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# DEVELOPMENT OF AN ONLINE TEMPERATURE MEASUREMENT SYSTEM IMPLEMENTING THERMOEMF TO DIGITAL CONVERSION TECHNIQUE

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## ABSTRACT

Development of an online temperature measurement system implementing thermoemf to digital conversion technique is explained in this paper. In this work, a class-I, K-type thermocouple is used as the temperature sensor. The thermoemf generated by the thermocouple is applied to a cold junction compensated K-type thermoemf to digital converter with resolution of $0.25^0$C. This is a 12-bit analog to digital converter with a temperature sensing diode for cold junction compensation. The internal circuitry of the converter provides the diode voltage (sensing ambient temperature) and the thermocouple voltage to the conversion function stored in the analog to digital converter to calculate the thermocouple hot junction temperature. The 12-bit output of the SPI compatible converter is read by an 8-bit microcontroller. A firmware has been developed to read digital data from the converter, for doing necessary data conversion of the digital data to temperature and to communicate with the PC via RS232 network for data logging and monitoring. Calibration method and performance of the system are described in the paper.

**Key words**: Microcontroller, K-Type Thermocouple, RS232 communication, Reference junction, Thermoemf

## INTRODUCTION

High precision thermometry is an essential component of any process control. There are various types of sensors for temperature measurement. Thermocouple, resistance temperature detector, thermistor, integrated circuit (IC) temperature sensors are some of the mostly used temperature sensors. Among these sensors,thermocouple is a highly reliable and widely used temperature sensor. It is the most suitable sensor for industrial environment. Main advantage of thermocouple over resistance temperature detector (documents at www.acromag.com), thermistor and PN junction diode is self electrical signal generation without external excitation signal(Bentley 1984) (IEEE Std 1451.2-1997) and wide operating range.

Di Peng et al. developed an industrial temperature monitoring system using infrared temperature sensor TS 118-3 for non contact applications(Peng and Wan 2013). Parne Saidy Reddy et al. has developed a fiber bragg grating sensor of range from $30^0$C to $900^0$C(Reddy et al. 2010). But for most of the industrial application, use of non contact type temperature sensors is impractical. Shobha Nikam et al. did a work to develop a universal analog frontend for industrial temperature measurement. Their work incorporates the use of a signal conditioning circuitry compatible with different temperature sensors and sends them to a computer placed in a control room via RS232(Nikam et al. 2015). Weimin Zhu et al. worked with thermocouple to develop a high precision temperature measurement system using NI LabVIEW(Zhu et al. 2015). LM35 is an IC temperature sensor widely used for low temperature measurement(Muruganet et al. 2012)(Kumar and Kumar 2013)(Ali et al. 2011). But when it is a concern of high temperature and precision measurement, application of thermocouple is better choice than IC temperature sensors like LM35.

Difficulties with thermocouple in high precision applications are

i. nonlinearity in response

ii. differential output

iii. pick up radio frequency and electromagnetic interference

As the thermocouple response is differential in nature, so reference junction or cold junction compensation must be done for getting the absolute value. To reduce the error generated by employing extra circuit for reference junction compensation, a precalibrated temperature to digital converter is used where reference junction compensation facility is employed with on chip circuit (Datasheet of MAX6675). This also helps in reducing the effects due to Electromagnetic (EM) and Radio Frequency (RF) interferences.

The data is sent to a computer via RS232 where display of data and storing in the hard drive of the computer are done by a graphical user interface (GUI) developed in NI LabVIEW. The system description, firmware development, data acquisition software development and calibration of the whole system are described in the following sections.

## METHODOLOGY

### System Description

The block diagram of the system is shown in the Figure 1. The thermoemf generated by the K-type thermocouple is fed to the input pin of MAX6675 IC. MAX6675 is an IC for converting the thermoemf to digital data with cold junction compensation. Cold junction temperature is measured by a PN junction diode and fed to the Analog to Digital Converter (ADC) with the amplified thermoemf. The framing of the 16-bit output of the MAX6675 is shown in the Figure 2. The converted temperature reading from thermoemf is in the digital format from D14 to D3 in the order of MSB to LSB. Bit D2 indicates whether the thermocouple is open or not which remains low normally and goes high when the thermocouple is open. D1 bit remain slow to provide the device information for the MAX6675(datasheet of MAX6675). The 16-bit output of the MAX6675 is fed serially to the P89V51RD2, a member of popular 8051 microcontroller family. At every falling edge of the 16 clock pulses, the microcontroller reads the 16-bit output of the IC. The output of the microcontroller is monitored on a computer based graphical user interface(GUI) developed in NI LabVIEW. RS232 communication protocol is used to communicate between the microcontroller and the host computer.

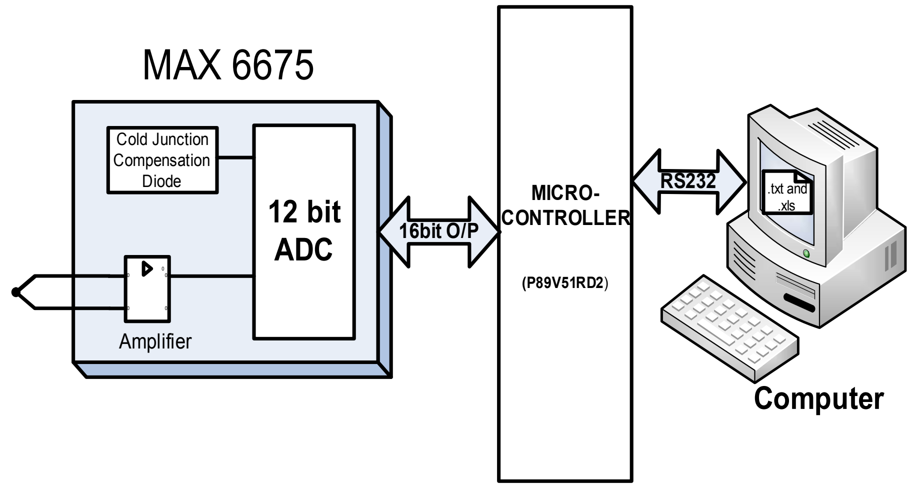


Fig. 1: Block diagram of the temperature measurement system

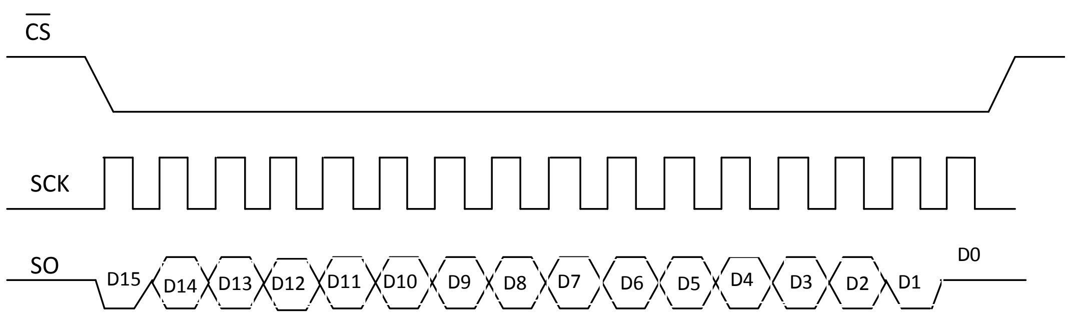


Figure 2: Data framing of 16-bit output data of MAX6675 (datasheet of MAX6675)

**Firmware and Data Acquisition Software Development**

Firmware is developed to read MAX6675 and establish the communication between microcontroller and the computer via RS232 network. The flowchart representation of the program developed and flashed to the microcontroller is given in the

Figure 3. The firmware is developed for doing the whole work in three different segments. First part is to collect the 16-bit raw data from the MAX6675 IC and then extract the 12-bit temperature reading from the raw data. The final part is to send the temperature reading to the computer via RS232 communication.

Data acquisition software has been developed in NI LabVIEW for collecting the temperature readings from the microcontroller and monitoring them. The flowchart representation is shown in the Figure 4.

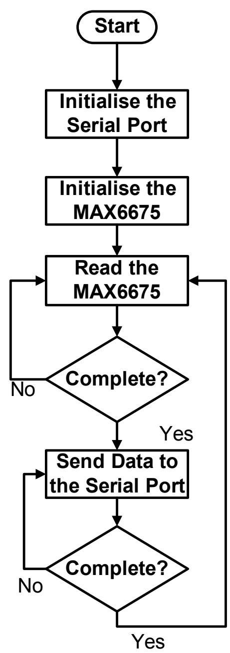


Fig. 3: Flowchart of the Firmware

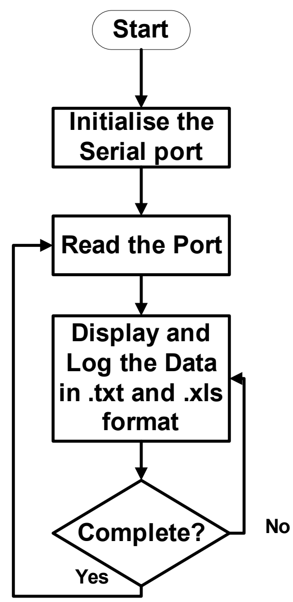


Fig. 4: Flowchart of the Software

## RESULT AND DISCUSSIONS

The temperature measurement system is calibrated using a low cost system taking the NIST (National Institute of Standards and Technology) datasheet as the standard (ITS-90 Table for type K thermocouple)(Sarma and Boruah 2010). Heating elements are heated using a variac which is powered from a stabilized AC outlet. Temperature is measured simultaneously by the system and by a $6\frac{1}{2}$ digit digital multimeter (DMM) 34401A from Keysight technology(datasheet of 34401A DMM). The DMM of 1µV resolution is kept in mV range. The thermoemf measured by the DMM is converted into temperature using NIST datasheet (Sarma and Boruah 2010). For cold junction compensation, reference junction temperature is measured using an IC temperature sensor LM35. The calibration system is shown in the Figure 5.

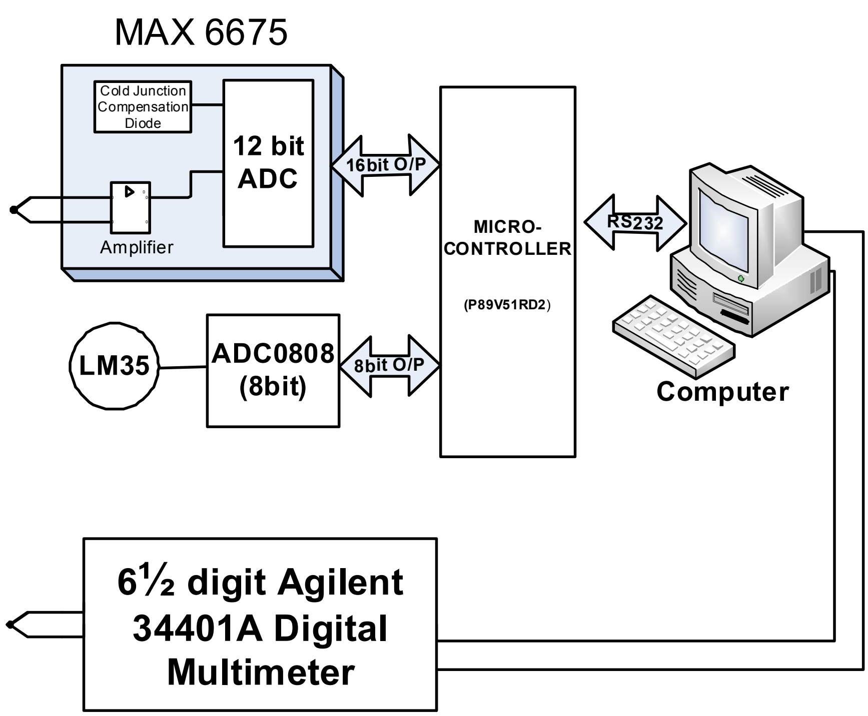


Fig. 5: Calibration System

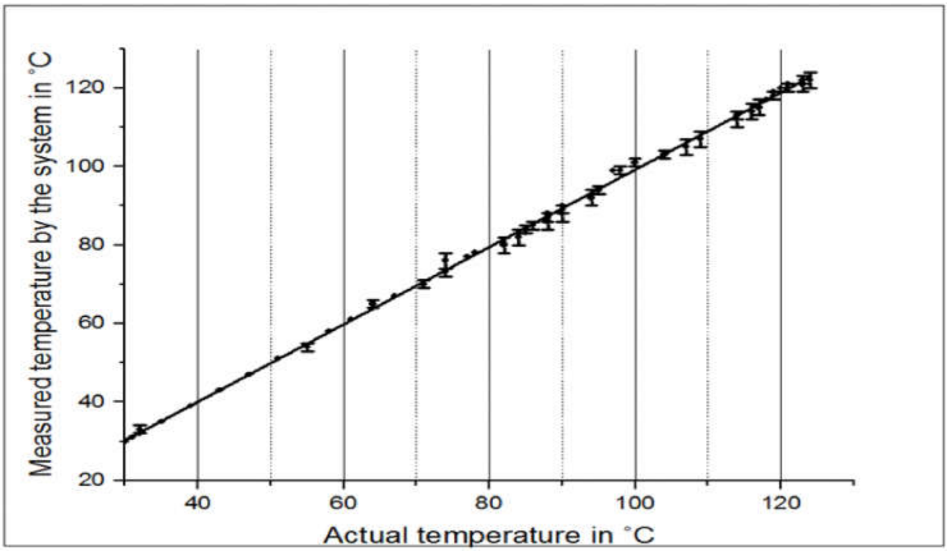


Fig. 6: Calibration Curve

**y = 0.983x + 0.728**

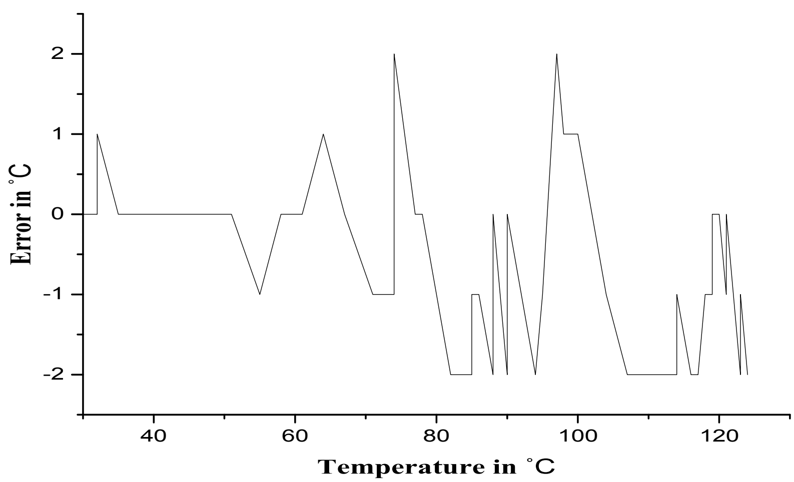


Fig. 7: Error Curve

Calibration is done for temperature from 30$^0$C to 130$^0$C because the temperature range of general industrial applications falls within this range. The error curve, shown in the Figure 7, shows that maximum error for the system is ±2$^0$C. The followings are the sources of errors observed

i. Non linearity of the thermocouple response
ii. System error
iii. Error of MAX6675 IC
iv. Calibration system error
v. Error of LM35 used for the reference junction temperature measurement in calibration system.

The calibration Curve is depicted in the Figure 6 and is almost linear with goodness of fit($R^2$) 0.998.

## CONCLUSION

The temperature measurement system implementing thermoemf to digital conversion technique is successfully developed and calibrated. The system gives temperature with resolution 1$^0$C. The calibration curve shows a linear response with goodness of fit ($R^2$) = 0.998. The error curve shows that the system gives temperature with ±2$^0$C accuracy.

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## REFERRENCES

1. Criteria for temperature sensor selection of T/C and RTD sensor types (https:/ www.acromag.com/sites/default/files Comparison_of_Thermocouple_and_RTD_ Temperature_Sensors_918A.pdf), visited on 31st October,2015

2. Bentley J. P. (1984) Temperature sensor characteristics and measurement system design,*J. Phys. E: Sci. Instrum.,*17: 430-439

3. Criteria for temperature sensor selection of T/C and RTD sensor types (https://www.acromag.com/sites/default/files/Comparison_of_Thermocouple_and_RTD_Temperature_Sensors_918A.pdf), visited on 31st October,2015

4. Datasheet of MAX6675 (https://www.sparkfun.com/datasheets/IC/MAX6675.pdf),visited on 31st October,2015

5. Datasheet of 34401A DMM ( http://cp.literature.agilent.com/litweb/pdf/5968-0162EN.pdf), visited on 31st October,2015

6. IEEE Std 1451.2-1997,IEEE standard for a smart transducer interface for sensors and actuators and transducer to microprocessor communication protocols and transducer electronic data sheet (TEDS) formats

7. ITS-90 Table for type K thermocouple (http://srdata.nist.gov/its90/download/type_k.tab), visited on 31st October,2015

8. Kumar S. Rajesh and S. Ramesh Kumar(2013) Industrial temperature monitoring and control system through ethernet LAN,*International Journal Of Engineering And Computer Science*, 2(6): 1988-1991

9. Murugan T., Azha. Periasamy and S. Muruganand (2012) Embedded based industrial temperature monitoring systems using GSM,*International Journal of Computer Applications*, 58(19): 6-11

10. Nikam Shobha, Yogesh Patil, Kaustubh Rajvaidya and Vinay Kumar (2015) Universal analog frontend for industrial temperature measurement,*International Journal of P2P Network Trends and Technology*, 16(1):1-4

11. Peng Di, Shengpeng Wan (2013) Industrial temperature monitoring system design based on zigbee and infrared temperature sensing, *Optics and Photonics Journal* 3: 277-280

12. Reddy Parne Saidy, Ravinuthala L.N. Sai Prasad, Kamineni Srimannarayana, MadhuvarasuSai Shankar and Dipankar Sen Gupta(2010) A novel method for

high temperature measurements using fiber bragg grating sensor,*Optica Applicata*, XL( 3): 685-692

13. Sarma Utpal and P.K. Boruah(2010) Design and development of a high precision thermocouple based smart industrial thermometer with online linearization and data logging feature,*Measurement*, 43: 1589-1594
14. Zhu Weimin, Haima Yang, Jin Liu and Chaoghao Yan (2015) Design of high precision temperature measurement system based on Labview,*International Journal of Advanced Computer Science and Applications*, 6(6): 153-155