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Design and Implementation of a Microcontroller Based Digital Thermometer

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Abstract- In the past, digital thermometers are mostly designed using discrete components (such as timers, counters, decoder drivers etc.) and temperature sensors (such as thermistors etc.). However, advances in electronics engineering has made it possible to have a computer in a chip "Microcontroller" and also integrated circuit temperature sensors. This paper presents the design and implementation of a microcontroller based digital thermometer. The system is based on PIC16F877A microcontroller interfaced with LM35DZ temperature sensor, seven segment led display and a buzzer. The system design is in two phases; hardware and software. The system makes an alarm when the temperature reading is 40°C and above. The system result after testing showed a mean absolute percentage deviation (MAPD) of 4.69% when compared to standard mercury in glass thermometer. The device can be used in laboratories, industries as well as other application requiring accurate temperature measurements.

Keywords: Thermometer, Digital, PIC16F877A, LM35DZ, Microcontroller, Firmware.

1. Introduction

A thermometer is a device that measures temperature or temperature gradient. It has two important elements; the temperature sensor in which some change occurs with temperature change, and a converter which converts this into numerical value. (https://en.wikipedia.org/wiki/thermometer). Thermometers are of different type, among which is a digital thermometer. Digital thermometers are temperature sensing instruments that are easily portable, have permanent probes and a convenient digital display. (http://www.globalspec.com/)

Most digital thermometers and temperature related devices designed and constructed earlier used discrete components (such as timers, counters, decoder drivers etc.) and temperature sensors (such as thermistors etc.) [1][2] Though, some used microcontrollers with external analogue to digital converter (ADC) [3]. However, these devices occupied much space, have more weight, consume much power and are less flexible such that modification of the system requires replacing hardware components. On the other hand, the temperature sensor suffers problems such as non-linearity among others [4]. Meanwhile, for the microcontroller design, a microcontroller with an internal ADC incorporated is required. In this paper, a microcontroller based digital thermometer is designed and constructed. It is based on PIC16F877A microcontroller (as the heart of the system). Figure 1, gives the system block diagram and is in five modules; power supply, temperature sensor, PIC16F877A microcontroller, display and the alarm modules. The temperature sensor (LM35DZ) senses the surrounding or object temperature, the sensed temperature is then being decoded by the PIC16F877A microcontroller and finally the corresponding digital equivalent is displayed (in degree Celsius) on the display unit (7- segment display). The system (with the aid of a buzzer) also makes an alarm when the temperature reading is 40°C and above. This work shows that microcontrollers can be used as main control element/device to many electronic circuits, providing control, accuracy and flexibility in designs such that, system modification has nothing to do with the hardware part but the software code as opposed to discrete components design. The work also illustrates the elimination of external ADCs in microcontroller designs dealing with analogue signals.

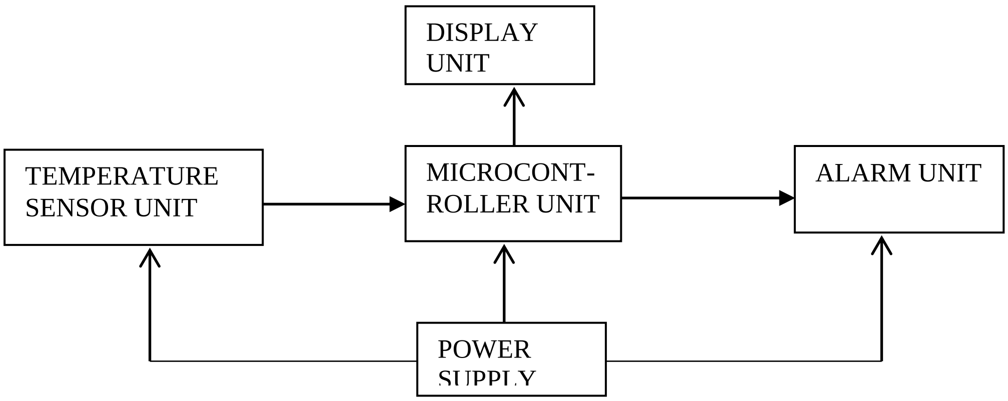


Fig. 1. System block diagram.

2. Design Methodology

The digital thermometer design is in two phases; Hardware and Software (firmware).

2.1 Hardware Design

The hardware design is divided into five units; power supply, microcontroller, temperature sensor, display and the alarm units. Figure 2 below gives the digital thermometer circuit diagram.

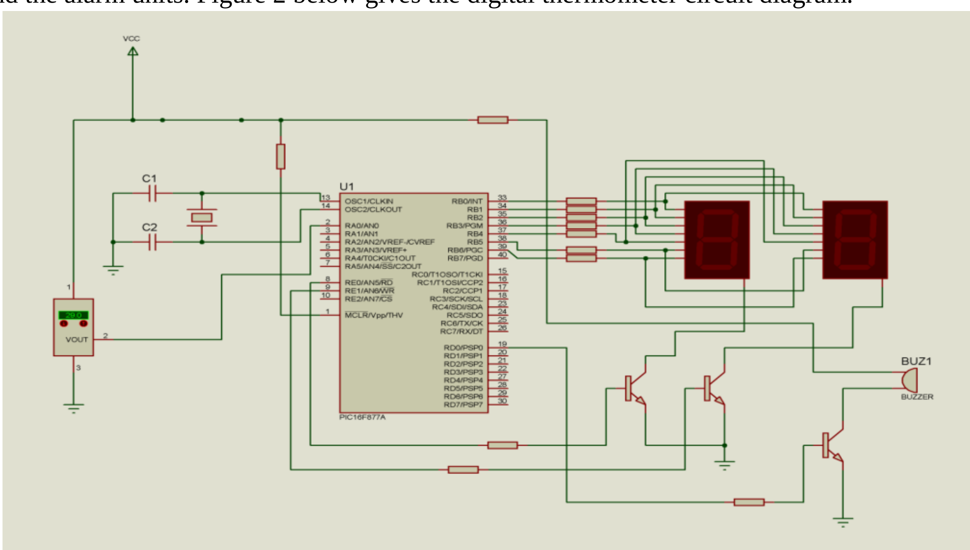


Fig. 2. Digital thermometer circuit diagram

2.1.1 Power Supply unit

The power supply requirement for the design is shown below;

$V = 6V$ [5][6][7]

$$I_L = 300.06mA \text{ , } where\ I_l = I_{load} = I_{MCLR} + I_{VDD} + I_{BUZZER} + I_{LM35}. -----(1)$$

I_{LM35} = Current through the LM35 (sensor) supply pin (0.06mA). [5]

I_{MCLR} = *Current through the reset pin* (25mA). [6]

I_{VDD} = Current through the microcontroller supply pin (250mA). [6]

I_{BUZZER} = Current through the buzzer supply pin (25mA). [7]

A 9V dc battery (Energize 522) [8] is used as the power supply with LM7806IC to regulate the voltage to a steady +6V. The battery makes the device portable and is readily available in the market.

2.1.2 Microcontroller unit

The microcontroller selected for this work is PIC16F877A. It is a 40-pins dual inline package (DIP), having five ports (A-E), 8- input channels (analogue to digital module), 8k flash program memory and much more [6]. It is chosen due to its in-built analogue-to-digital module, reduced instruction sets (35), among other features [6]. The microcontroller is also readily available in the market. Its diagram and pin connection is shown in fig. 3 below.

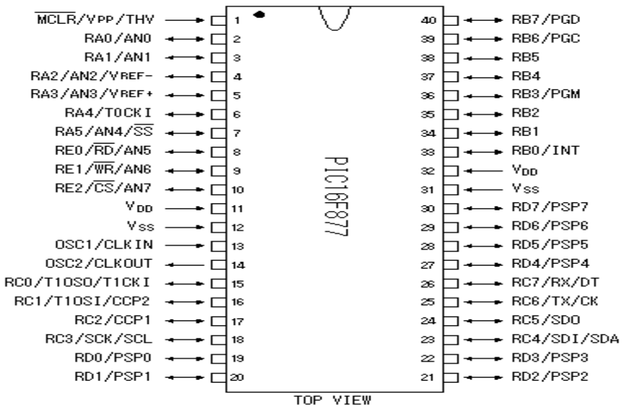


Fig. 3. PIC16F877A [6]

Quartz crystal is chosen for this work due to its stability. The PIC16F877A oscillator is configured as an on-chip, only requiring the crystal oscillator at pin 13 and 14, with appropriate capacitors C1 and C2 respectively [6]. It is recommended that 15pF capacitor be used each for both C1 and C2 for a clock frequency of 4MHz. The clock frequency (4MHz) is chosen for ease of calculation and perfect timing since; one instruction cycle is equal to four oscillation periods [6]. Therefore, for an oscillator frequency of 4MHz, the execution time will be 1-microsecond. Fig. 4 below gives the crystal oscillator set up diagram.

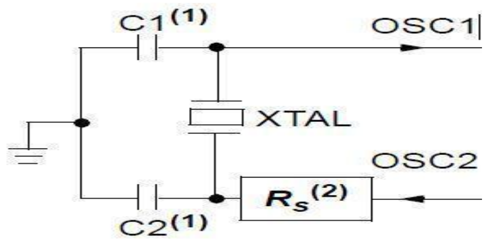


Fig. 4. Crystal oscillator set-up diagram [6]

2.1.3. Temperature sensor unit

LM35DZ [5] of the LM35 precision centigrade, integrated circuit temperature sensor series was selected for this work. Its output is linearly proportional to the Celsius (centigrade) temperature scale, as user does not require any calibration to obtain convenient centigrade scaling [5]. Its linear output [5], low output impedance [5], inherent precision calibration [5], easy interfacing and availability make it the choice for this work. Its output voltage is given by;

$$Vout = 10mV * T \qquad (1)$$

Where V_{out} is the LM35 output voltage and T is the temperature in ^{o}C

The output temperature range of LM35DZ is 0 ^{o}C to 100 ^{o}C [5]. Using eqn.1 above, the output voltage range is 0V to 1V.

The LM35DZ voltage supply is given by; $4V \leq Vs \leq 30V$ [5] (2)

And the digital thermometer power supply is 6V. Thus, the condition in eqn. 2 above is satisfied.

2.1.4 Display unit

The display unit displays the sensed temperature in digital form after being processed by the PIC16F877A microcontroller. A seven segment led display (double digit) [9] is used in this work in multiplexed mode. The common cathode type (523E) [9] is used. The LEDs in the seven segment display are operated in forward bias as shown in fig. 5 below. This display type is used due to its high brightness and high contrast, solid state reliability, wide viewing angle (http://www.digikey.com), availability and easy interfacing.

$I_F = 25mA$, where I_F is the diode forward bias current [9].

$R = V/I = 5/(25 \times 10^{-3}) = 200 ohms$.

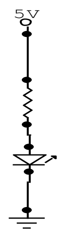


Fig. 5. LED Circuit in Seven Segment Display

The display unit and the buzzer (alarm unit) are both connected and disconnected from the microcontroller with the help of some transistors. Three 2N3904 general purpose [10] transistors were used for these purposes. This transistor is used due to its small load switching capability, with high gain and low saturation [10]. It is also readily available. The base current I_b and the base limiting resistor R_b were found as shown below using the other variable value from the 2N3904 datasheet [10].

$$I_b = \frac{I_{c(sat)}}{h_{fe}} \; [10] \qquad (3)$$

$$= 0.2/200 = 1mA$$

$$R_b = \frac{V_{CC} - V_{be}}{I_b} \; [10] \qquad (4)$$

$$= (5 - 0.7)/(1 \times 10^{-3}) = 43K\Omega \quad ,$$

$$where \; V_{be} = 0.7V \; for \; silicon.$$

2.1.5 Alarm unit

A buzzer (EMB-2306L) [7] is used to generate a sound when the sensed temperature is 40 ºC and above. This buzzer is chosen due to its low cost, and built-in drive circuitry (http://www.kitronik.co.uk). The buzzer supply current-limiting resistor R is given by;

$$R = V/I = 6/(25 \times 10^{-3}) = 240\Omega.$$

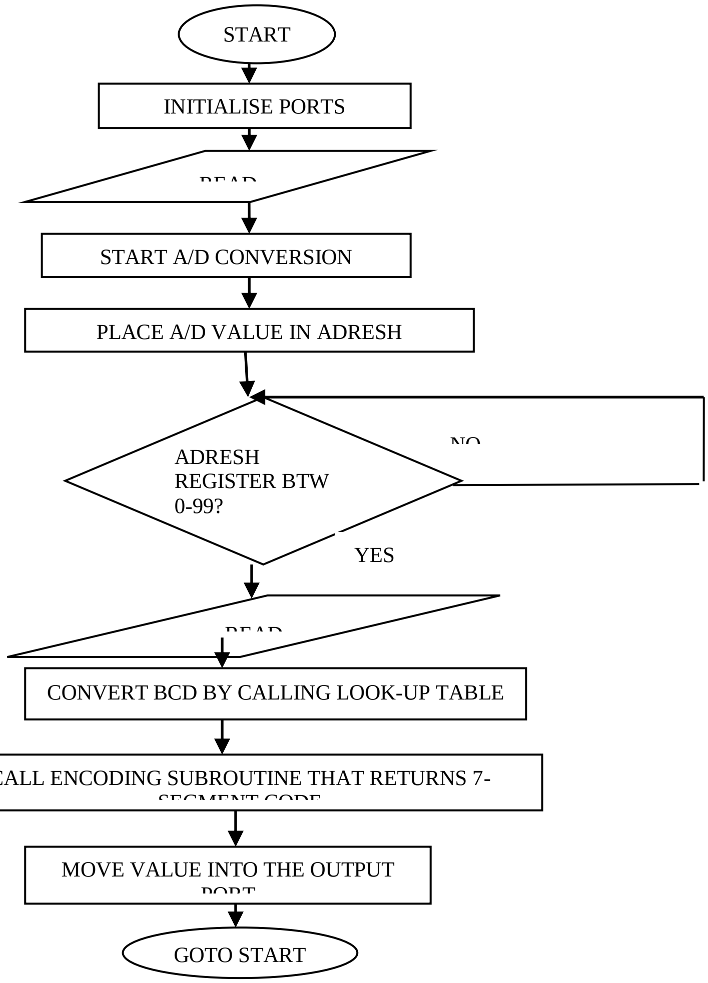


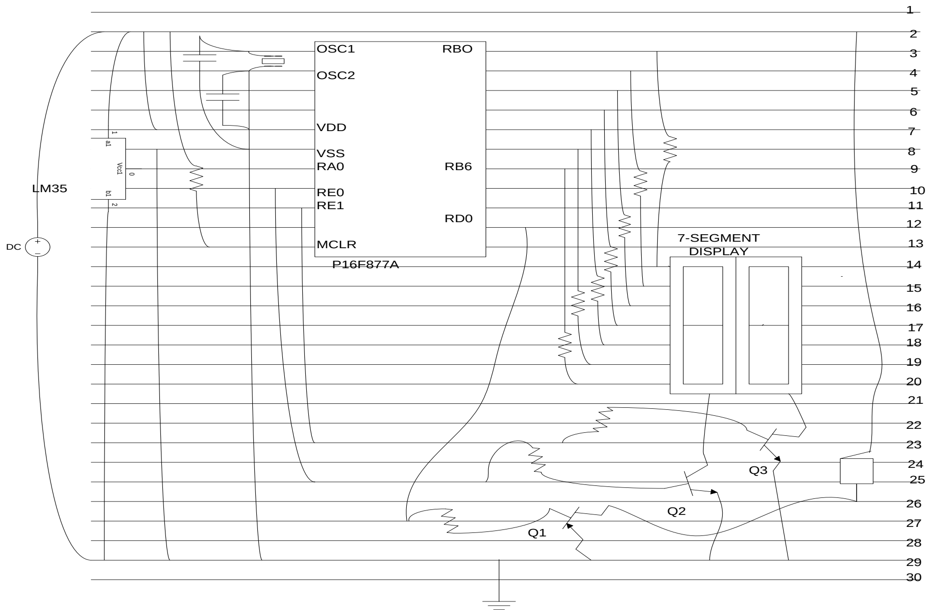
Fig. 6. Program flow chart

2.2 Software Design (Firmware)

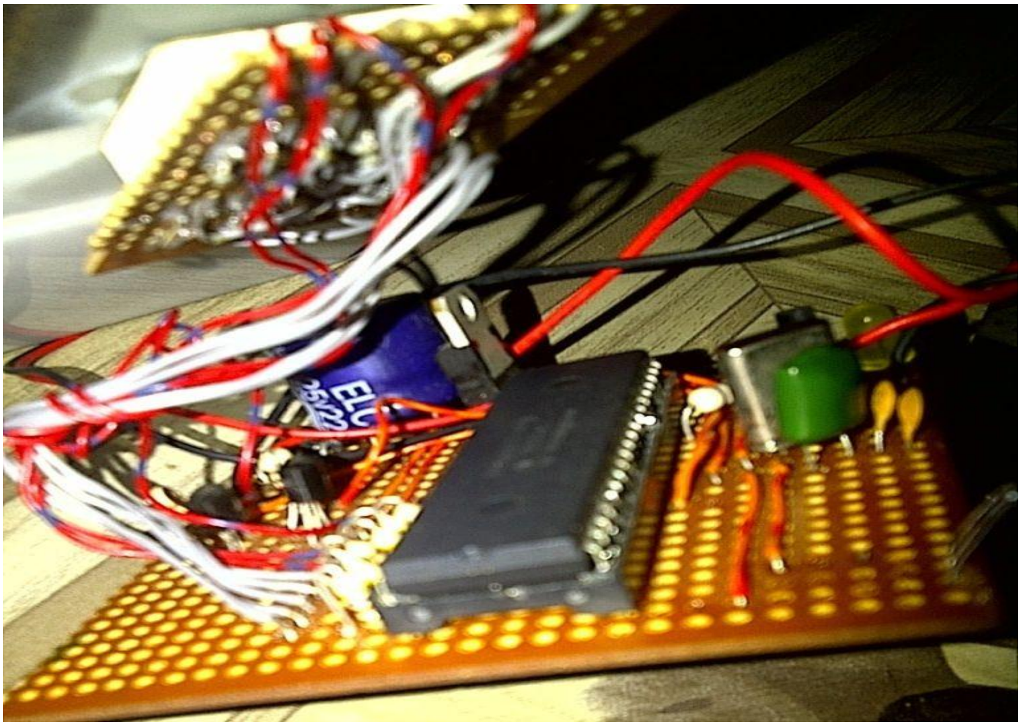
The firmware design constitutes the program flow chart and the control program codes. The program flow chart is given in fig. 6 below. The system control as well as the digitization of the analogue signal (sensed temperature) is done by the firmware. The source code is written in assembly language and assembled using MPLAB IDE (http://www.microchip.com), then burnt on to the PIC microcontroller program memory.

3. Implementation (Construction)

Before implementing the circuit on a Vero board, the components were tested to confirm their rated values. The components were carefully soldered to avoid damage. Short circuits and continuity test were then carried out on the circuit board. Fig. 7 (a) and (b) below respectively, gives the connections diagram and the system snap during implementation.



(a)



(b)

Fig. 7. (a) Connections diagram, (b) System snap shot during implementation

4. Discussion of Results

On completion of the system assembly, the digital thermometer was tested and compared to standard mercury in glass thermometer to measure temperatures. The result is tabulated as shown in table 1 below and fig. 8 gives the graphical result of the comparison.

Table 1. Experimental results

S/No	READING (^{0}C) MERCURY THERMOMETER	READING (^{0}C) DIGITALTHERMOMETER	DIFFERENCE	% ERROR
1	20	21	1	5.00
2	22	23	1	4.55
3	24	26	2	8.33
4	26	28	2	7.69
5	28	29	1	3.57
6	30	29	1	3.33
7	32	33	1	3.13
8	34	36	2	5.88
9	36	37	1	2.78
10	38	39	1	2.63

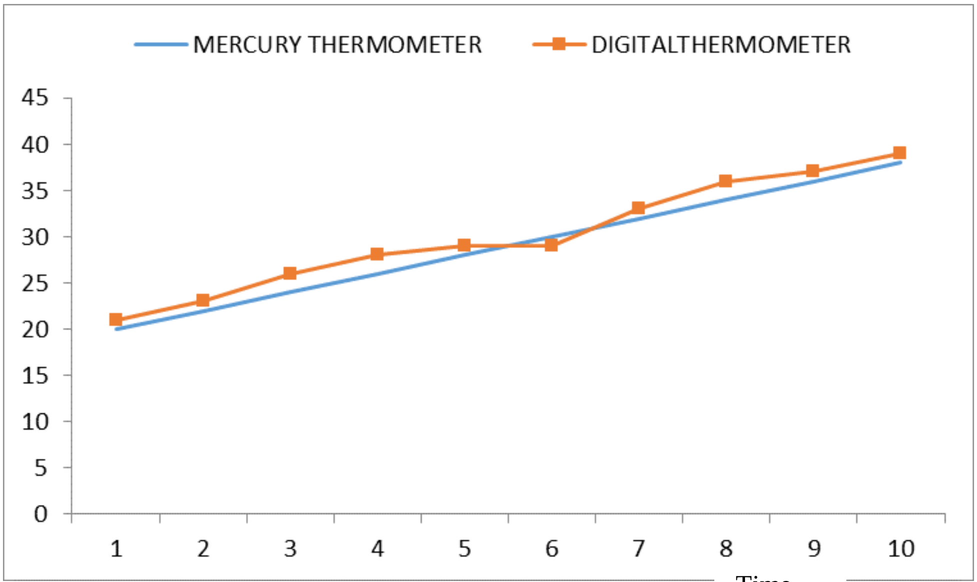


Fig. 8. Graph of measured temperatures against ti

The percentage errors [11] in Table 1 above are found using the relation;

$$\%error = \frac{|\text{Exact value} - \text{Approximate value}|}{\text{Exact value}} * 100 \qquad (5)$$

Where exact value is the temperature reading from the mercury thermometer, approximate value is the temperature reading from the digital thermometer.

To find the deviation of the digital thermometer, the mean absolute percentage deviation (MAPD) [12] is used. The mean absolute percentage deviation (MAPD) is given by the relation;

$$M = \frac{100\%}{n} \sum_{t=1}^{n} \left| \frac{A_{t-F_t}}{A_t} \right| \qquad (6)$$

Where A_t is the temperature reading from the mercury thermometer, F_t is the temperature reading from the digital thermometer, and n is the number of different times the readings are taken.

From eqn. 6 above,

$$\text{MAPD} = 4.69\%$$

It could be seen from the above results that the digital thermometer has a mean absolute percentage deviation (MAPD) of 4.69% when compared to the standard mercury in glass thermometer. This is possibly due the display unit used as it cannot display fractional temperature readings. This also proves the linearity in the output of the temperature sensor and the accuracy of the analogue to digital conversion process by the PIC16F877A ADC module. The system also makes an alarm when the temperature reading is 40 ^{o}C and above during testing.

5. Conclusion and Recommendation

In this paper, a digital thermometer based on the PIC16F877A microcontroller has been designed and implemented, hence the aim achieved. The temperature sensor (LM35) senses the surrounding temperature. The sensed temperature (analogue signal) is then being decoded by the microcontroller and finally displayed on the display unit (seven-segment display) in digital format (in degree Celsius). The system also makes an alarm when the temperature reading is 40^{0}C and above with the aid of a buzzer. It is recommended that this thermometer may be enhanced by using Liquid Crystal Display (LCD) to increase the output precision and memory device to store measured readings.

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