDs, and other displays. Controls simulate instrument input devices and supply data to the block diagram of the VI. Indicators simulate instrument output devices and display data the block diagram acquires or generates. The front panel of temperature process is shown in Fig. 6.

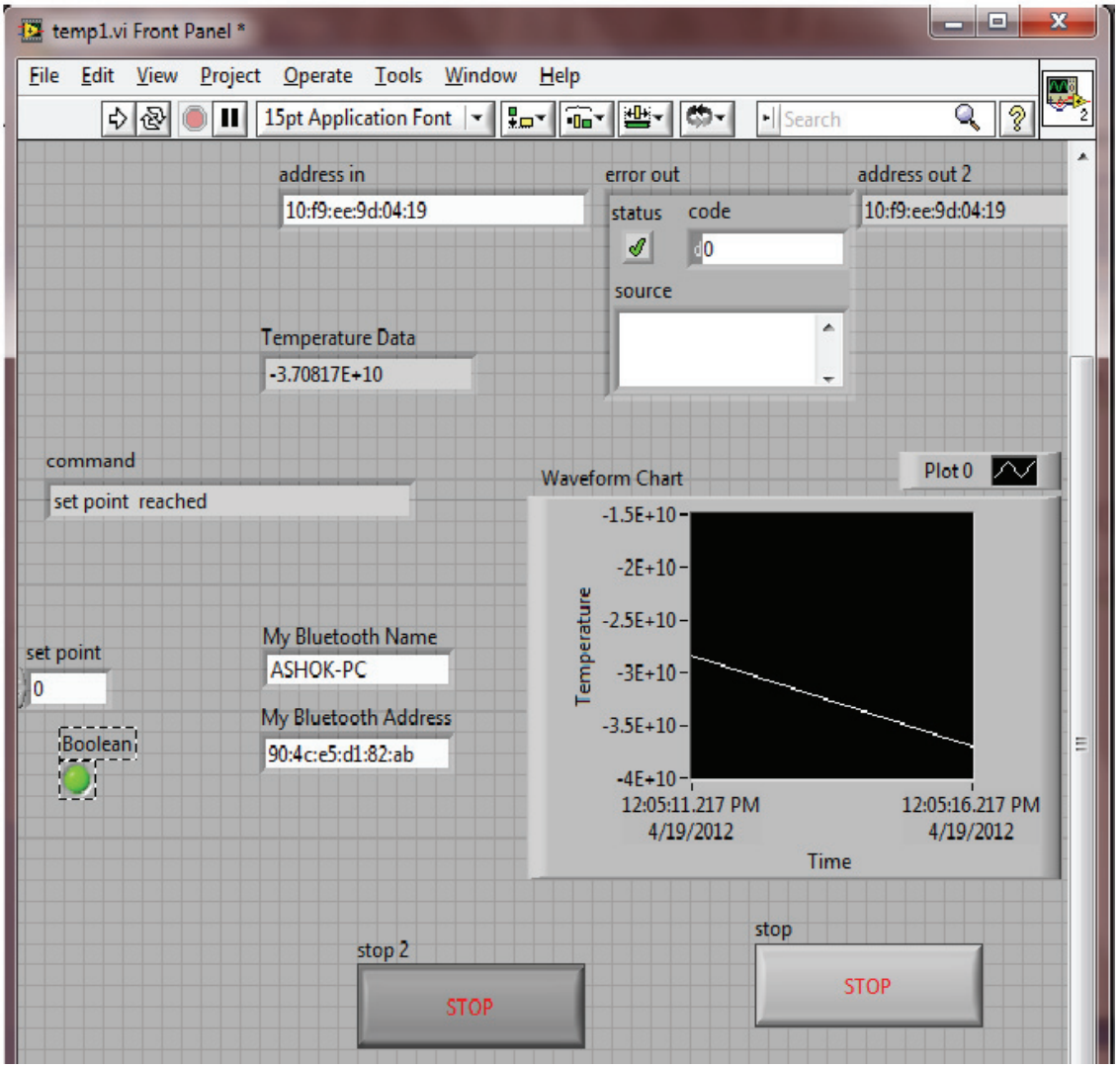


Fig. 6. Front Panel Window.

5.3. Discussion

J-type thermocouple is inserted into the water bath. The two leads of thermocouple are connected to the DAQ hardware at 4&5 port of DAQ channel-0. By heating the water the temperature is raised. The thermocouple is placed inside the water bath when the water gets heated and the temperature value of the water is sensed by the thermocouple. Among the various types of DAQ hardware we are using is NI cDAQ-9174. It has four slots, where 3 slots act as an input and output slots and the remaining one acts as a processor. Each slot having 4 channels a0, a1, a2, a3 and each channel has 6 ports. The thermocouple leads are connected to the I/O slot in a0 channel. The positive lead is connected to the port number 4 and the negative lead is connected to the port number 5. The DAQ card is interfaced with PC using USB port. so that the temperature value is send to LabVIEW by means of DAQ hardware.

PC with LabVIEW software receives the temperature value through DAQ assistant. In the block diagram window of the LabVIEW temperature measuring coding is performed. In PC DAQ assistant collects the data from the hardware and waveform chart in the front panel displays the temperature data. The set point is manually set in the front panel and in the block diagram comparator is used to compare the actual temperature and the set point. The data from the comparator is given to the case structure where two conditions will be performed that is "TRUE" or "FLASE". When the condition is true "SET POINT IS REACHED" command and the condition is false "SET POINT NOT REACHED" commands are displayed in the front panel. This command is also send as a SMS to the mobile phone or PC through the Bluetooth connectivity using LabVIEW. This data is sent with the use of Bluetooth commands like Bluetooth discover which detects the Bluetooth devices. Then the Bluetooth read records the data which has been to send and Bluetooth write will send the data to the mobile phones. When the condition is true the temperature process will be stopped automatically.

6. Conclusion

Here we conclude our real time process "Temperature Measurement Based on LabVIEW and SMS" which replaces the manual operation of controlling the temperature. The main advantage of our project is there is no need of human near the temperature system to control the temperature. We are using LabVIEW software, Data Acquisition hardware and J-type thermocouple to measure and control the temperature value. The block diagram and front panel diagram in the LabVIEW used to simulate and execute the program. The temperature of the water is taken and compared with set point which we given manually inside the front panel diagram. Likewise the waveform will vary according to the increase or decrease of the temperature. If the temperature exceeds the set point then the command "SET POINT IS REACHED" is received to the PC through Bluetooth. If the temperature is below the set point then the command "SET POINT NOT REACHED" is received to the PC. Then by interface the PC Bluetooth device with the mobile Bluetooth device through Bluetooth address we can send the report or command from PC to mobile phone which is placed near the Bluetooth discoverable area. This project can be extended for various types of measurements and control of pressure, level, humidity etc.

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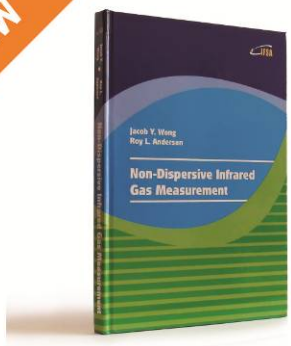
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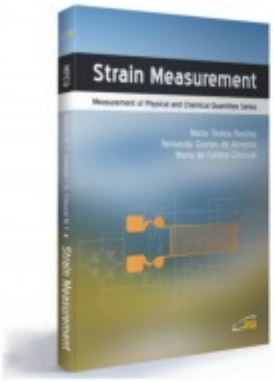
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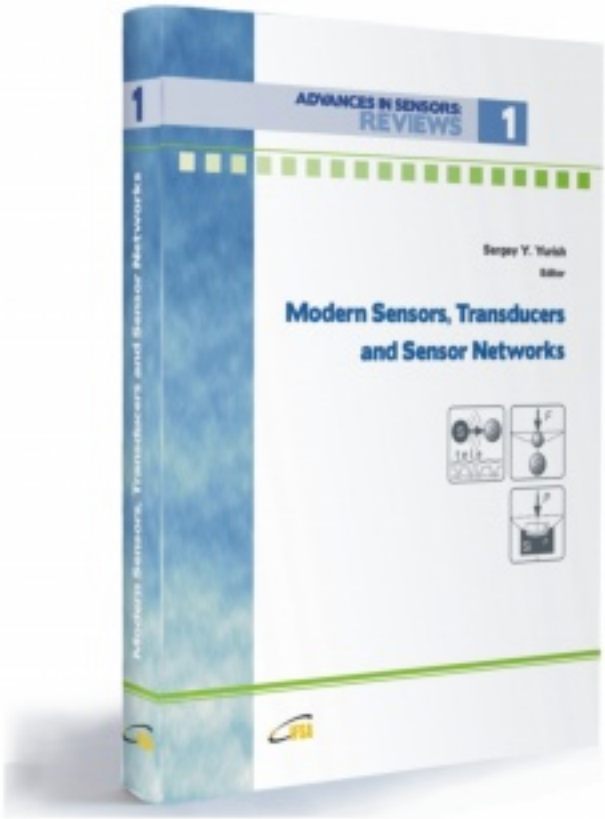
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