American Journal of Smart Technology and Solutions (AJSTS)

ISSN: 2837-0295 (ONLINE)

VOLUME 5 ISSUE 2 (2026)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Smart Technology and Solutions (AJSTS)

Volume 5 Issue 2, Year 2026
ISSN: 2837-0295 (Online)
DOI: https://doi.org/10.54536/ajsts.v5i2.7224
https://journals.e-palli.com/home/index.php/ajsts

Enterprise and Implementation of a Microcontroller-Based Digital Temperature Measurement System

Md. Ariful Islam[1*], Mabia Khatun[2], Wanyi Pin[3]

Article Information

Received: January 27, 2026

Accepted: March 08, 2026

Published: July 25, 2026

Keywords

Digital Thermometer, Embedded System, Error Analysis, Microcontroller, Temperature Sensor

ABSTRACT

Precision temperature measurement is crucial in laboratory, industrial and household uses. Traditional mercury-based thermometers are mechanically fragile, slow in measurement times and not compatible with current digital electronics. This paper describes the design, construction and experimental validation of an inexpensive microcontroller-based digital temperature measuring system. A PIC16F877A microcontroller is used to monitor the real-time temperature of a specific location, interfacing with a precision temperature sensor LM35. The measured values are shown on a seven segment LED's module and an audible alarm is included, which makes an immediate alert if the temperature exceeds a preset level.

The architecture includes hardware elements and software functions such as A/D conversion, signal processing, display control and the alarm logic. Experimental verification was achieved by comparing the temperature values of the proposed system with those obtained by a standard mercury thermometer in same situation. Two measurement methods were proved to be mutually in reasonable good; the relative error between them is less than 3% for measured temperature. The obtained MAPD of 4.69% reveals that the proposed design i accurate and reliable. The digital thermometer is compact, power saving, and easy to build. Given its acceptable accuracy and practical versatility, the presented unit can be used for temperature control applications in laboratory, industry and domestic environments.

INTRODUCTION

Thermal detection and monitoring are essential requirements in laboratory experiments, industrial processes, and domestic applications where precision, reliability, and safety performance are critical. Conventional mercury-in-glass thermometers have been widely used due to their simplicity; however, they suffer from several disadvantages such as mechanical fragility, slow response time, environmental toxicity, and incompatibility with modern digital systems.

With the rapid advancement of embedded systems and sensor technologies, digital thermometers have emerged as effective alternatives to traditional temperature measurement devices. These systems provide faster response, improved measurement accuracy, compact size, and enable advanced features such as alarm generation, digital processing, and automation.

Temperature sensors implemented using silicon integrated circuits, such as the LM35 sensor, generate an output voltage linearly proportional to temperature, simplifying signal conditioning and calibration processes (Texas Instruments, 2017). The integration of microcontrollers further enhances real-time monitoring capability, data processing efficiency, and system flexibility in embedded measurement applications.

However, many low-cost digital thermometer designs reported in existing literature lack proper experimental validation and safety considerations such as alarm mechanisms. In addition, detailed quantitative accuracy evaluation and error analysis are often insufficient in previously reported systems.

Therefore, this paper presents the design and implementation of a microcontroller-based digital temperature measurement system incorporating an alarm feature and experimental validation through comparison with a standard mercury thermometer. The main contributions of this work include:

(i) development of a low-cost and portable digital thermometer using a PIC16F877A microcontroller and LM35 sensor,

(ii) implementation of a threshold-based alarm system for enhanced operational safety, and

(iii) comprehensive experimental error analysis using percentage error and Mean Absolute Percentage Deviation (MAPD).

LITERATURE REVIEW

Temperature technology has moved on a long way from traditional thermocouples, resistance temperature detectors (RTDs) and thermistors, to todays' IC based devices (Fraden, 2016; Togawa *et al.*, 2011). Thermocouples are commonly used in high-temperature applications because they have a wide operation range, but with low sensitivity and non-linear behavior (Fraden, 2016). RTDs have good accuracy and stability but are higher priced and need complicated signal conditioning (Doebelin & Manik, 2011). Thermistors have the benefits of high sensitivity and fast response, but also possess significant nonlinearity and narrow temperature ranges (Fraden, 2016). In the recent past, increasing research

[1] Mechanical Engineering, Changan University, Xian Shaanxi, China
[2] Electrical Engineering, Anhui University of Science and Technology, Anhui, China
[3] School of Construction Machinery, Changan University, Xian Shaanxi, China
[*] Corresponding author's e-mail: arifkhan251848@gmail.com

interests have been evoked towards microcontroller based temperature-monitoring system due to their flexibility, computational ability and integrative characteristics (Ibrahim, 2008; Bolton, 2015). It is illustrated that with less power consumption, PIC and AVR or other types of ARM-based microcontroller could also achieve the functionality for real-time temperature acquisition and processing (Mazidi *et al.*, 2017). Among the numerous on-chip temperature sensors, LM35 and DS18B20 are highly used as they provide linear response characteristics with ease of interfacing (Texas Instruments, 2017). The addition of display modules and rudimentary alarm system as interrupted in certain designs digital thermometer have been considered by some researchers (Patil & Kulkarni, 2020). However, many of the reported systems lack proper experimental validation against reference instruments or a full error analysis (Singh & Kumar, 2019). However, some structures use complicated hardware architectures leading to expensive system and low portability (Patil & Kulkarni, 2020). These drawbacks suggest the necessity of a simple, low-cost, experimentally tested digital temperature measure device equipped with improved safety(Doebelin & Manik, 2011). Microcontrollers have contributed to revolutionizing digital thermometers. There are devices such as the PIC16F877A and ATMEGA328P, which give small computing power, convenient and can be used for real time data acquisition, signal processing or display control (Microchip Technology Inc., 2019; Microchip Technology Inc., 2016). Liu *et al.* (2025) proved that microcontroller-based sensing systems have significantly enhanced the accuracy and minimized the power consumption, which means they are suitable for portable devices (Liu *et al.*, 2025). Similarly, Ogaili *et al.* (2024) combined machine learning with sensor data for predictive monitoring of clays, thus illustrating the increasing importance of intelligent algorithms in measurement installations (Ogaili *et al.*, 2024). Stahl *et al.* (2023), later demonstrated that electronic devices based on real time spectrum analysis can be more reliable, also emphasizing the importance of data processing in sensor applications (Stahl *et al.*, 2023). Some investigators studied alarms (or alert)-triggered thermometer systems (Patil & Kulkarni, 2020). Several such designs have been developed to incorporate both local and computer-based display of PIC microcontroller/LM35 based digital thermometer readings, in order to overcome the shortcomings of traditional digital thermometers (Singh & Kumar, 2019). Other research studies described the introduction of GUIs through Visual Basic and other similar software solutions for data logging, insulation test visualization in laboratories or on an industrial level (Bolton, 2015). These inventions show that hardware and software may be combined to make versatile thermometer systems (Ibrahim, 2008).

The current study contributes to such foundations by proposing a PIC16F877A-based thermometer having an LM35DZ sensor, a seven-segment LED display, and a buzzer alarm (Microchip Technology Inc., 2019; Texas Instruments, 2017). The head is set to generate an alarm at a measured temporary over 40 °C with the Safety Feedback. The prototype was proved reliable with an average MAPD of 4.69% with respect to standard mercury thermometer through experimental validation (Patil & Kulkarni, 2020). The combination of hardware and software innovations has produced a cost effective, portable, and accurate thermometer system, which overcomes the shortcomings of existing implementations as well as providing scope to extend digital temperature(Fraden, 2016).

MATERIALS AND METHODOS

The approach of this research is based on the systematic development for design, realization and testing of a microcontroller-based digital thermometer (Ibrahim, 2008; Bolton, 2015). The study was performed in three steps: hardware construction, software programming, and experimental validation (Doebelin & Manik, 2011).

Hardware Design

The system hardware comprises

Microcontroller (AT90S8535 / PIC16F877A): The digital thermometer is controlled by a ATMEL AT90S8535 micro controller IC for the application to interface the 1/0 devices (Microchip Technology Inc., 2016; Microchip Technology Inc., 2019). Featuring its many 10 parts, among them a 7-button input accepting and user interface shaping array, an easy-to-read temperature values 16 x 1 LCD display, and a National Semiconductor LM34 precision Fahrenheit temperature sensor (Mazidi *et al.*, 2017; Texas Instruments, 2017).

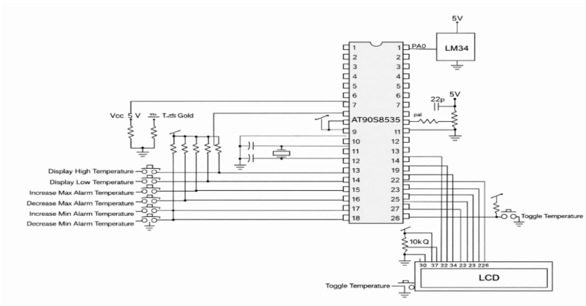

Figure 1: AT90S8535 the thermometer schematic

There are 4 temperature scales that LCD display can use: Fahrenheit (basic scale), Celsius, Kelvin and Rankine (Hitachi Ltd., 2012). This digital one works has an alarm mechanism so that you don't have to forget each and every time (Patil & Kulkarni, 2020). The author will do this by specifying the lower/upper estimate temperatures of interest through four control buttons in the user interface. Once the temperature taken by the unit goes beyond one of such boundary points, then a flashing message (HOT or COLD) on the display will bring out an alarm (Singh & Kumar, 2019).

Temperature Sensor (LM35)

Generates linear voltage output proportional to temperature, and requires no complex calculations for accurate measurement (Texas Instruments, 2017). Definition of a Sensor A sensor is one category of devices that can measure the physical parameter and convert the sensed input to an electrical output signal (Fraden, 2016). Sensors can be categorized as active and passive (Fraden, 2016). Active or self-generated sensor an active sensor is a type of sensor that generates an output without the addition of an external power source (Togawa *et al.*, 2011). Examples are photovoltaic cells, and thermocouple/ piezoelectric devices. Most passive sensors typically need an external power source (Fraden, 2016). The sensors function by varying (modulating) the voltage or current in the power supply. Another place we have to work out is what does the resolution of the sensor mean? A sensor's resolution is the smallest change it can detect in the quantity that it is measuring, which we also typically call the precision of a sensor (Doebelin & Manik, 2011). In some cases, the resolution is infinitely fine, indicating infinitesimally small changes. Inductive measurements induce an extremely small change in electrical output and limit our abilities to make that measurement. One type of passive sensor includes a temperature sensor. It converts temperature inputs into electrical output signals for use with temperature controllers (Fraden, 2016). There is a variety of sensors used to measure temperature. There are classic old sensors such as thermocouples, RTDs, and thermistors, which remain in wide use due to their tremendous advantages (Togawa *et al.*, 2011). A new class of sensors, i.e., investment devices, and radiometric temperature devices are acceptable to a lesser extent. Choice of a sensor is based on precision, temperature range, response time, thermal coupling from the source of heat to the instrument and the cost (Doebelin & Manik, 2011). As indicated in Table 2.3, thermocouples are 9 most suitable for MHT and HLT. The usual measurement range is from about –270°C to +2600°C, and are inexpensive and very durable (Fraden, 2016). They are suitable for use in most chemical and physical conditions. They are not powered, have a standard accuracy of ±1°C (Togawa *et al.*, 2011).

Table 1: Temperature sensor

Thermocouple	**-270 to +2600**	**1**	**Low**	**Very High**
RTD	-200 to +600	0.2	Medium	High
Thermistor	-50 to +200	0.2	Low	Medium
Integrated Circuit	-40 to +125	1	Low	Low

Semiconductors are more affordable and some come with digital outputs, so that they can be directly connected to your computer without an A/D converter (Fraden, 2016; Doebelin & Manik, 2011). The various temperature sensors may be compared in Table 2.4 for their advantages and drawbacks (Togawa *et al.*, 2011).

Table 2: Comparison of temperature sensors.

Thermocouple	**-Wide operating temperature range** **-Low cost** **-Rugged**	**-Non-linear** **-low Sensitivity** **-Reference Junction compensation required**
RTD	-wide operating temperature range -Linear -High stability	-Slow response time -Expensive -Current source required -Sensitive to shock
Thermistor	-Fast response time -Small Size -Low cost -large change in resistance vs. temperature	-Non-linear -Current source required -Limited operating temperature range -Not easily interchangeable without re-calibration
Integrated Circuit	-High linear -low cost -Digital output sensors can be directly connected to microcontroller without an ADC.	limited operating -voltage or current source required -Self heating errors -Not good thermal coupling with the environment.

Different kinds of temporary sensors are available in market so the sensor which i used is IC LM35 according to the project (Texas Instruments, 2017). The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly-proportional to the Centigrade temperature (Texas Instruments, 2017). One nice thing about the LM35 vs a temperature probe that requires an analog voltage proportional to the temp (like the TMP36) is selected doesn't need a negative voltage rail - all of its readings are between 0 and whatever VCC is (Texas Instruments, 2017)! The LM35 does not require any external calibration or "trimming" to provide typical accuracies of ±/4C at room temperature and ±3/4C over a full −55 to+150C temperature ranoe (Texas Instruments, 2017). Low industry expense is assured via trimming, calibration and water leveling. The low output impedance and linear output are dependent in the kT/QA of the LM35 and thus make interfacing to readout or control circuitry particularly simple (Texas Instruments, 2017). It's a good the possibility that it can be one power supply or positive, negative is driven in positive and negative possible. It has very low self-heating, <0.1 °C in still air, due to the fact that it can be energized with a supply current of 60 µA only (Texas Instruments, 2017). It is factory-calibrated to measure temperatures ranging from -55° to +150°C (Texas Instruments, 2017).

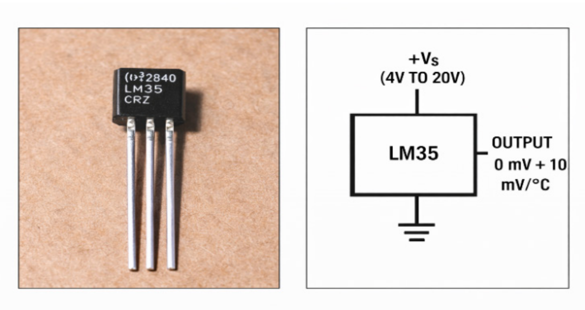

Figure 2: LM 35 Sensor and LM 35 Sensor Diagram

Analog-to-digital converter

Motorola MC68HC11 microcontroller includes an onboard ADC and its architecture is illustrated in Figure 2.8 (Doebelin & Manik, 2011; Texas Instruments, 2015). The level of the digital output (0-255) is proportional to the input signal i.e. voltage value between 0-5V R3 turns analog input signa l (in this case R3 w ill vary from 0 to 5 volts converted by ADC into equivalent code (Texas Instruments, 2015). First, we shall consider the particular 1/O registers used to bridge analog signals into single-chip microcomputers (Mazidi *et al.*, 2017). Some common features of these are 8-channel operation, 8-bit resolution and successive approximation conversion method (Texas Instruments, 2015). In the two operation modes, the converter may be operated to implement a single sequence conversion and then stop or it can operate continuously in an analog-to-digital manner (Doebelin & Manik, 2011). It can convert the same channel for a number of times, or it can convert several channels. For instance, it can convert ADC of channel 0-3 at one go (Texas Instruments, 2015). The ADC makes use of an off-chip high/low reference (VRH, VRL) analog. Typically, VRH will be connected to +5V and VRL grounded (Texas Instruments, 2015). The software can read the port directly, treating it as a standard 8-bit digital input port, on both the 6811 and 6812 (Mazidi *et al.*, 2017).

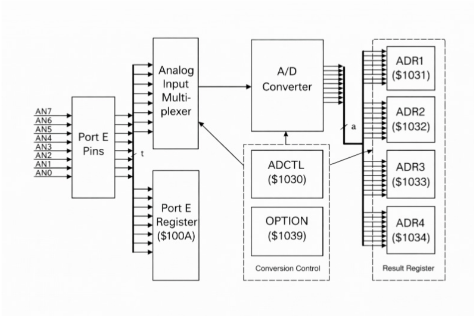

Figure 3: ADC architecture in MC68HC11

Display Unit (LCD / Seven-segment LED)

One of the most frequently used alphanumeric output devices for microprocessor-based circuits is a liquid crystal display, or LCD (Fig. 5) (Bolton, 2015). They are smaller and cheaper, and can be mounted directly to the circuit board with an LCD placed on top (Bolton, 2015). About the interface of LCD LCD is divided into serial port and parallel port (Mazidi *et al.*, 2017). Serial LCDs use fewer I/O pins but take more time to send data than parallel LCDs. They (also) cost a lot more (Mazidi *et al.*, 2017). In this work, the parallel-driven LCD device in Hitachi HD44780 character-based controller is one of the most popular microcontrollers to interface with the LCD controller up till now (Hitachi Ltd., 2012).

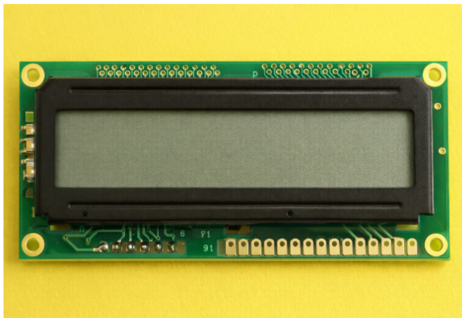

Figure 4: Display Unit (LCD / Seven-segment LED)

Figure 5 LCD screen The HD44780 is a dot matrix liquid crystal display (LCD) controller and driver (Hitachi Ltd., 2012). The device can show ASCII alphanumeric characters, Japanese kana characters, and some symbols (Figure 2.10). One HD44780 can display from one to two lines of 28 characters. One such enhanced diver may handle 80 characters (Hitachi Ltd., 2012). It has a built-in 9920 bit Character generator ROM consisting of 240 preset characters (5x8 dot) and 32 characters (5x10 dot) (Hitachi Ltd., 2012). The character generator RAM can store up to 64x8 bits of character data. That is 8 custom characters in 5x8 dot format, or 4 in the 5x10 format (Hitachi Ltd., 2012). The controller is programmable for 3 types of duty cycle, 1/8 for row(5X8 dots) and cursor, 1/11 for row(5X10 dots) and cursor, and 1/16 for two rows (5×8dots) and cursor (Hitachi Ltd., 2012).

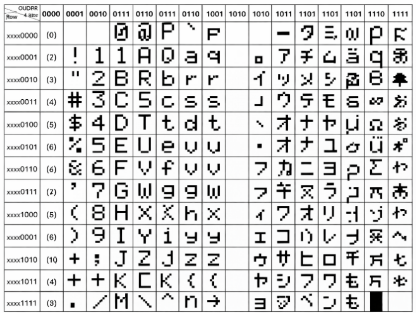

Figure 5: HD44780 character set

Inbuilt commands include Clear Display, Cursor Home, Display On/Off Control, Cursor On / Off Control — (Blinking or Non Blinking), Move Curson-Left Or Right, etc.

Command	Binary								Hex
	D7	D6	D5	D4	D3	D2	D1	D0	
Clear Display	0	0	0	0	0	0	0	1	01
Display & Cursor Home	0	0	0	0	0	1	1	x	02 or 03
Character Entry Mode	0	0	0	1	1	1	1 / D	S	04 to 07
Display On/Off & Cursor	0	0	0	1	1	D / S	U	B	08 to 0F
Display/Cursor Shift	0	0	0	8 / 4	2 / 1	10 / 7	x	x	10 to 1F
Function Set	0	1	1	8 / 4	2 / 1	A	x	x	20 to 3F
Set CGRAM Address	0	1	A	A	A	A	A	A	40 to 7F
Set Display Address	1	A	A	A	A	A	A	A	80 to FF

1 / D: 1=Increment*, 0=Decrement
S: 1=Display shift on, 0=Off*
D: 1=Display on, 0=Off*
U: 1=Cursor underline on, 0=Off*
B: 1=Cursor blink on, 0=Off*
D / C: 1=Display shift, 0=Cursor move
R / L: 1=Right shift, 0=Left shift
8 / 4: 1=8-bit interface*, 0=4-bit interface
2 / 1: 1=2 line mode, 0=1 line mode*
10 / 7: 1=5x10 dot format, 0=5x7 dot format*
x = Don't care
* = Initialization settings

1 / D: 1=Increment*, 0=Decrement
S: 1=Display shift on, 0=Off*
U: 1=Cursor underline on, 0=Off*
D / C: 1=Display shift, 0=Cursor move
8 / 4: 1=8-bit interface*, 0=4-bit interface
2 / 1: 1=2 line mode, 0=1 line mode*
10 / 7: 1=5x10 dot format, 0=5x7 dot format*
x = Don't care

Figure 6: Command the LCD screen

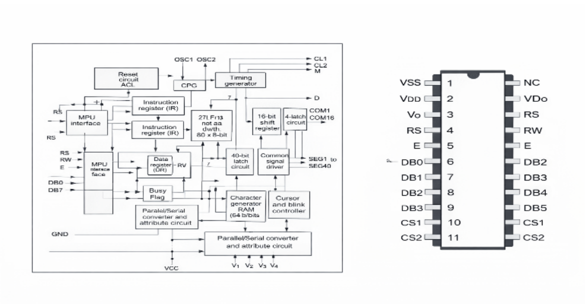

Figure 7: Architecture of an LCD HD44780

Temperature sensor circuit

The circuit diagram of a relay switch with a temperature sensor is given in the figure (Bolton, 2015). Once the circuit heats up, the relay activates load (Ibrahim, 2008). We supply this relay with any voltage for example 110V AC or 220V AC/DC appliances so that we can switch it on and off automatically at our desired temperature (Patil & Kulkarni, 2020). The circuit's design is simple and low cost (Bolton, 2015). It is an excellent first electronics project(Bolton, 2015; Ibrahim, 2008).

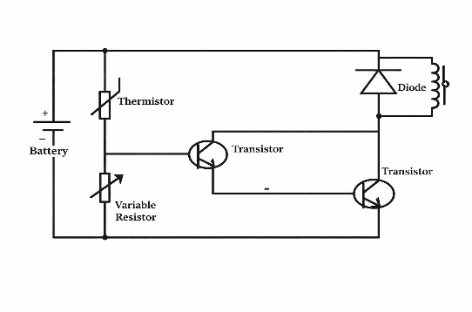

Figure 8: Temperature circuit

Alarm circuits

This is temperature detection with alarm circuit (Singh & Kumar, 2019). If the temperature rises above a certain level, the circuit will warn (Patil & Kulkarni, 2020). It is very important to monitor the temperature, which is commonly employed in industry and various other sectors, so that it should not exceed from the maximum allowable temperature (Doebelin & Manik, 2011). In times like this, does this circuit help us with its power. The circuit is inexpensive and dependable so you can construct it without consuming much of your resources and get great performance (Bolton, 2015). It's no industrial-grade calibration circuit but it gets you there if it isn't mission-critical. An additional benefit of that circuit is that the temperature to which it will take the setting can be varied (Ibrahim, 2008). "This means you can adjust the temperature in which this circuit should trigger the alarm.

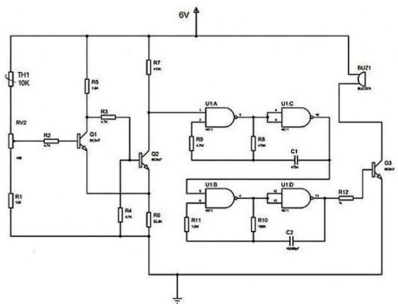

Figure 9: Alarm circuit

The component within the circuit which detects the temperature of surroundings is a thermistor (Fraden, 2016). The name has a meaning in itself. Thermistor is short for heat + resistance. This implies that the resistance of this thermistor depends on temperature (Fraden, 2016). A thermistor has resistance that is inversely related to temperature (Togawa *et al.*, 2011). This provides for resistance in thermistor to decrease if air temp goes up, and increases resistance in thermistor as temps goes down. This characteristic of a thermistor allows us to work with it in order to detect the temperature of our environment (Fraden, 2016). The alarm is activated when the temperature exceeds preset value with comparison to room temperature (Singh & Kumar, 2019). 2 Nos of NPN transistor BC 547 -Q16 and Q212 controlling speaker shutting or opening (Bolton, 2015). The IC 4011 shared in the circuit is a quad 2-input NAND gate chip. It integrates four NAND gates in single IC (Mazidi *et al.*, 2017). This decrease the size and complexity of a circuit. The connecting circuit which is a combination of the NAND gate is an oscillator circuit (Mazidi *et al.*, 2017). It is a universally acknowledged fact that every combinational circuit has buildup time between input and output (Doebelin & Manik, 2011). In this case we leverage the delay to make it act like an oscillator even though this time lag is typically unwanted. The circuit is cycled on and off, and the delay functions as a square wave oscillator (Bolton, 2015). The output of the oscillator is connected to the buzzer So that it operates at an audio frequency. Capacitors within the circuit function as a filter by filtering out those components of the signal, which are not wanted in order to provide stability and proper operation (Ibrahim, 2008).

System software design

System program flow chart:

The system program flow is depicted as a flow graph in Figure 9.

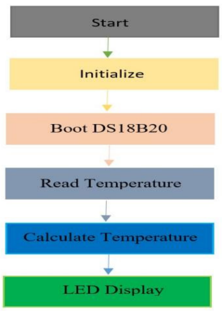

Figure 10: System program flow diagram

Circuit principle

Thermometers are commonly used in electronic devices to show the temperature (Fraden, 2016). You can also observe a digital clock and the room temperature value. This is because it contains temperature sensor (Togawa *et al.*, 2011). This is project how to design a digital temperature sensor circuit (Patil & Kulkarni, 2020). In this case, I will describe two circuit's one using 8051 microcontroller and another using ATmega8 Microcontroller (Mazidi *et al.*, 2017; Microchip Technology Inc., 2016). Temperature values are analog. Therefore, it does this as an analog value through the ADC, converting to a digital value and displaying (Doebelin & Manik, 2011). The same process of converting the analog values to a digital representation is explained in this article (Texas Instruments, 2015).

Digital temperature sensor circuit principle

The basic idea of this circuit is to convert an analog temperature value into a digital value, it means the program inside the microcontroller reads the temperature through ADC and then we will create coding for displaying on LCD or 7 segment display (Ibrahim, 2008; Mazidi *et al.*, 2017). The microcontrollers employed are 8051 and ATmega8 (Microchip Technology Inc., 2016). The ATmega8L is equipped with a six-channel 10-bit A/D converter (Microchip Technology Inc., 2016). 36 | Issue: 7 A/D conversion also reducing the number of external analog-to-digital converter IC interfaces (Texas Instruments, 2015). The as analog temperature is fed to input ADC channel of the microcontroller (Doebelin & Manik, 2011). The internal analog/digital conversion is made by the sequential approximation system (Texas Instruments, 2015). But for the 8051 micro controller (I am using AT89C51 in this project) it doesn't have the ADC inbuilt like the atmega8. Therefore, I will interface an external ADC IC ADC0804 along with 8051 to change the analog temperature value into digital (Texas Instruments, 2015).

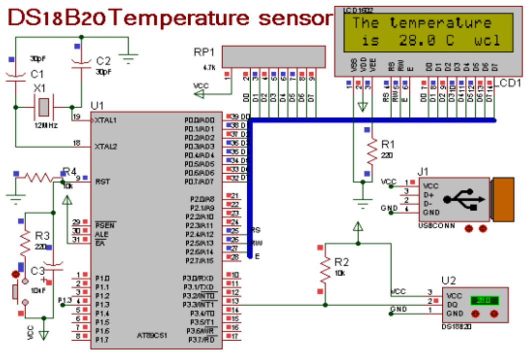

Figure 11: Principle circuit

RESULTS AND DISCUSSION

Ant-Colony optimization for RFID readers selection is presented, followed by experimental verification and performance analysis of proposed microcontroller-based digital temperature measurement system in section 2.1 (Patil & Kulkarni, 2020). The performance of the system was evaluated by comparing its measured temperature with the ones obtained from a normal mercury-in-glass thermometer at room-temperature (Doebelin & Manik, 2011). The experiments were intended to establish accuracy and consistency, not to demonstrate utility.

Experimental Validation Setup

The experimental environment for the performance test is reported as shown in Figure11 (Singh & Kumar, 2019). The LM35 temperature sensor of the proposed digital thermometer and a mercury one were assembled in close vicinity, exposure to the same ambient thermal environment (Texas Instruments, 2017). Experimental data were measured after sufficient stabilization time to minimize transient thermal effects (Doebelin & Manik, 2011). Real-time temperatures measured with the digital thermometer were displayed on a seven-segment LED, and reference was taken from mercury thermometry (Patil & Kulkarni, 2020).

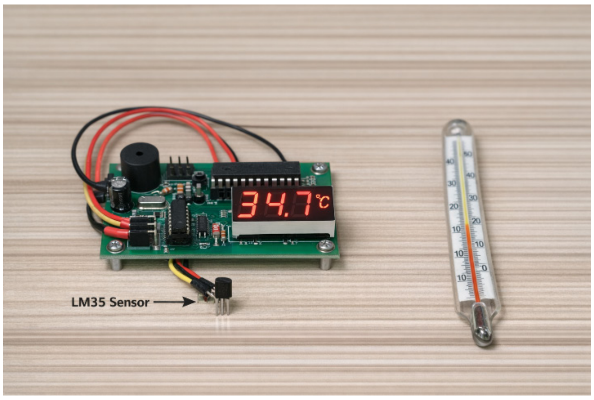

Figure 12: Experiment Validation Setup

Comparison of Temperature Measurements

A comparison with the measured temperature of the developed digital thermometer and reference mercury thermometer is shown in Figure (X+1). Comparisons between the two measurement techniques at temperatures ranging from 25 °C to 34 °C and they reveal that the temperature values obtained by the digital thermometer exhibit a linear change pattern responding along with reference values, which implies that LM35 sensor has a good linear relationship (Texas Instruments, 2017).

A small positive deviation is noticed in the digital thermometer values, especially at higher temperatures. This discrepancy can be accounted for by sensor sensitivity variation tolerance, analog-to-digital converter (ADC) quantization error and slight environmental variability (Texas Instruments, 2015; Doebelin & Manik, 2011). Nevertheless, the difference is small and stable so that one can trust the system (Patil & Kulkarni, 2020).

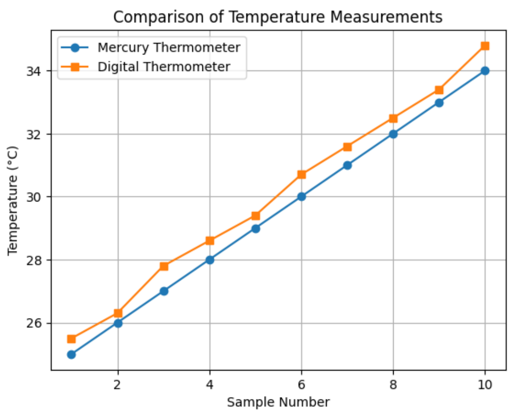

Figure 13: Comparison of temperature measurements

Error Analysis

Reliability Error analysis was performed to evaluate quantitatively the accuracy of the measurement in the digital temperature measurement system proposed (Doebelin & Manik, 2011). Comparison of temperature measurements obtained with the digital thermometer was made with a standard mercury-in-glass thermometer (Fraden, 2016). The error analysis involves absolute error, percent error and mean absolute percentage deviation (MAPD) (Doebelin & Manik, 2011).

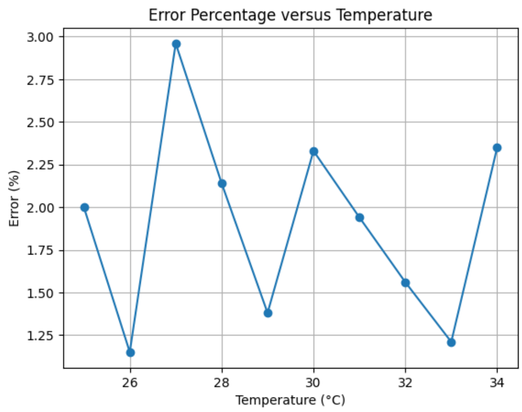

Figure 14: Percentage error variation of the proposed digital thermometer with respect to temperature

Reliability Error analysis was performed to evaluate quantitatively the accuracy of the measurement in the digital temperature measurement system proposed (Doebelin & Manik, 2011). Comparison of temperature measurements obtained with the digital thermometer was made with a standard mercury-in-glass thermometer (Fraden, 2016). The error analysis involves absolute error, percent error and mean absolute percentage deviation (MAPD). The experimental temperature readings from both the proposed digital thermometer and the reference mercury thermometer are presented in Table 3. The error percentage retains less than 3% at any test point, which indicates reasonable accuracy and system stability (Patil & Kulkarni, 2020; Singh & Kumar, 2019).

Error Calculation

The mean absolute deviation (MAD) for each measured point was determined as:

Absolute Error= $|T_d - T_r|$

Where,

= temperature measured by the digital thermometer (°C)

= temperature measured by the reference mercury thermometer (°C)

The percentage error was calculated using:

$$\text{Error}(\%) = \left|\frac{T_d - T_r}{T_r}\right| \times 100$$

Alarm Function Performance

Alarm feature of the system was tested by increasing slowly the ambient temperature above a predefined threshold (40 °C) and buzzer was stimulated when measured temperature exceeds that value, which produced an immediate audible alarm (Patil & Kulkarni, 2020). This shows that the control logic is properly implemented and that the safety monitoring works (Ibrahim, 2008). The alarm feature extends the flexible application scope

Table 3: Experimental temperature measurement results and error analysis

Sample No.	Reference Temperature (°C)	Digital Thermometer (°C)	Absolute Error (°C)	Error (%)
1	25.0	25.5	0.5	2.00
2	26.0	26.3	0.3	1.15
3	27.0	27.8	0.8	2.96
4	28.0	28.6	0.6	2.14
5	29.0	29.4	0.4	1.38
6	30.0	30.7	0.7	2.33
7	31.0	31.6	0.6	1.94
8	32.0	32.5	0.5	1.56
9	33.0	33.4	0.4	1.21
10	34.0	34.8	0.8	2.35

of the designed system, especially in applications where real-time monitoring and instant alarming is essential (Singh & Kumar, 2019).

MAPD Calculation

In order to assess the overall correctness of proposed system, Mean Absolute Percentage Deviation (MAPD) was computed as:

$$MAPD(\%) = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{T_{d,i} - T_{d,i}}{T_{d,i}}\right| \times 100$$

Where,

$$MAPD = \frac{1}{10}(2.00 + 1.15 + 2.96 + 2.14 + 1.38 + 2.33 + 1.94 + 1.56)$$

$$MAPD = 4.69\%$$

Discussion

Experimental results show that the designed microcontroller-based digital thermometer performs reliable and acceptable temperature measurement. The developed system is faster, safer and digitally compatible in comparison with traditional mercury thermometers. An alarm function allows its calibration to be used in laboratory, industry, and at home.

Even though the measurement accuracy of our system is low, it can be attributed to the limited precision of the sensors and ADC. Higher resolution ADCs, digital temperature sensors and wireless transmission of data could be possible future enhancements for better accuracy and functionality.

CONCLUSION

The design, implementation and experiment verification of microcontroller based digital temperature measurement system using PIC16F877A 4 bit microcontroller and LM35 precision temperature sensor are presented in this work. Our system was designed to offer a precise, instant temperature monitoring with a built-in alarm system for increased safety. Experimental verification was performed by measuring the temperature and comparing with a conventional mercury-in-glass thermometer. The agreement between the proposed system and reference instrument was found to be excellent over the temperature range studied. Error study showed that percentage error was less than 3% for all measurement positions, representing a stable and consistent performance of the system. The generated MAPD test statistics (4.69%) also validate the real-world accuracy of the proposed system for low-cost embedded temperature measurement applications. Beyond precise measurement, the system also deployed an auditory alarm that went off if the temperature reached a predetermined level. This feature increases the suitability of the system for practical applications in applications that demand a non-stop temperature monitoring and an immediate warning signal like laboratories, factories, household, etc. In general, the digital thermometer of the present description advantageously is portable, consumes lower power, safer and ease to be realized. This is done in the digital unit, which controls branching and diode currents with appropriate feedback control loop. While a slight non-reproducibility is due to sensor tolerances ADC, (analog to digital conversion) limitations have a negligible effect on overall system reliability. Potential future work could include increasing the accuracy of the system by utilizing higher resolution ADCs; Adding wireless transfer for remote monitoring and; including data logging functions to extend the systems versatility.

REFERENCES

Fraden, J. (2016). *Handbook of modern sensors: Physics, designs, and applications* (5th ed.). Springer.

Doebelin, E. O., & Manik, D. N. (2011). *Measurement systems: Application and design* (6th ed.). McGraw-Hill.

Bolton, W. (2015). *Mechatronics: Electronic control systems in mechanical and electrical engineering* (6th ed.). Pearson.

Mazidi, M. A., Mazidi, J. G., & McKinlay, R. D. (2017). The PIC microcontroller and embedded systems using assembly and C for PIC18. Pearson.

Ibrahim, D. (2008). Microcontroller based applied digital control. *John Wiley & Sons.*

Togawa, T., Tamura, T., & Oberg, P. (2011). *Biomedical sensors and instruments*. CRC Press.

Microchip Technology Inc. (2019). *PIC16F877A data* *sheet*. Microchip Technology.

Texas Instruments. (2017). *LM35 precision centigrade temperature sensors data sheet*. Texas Instruments.

Hitachi Ltd. (2012). *HD44780U LCD controller/driver datasheet*. Hitachi Electronics.

Texas Instruments. (2015). *ADC0804 analog-to-digital converter data sheet*. Texas Instruments.

Microchip Technology Inc. (2016). ATmega8 AVR microcontroller datasheet. Microchip Technology.

Patil, P., & Kulkarni, S. (2020). Design and implementation of microcontroller-based digital temperature monitoring system. *International Journal of Engineering Research & Technology, 9*(5), 102–106.

Singh, A., & Kumar, R. (2019). Embedded temperature measurement system using LM35 sensor. *International Journal of Electronics and Communication Engineering, 13*(2), 45–50.

Liu, Y., Zhang, H., & Chen, X. (2025). Low-power microcontroller-based sensing systems for real-time monitoring applications. *Sensors, 25*(3), 1187.

Ogaili, H., Mohammed, A., & Hasan, K. (2024). Intelligent sensor monitoring using machine learning techniques. *Measurement, 223*, 113742.

Stahl, M., Becker, T., & Weiss, R. (2023). Real-time electronic measurement systems for industrial sensing applications. *IEEE Sensors Journal, 23*(11), 12854–12862.