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Contents

Volume 87
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Editorial

Research Articles

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A Modified Design of a Thermocouple Based Digital Temperature Indicator with Opto-isolation

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Abstract: In the conventional thermocouple based digital temperature indicator the millivolt signal obtained from a thermocouple is first amplified and then converted into a digital signal by using analog-to-digital converter (ADC). This digital signal is then indicated as digital display of temperature using digital counter circuit or microprocessor/microcontroller based circuitry. In the present paper a modified AD conversion technique along with opto-isolation is used to indicate digitally the temperature without using any conventional analog-to-digital converter. The theory and design of the measuring technique are described in the paper. The non-linearity of thermocouple is eliminated by using look-up table within software program. The performance of the circuit has been experimentally tested by using mV input signal instead of a thermocouple as well as using a K-type thermocouple. The experimental results are reported in the paper. *Copyright © 2008 IFSA.*

Keywords: Opto-isolation, Temperature measurement, Thermocouple, LED, LDR.

1. Introduction

Accurate measurement of temperature [1] is an essential need in any process industry as well as in any other physical or biological process. There are many well accepted techniques[1,2] of temperature measurement such as mechanical technique like mercury in glass thermometer, mercury in metal thermometer etc, electrical technique like RTD, thermocouple etc, thermal radiation technique like radiation pyrometer, optical pyrometer etc. In thermocouple type temperature measurement the mV signal produced in the thermocouple is a non-linear function of the temperature difference between hot and cold junction temperature. In industrial application the cold junction is kept at room temperature, so the effect of variation of room temperature is eliminated by cold junction compensation (CJC) technique and the cost of the long cable between the sensor and the indicator in the control room by using compensated cable. In head mounted temperature measurement technique the cold junction is maintained at a constant temperature enclosure in the head mounted assembly and the usual copper cable is used instead of costlier compensating cable.

Different types of modifications on temperature measurement and control system are still being reported by various workers. Brokaw, A.P. [3] described a monolithic signal conditioner for direct thermocouple input which provides gain, common-mode signal rejection, and cold-junction compensation. Pereira, J. M. D et. al. [4] proposed a linearization technique based on a pulse width modulated analog-to-digital converter by varying the duty cycle of the PWM signal. K. Danisman et. al. [5] described an experimental method for the estimation of nonlinearity, testing and calibration of the different thermocouple types using artificial neural network based algorithms integrated in a virtual instrument. A new method for the reference junction temperature compensation of K type thermocouple based thermometer by using a PTC silicon resistive sensor KTY 10 is described by Zlatanovic M. et. al. [6]. Hadley I.C.D. et. al. [7] constructed an inexpensive digital thermometer for measurements on semiconductors using K type thermocouple. Sundarsingh V.P. [8] proposed a modified architecture for the non-linear analog-to-digital conversion of a transducer output by making use of a dual-slope A/D converter with variable clock frequency. Duncan M.G. [9] developed an instrumentation system to isolate part thermocouples from ground by up to 10.6 KV during ion plating with fiber optic link as signal isolator. Pereira J. M. D et. al. [10] proposed a solution to overcome the problem of temperature drift errors of conditioning circuits considering a thermocouple-based temperature measurement system.

In the present paper a modified head mounted temperature measurement system using thermocouple along with opto-isolation has been proposed. In this technique the thermocouple is connected to the terminals, mounted on the ceramic base in the head of the thermo-well. This head consists of two signal conditioners for thermocouple and head temperature sensing element of the enclosed chamber of the thermo-well head. The outputs of both the signal conditioner circuits are 4-20mA current signals, which are transmitted through copper cable to the receiver circuit placed in the control room. This current signal is converted into frequency signal by using opto-isolator circuit and astable multivibrator. Frequency or pulse width of the output of the astable multivibrator is non-linearly related with the current signal and hence temperature of the hot junction of the thermocouple. This pulse width is measured by a microcontroller based software program to display the value of process temperature. The non-linearity is eliminated by using look-up table technique. The experimental results for mV input signal as well as thermocouple input are reported in the paper.

2. Method of Approach

The proposed system consists of a thermocouple and its associated signal conditioning circuit as well as a thermocouple head temperature sensing signal conditioning circuit. The temperature of the enclosed chamber of the thermocouple head is sensed by IC temperature sensor IC AD590. Both the signal conditioning circuits convert the thermocouple output and head temperature sensor output into 4-20mA signals. At the receiving end each of these current signals is passed through a resistor R of value 250 Ω, 1/2Watt, 1% resistor in order to obtain 1-5V signal at the input of the buffer OPAMPs A_1 and A_2 as shown in Fig. 1. Each of this voltage drives an LED through current limiting resistor (R_1 or R_2).

In Fig. 1 the intensity of light emitted from light emitting diode (LED) depends on the input voltage (1-5V) across the 250 Ω resistor. The light emitted from LED falls on the working surface of a light dependent resistor (LDR). The LED and LDR unit shown in Fig. 1 placed in a closed enclosure with inside coated with black so that the light emitted from LED is only incident on LDR and no external light can interfere the LED light signal. So the resistance of LDR will depend on the input current signal. This resistance is again the part of R-C network of the astable multivibrator. So frequency of the astable multivibrator and hence its pulse width depends on the input current. Thus the technique also isolates the thermocouple circuit from the receiver circuit. This maintains the safety of the display unit from any surge voltage from the thermocouple circuit since the thermocouple may be mounted in an electric heater operated furnace. Thus safety design of a PC based temperature may be possible. The software program of the microcontroller is designed according to the flow chart as shown in Fig. 2.

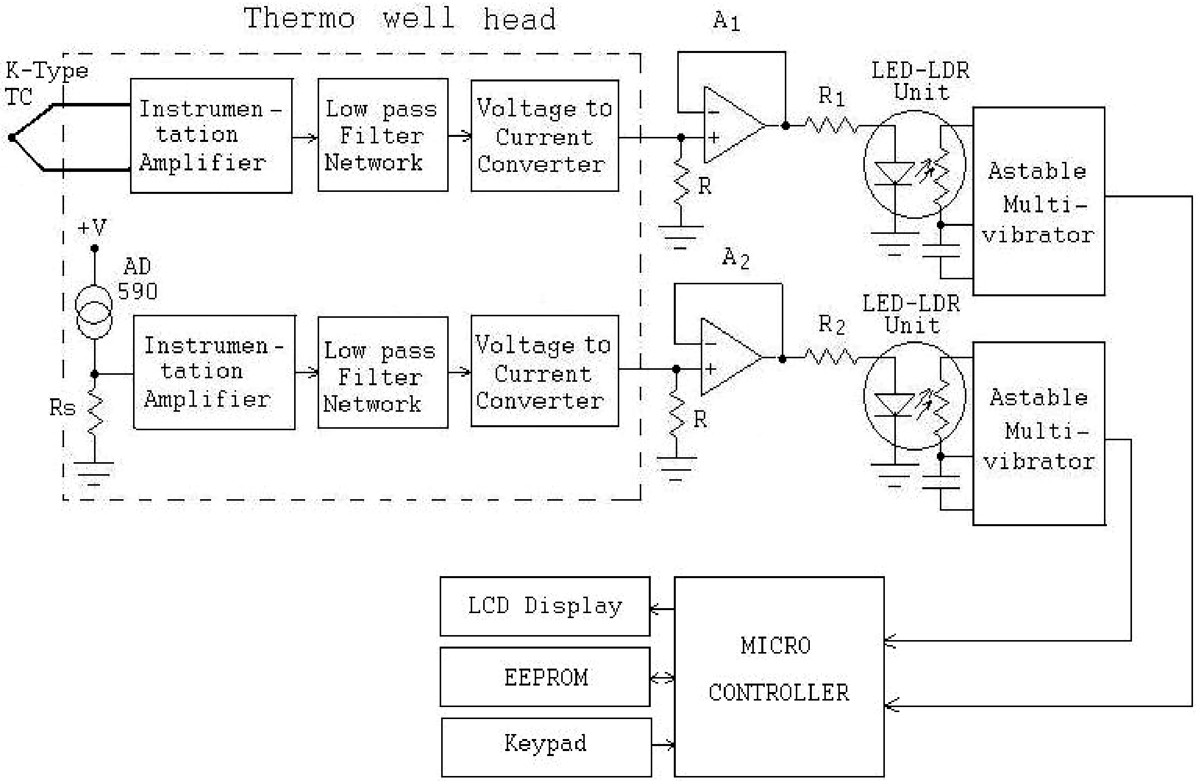
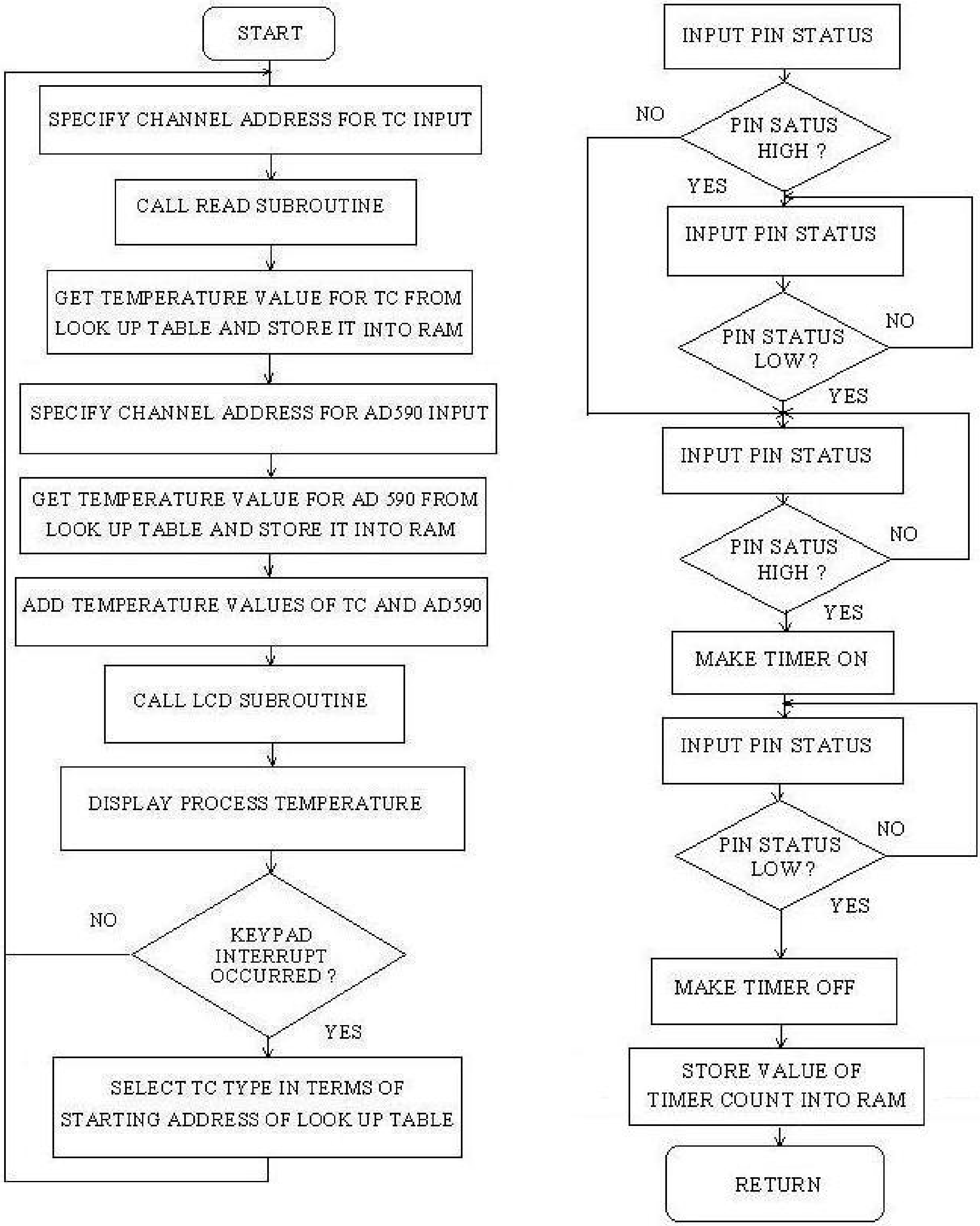


Fig. 1. Block diagram of the proposed temperature indicator circuit.

Here only two input ports of the microcontroller are needed to sense output signals of thermocouple and head temperature signal conditioning circuits as shown in Fig. 1 instead of 8 ports required for conventional ADC. The signal conditioning circuit of head temperature measuring circuit is so adjusted that the decrease of output current of the thermocouple signal conditioner circuit for each degree centigrade rise in temperature of the thermocouple head is just equal to the increase of output current of the head temperature signal conditioning circuit. This can also be easily done in the software program. So in the software the output of thermocouple signal conditioning circuit is simply added with the output of head temperature signal conditioning circuit. In this addition the digit count for a pulse of the astable multivibrator of thermocouple circuit is added with that of the astable multivibrator of the head temperature measuring circuit. The result thus obtained is displayed in terms of temperature by using a look-up table technique. The look-up tables for different thermocouples are stored in different locations and can be selected from key-pad by pressing particular type number of the thermocouple.



a) Main flow chart.

b) Read subroutine.

Fig. 2. Flow chart of software program for the temperature indicator.

3. Design

The proposed temperature indicator is designed according to block diagram as shown in Fig.1. Each of the signal conditioner circuits consists of adjustable gain instrumentation amplifier with zero adjustment network, filter network and voltage to current converter. The instrumentation amplifier is designed by low noise OPAMP OP07 instead of noiseless instrumentation amplifier ICs like INA01 in order to avoid higher cost. The zero adjustment network is used to bias the instrumentation amplifier output so that the LED can operate throughout the operating zone of thermocouple and AD590. The outside diameter of LDR is selected according to outside diameter of a red LED and both of them can be housed face to face inside a black enclosure of the same dimension so that the light emitted from LED can fall on the working surface of LDR and no interference due to any outside light source may occur. The astable multivibrator based in IC555 is selected for pulse width modulation of the analog signal coming from signal conditioning circuit. The microcontroller system is designed by using IC ATMEL 89C52, Serial EEPROM IC ATMEL 24C08, Hitachi HD 44780 based LCD unit and 4×4 matrix paper type keypad as shown in Fig. 1.

4. Experiment

Experiment has been performed to test the performance of the proposed temperature indicator. In the first part of the experiment, LDR characteristics with mV input signal of thermocouple circuit has been observed as shown in Fig.3. In the second part of the experiment change of pulse width against mV input signal has been measured by a DSO and has been found to be as shown in Fig. 4. In the third part, the variation of resistance of LDR of head temperature measuring circuit with temperature of a water bath has been observed and the characteristic graph is as shown in Fig. 5. In the next part of the experiment, the mV signal corresponding to K type thermocouple table with respect to cold junction temperature at 0^0C has been input to the instrument and its output is observed against input mV signal. In the last part of the experiment the K type thermocouple is placed in an electric heater operated furnace and the output temperature indicated by the instrument is observed when the actual temperature of the furnace was noted by a calibrated analog type temperature indicator(Make: Instrumentation Ltd., Kota, Rajasthan, India Sl.No.PIC-2, 700017, Range 0-400 ^{o}C). The characteristic graph is then drawn by plotting observed temperature against actual temperature as shown in Fig. 6.

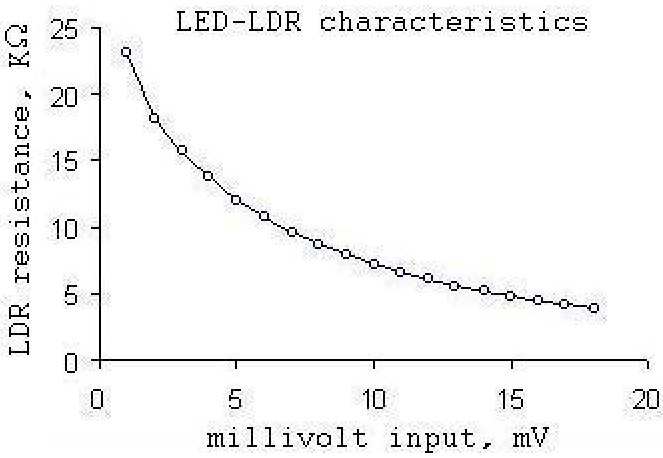


Fig. 3. LED-LDR Characteristics.

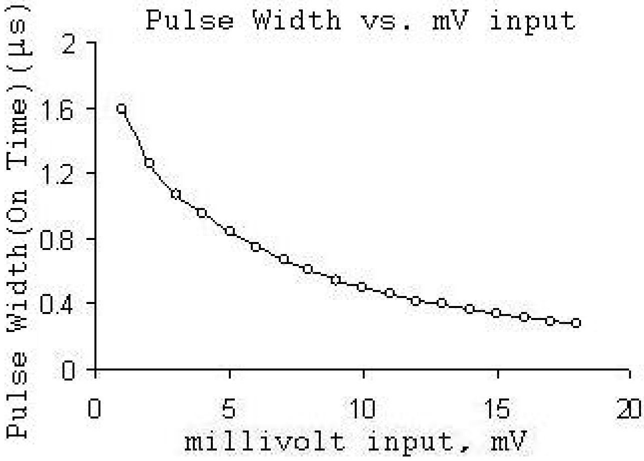


Fig. 4. Pulse Width vs. millivolt Input.

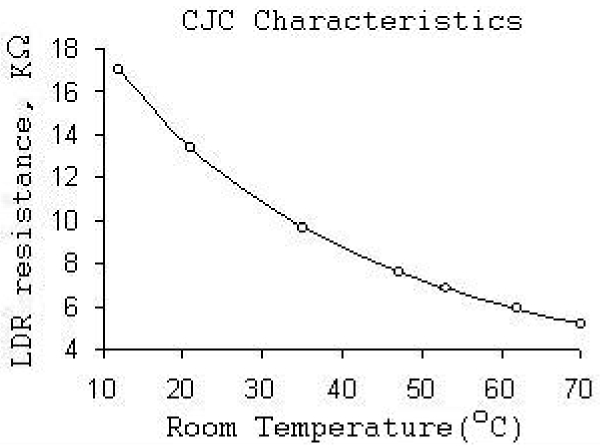


Fig. 5. LDR Resistance vs. Room Temperature Characteristics.

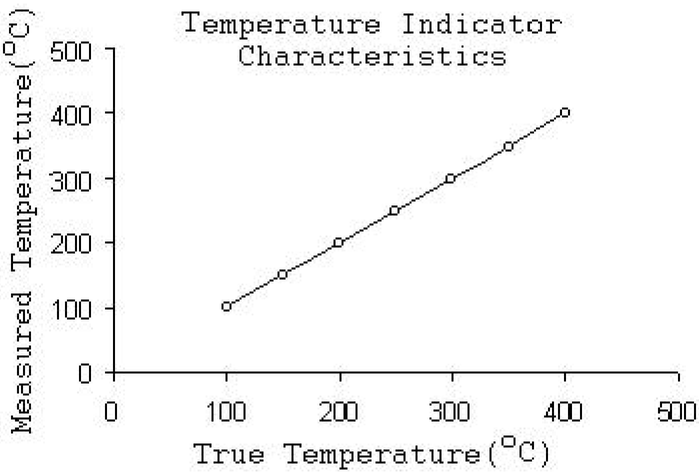


Fig. 6. Temperature Indicator Characteristics.

5. Discussions

From experimental curves as shown in Fig.2-6, it is found that the performance of the proposed instrument is quite satisfactory. Here the non-linearity of the characteristics of LED-LDR unit has been piecewise linearized by using look-up tables. The percentage error thus produced due to non-linearity between consecutive readings may be further reduced by supplying more close data in the look-up table. The major advantage of the proposed instrument is that the same instrument can be utilized for different thermocouples. In the conventional microprocessor based circuit ADC is directly connected with the signal conditioning circuitry, which may sometimes be disadvantageous if the signal conditioner supply voltage is higher than the rated voltage of ADC or the microprocessor. In our proposed set-up, the LED-LDR combination isolates the signal conditioning circuit from the microcontroller. Thus the microcontroller circuit can be protected from any surge voltage obtained from signal conditioner side if the thermocouple is mounted in an electric heater operated furnace. Moreover in ordinary microprocessor based indicator 8 pins are required to interface 8 bit ADC with the microprocessor. But in our proposed circuit no such conventional ADC is required. Here only 2 pins of the microcontroller IC are utilized so that the remaining 6 pins of the corresponding microcontroller port can be used for other purposes. Again the indicated temperature data can be utilized to produce a control action signal by using a software program in the microcontroller and thus an effective temperature control system can be easily designed by using the proposed technique. This part of the work is now in progress.

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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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- Sensor instrumentation;
- Virtual instruments;
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- Signal processing;
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- Technologies and materials;
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