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Design Implementation of a Logger-Based Digital Thermometer

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Abstract. LM35 temperature sensor is a widely used 3-terminal sensor known for its precise temperature measurement capabilities without the need for external calibration circuitry. With a sensitivity of 10mV/°C, it operates within a temperature range of -55°C to 150°C, with an error margin of 0.5°C. This paper presents the development and testing of a logger-based digital thermometer using LM35 sensor, integrated with a dsPIC30F4013 digital signal processing controller, an LCD, a real-time clock (DS1307), and other essential components. The methodology involves the analysis of the sensor's sensitivity and its response under both stress and non-stress temperature conditions. The findings indicate that the sensor's output closely follows the theoretical sensitivity, with a negligible offset, ensuring accurate temperature measurements. Comparative analysis with a standard laboratory thermometer suggests that the digital sensor provides superior precision, with an error margin of ±0.01°C. The results confirm LM35's suitability for accurate ambient temperature monitoring and validation of environmental temperature fluctuations.

Keywords: LM35 temperature sensor, sensitivity, measurement, monitoring

Introduction

A logger-based digital thermometer is a device that combines the functionality of a thermometer with the capability to log and record temperature data over time (Bryzek, 2005). This type of thermometer is commonly used in various industries and applications where accurate temperature monitoring and data analysis are crucial (Pecoraro *et al*., 2021). The logger-based digital thermometer typically consists of a temperature sensor, a digital display, and a data logging system. The temperature sensor measures the ambient temperature and sends the data to the digital display, which provides real-time temperature readings. Additionally, the thermometer is equipped with a data logging system that allows the user to record and store temperature data at regular intervals. One of the key advantages of this digital thermometer is its ability to provide a comprehensive temperature profile over a specific period (Alan and Reza, 2021). This is particularly useful in environments where temperature fluctuations need to be closely monitored, such as laboratories, food storage facilities, or industrial processes. By logging temperature data at regular intervals, users can analyse trends, identify anomalies, and make informed decisions based on the collected data (Saidu *et al.*, 2014). Furthermore, logger-based digital thermometers often offer features like alarm notifications, data export options, and customizable logging intervals, providing users with flexibility and convenience in temperature monitoring (Jose *et al*., 2014). Some models may also include additional sensors to measure parameters like humidity or pressure, further enhancing their versatility (Akinloye *et al.*, 2016). In summary, a logger-based digital thermometer is a powerful tool for accurate temperature monitoring and data logging. Its ability to record temperature data over time enables users to gain valuable insights, ensure compliance with regulations, and make informed decisions based on the collected data.

LM35 temperature sensor

LM35 is a 3-terminal sensor used for temperature measurement. It provides an analog output voltage which is proportional to the Centigrade (Celsius) temperature (Oluleke et al., 2017). Hence, it does not require any external calibration circuitry. With sensitivity of

10mV/degree Celsius, it measures temperature within the range of -55 °C to 150 °C with an error margin of 0.5 ^oC (Rob et al., 2017). Full specifications of the sensor are shown in the datasheet on Appendix 5. Table 1 shows the pin description while Figure 1 presents the schematic diagram of LM 35 temperature sensor respectively.

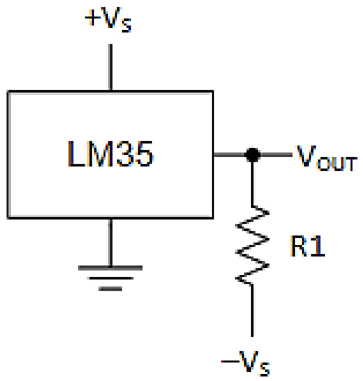


Figure 1: Schematic Diagram of LM 35 Temperature Sensor *(Texas Instrument, 2018)*

Table 1: Pin and Pin Description of LM 35 Temperature Sensor

Pin	Description
VCC (Pin1)	Supply Voltage (5V)
Out (Pin2)	Analog output voltage (mV)
GND (Pin3)	Ground

Since it has a sensitivity of 10mV/^oC, we can write the temperature-sensitivity Equation 1 thus:

$$Temperature = (V_{out}/10mV) * {}^oC \quad (1)$$

where V_{out} is output voltage in mV.

For full temperature range implementation, a resistance is clamped at the output as shown in Figure 2. The value of the resistance is given by Equation 2 (LM35 datasheet):

$$R_1 = -V_s/I_{load} \text{ (where } -V_s \text{ is the negative voltage supply)} \quad (2)$$

Materials

The following materials were used in realizing the research: Digital signal processing controller (dsPIC30F4013), Liquid Crystal Display (LCD), Real time clock (DS1307), Memory (µSD card), Voltage Regulators (LM7805 and LM7808), Temperature sensor (LM 35), Passive and active components, Programmer (PIC kit 3), DC sources (11.1v and 3.3v), MPLab IDE, Proteus, mikroC PIC Compiler, Mat Lab/Origin Lab.

Methods

Development of the Temperature Sensing Unit

In this work, LM35A is deployed as the temperature sensor due to its low current consumption (60µA) (Oluleke et al., 2017), good range (-55 °C to 150 °C) which accommodates the weather temperatures as well as its precise temperature output over thermistor and low impedance (0.1Ω) (Rob et al., 2017). For full temperature range implementation as shown in Figure 2, a resistance value, R is obtained from Equation (2),

$R = -V_s/I_{load}$ ($-V_s$ is the supply voltage and I*load* is the load current).

In this circuit, $V_s = 5.0V$, $I_{LOAD} = 50\ \mu A$ (datasheet) leading to R = 100k.

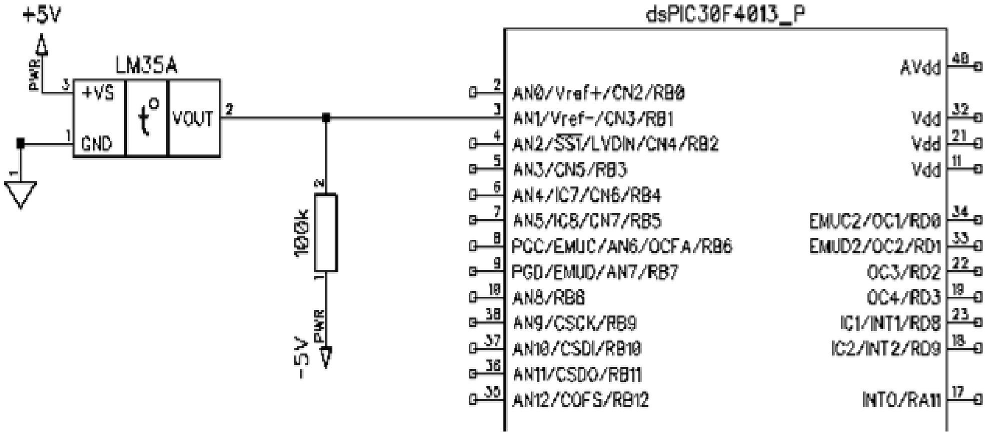


Figure 2: LM35 in Full-Range Temperature Sensor Configuration

Using the sensitivity Equation (57), *Temperature* = $(V_{out}/10mV) * {}^oC$ (where $-550mV \leq V_{out} \leq 1500$ mV), the algorithm for the temperature sensor was developed thus (Microchip, 2010; PIC C Compiler Reference, 2016):

```
/*Algorithm for temperature transducing interface with dsPIC30f4013*/
#define Temperature_Sensor 3 //Temperature Sensor input
//---Reading Temperature Sensor
void Process_Temp_Value()
{
ADC_Value = ADC1_Get_Sample (Temperature_Sensor);
Temp_Value = 0.00122 * ADC_Value; //convert 12-bit adc result to voltage
5/4096=0.00122
Temp_Value = Temp_Value / 0.01; //
//Temp_Value = Temp_Value + 0.5; // correcting error
}
```

To carry out the accuracy test of the thermometer, the digital thermometer along with other calibrated thermometers, were then subjected to both stress and non-stress (ambient) temperature conditions. The test results obtained are presented in Table 2.

From the result, Temperature = $(V_{out}/10.01339mV)* {}^oC - 4.26564$ which is in agreement with the sensitivity relation (Equation 2): Temperature = $(V_{out}/10\ mV) * {}^oC$ provided by LM35 datasheet.

Results and Discussion

Results

Table 2: Voltage-temperature Response and Stress Test Results for the Implemented Temperature Sensor (LM35A)

S/No	θ_A (°C)	θ_D (°C)	Voltage output (mV) (Measured)	Voltage output (mV) (Calculated)	ΔV(mV)	Error (°C) (Measured)
1.	0.50	0.00	0.002	0.000	2.0	0.50
2.	11.0	10.85	104.9	108.5	3.6	0.15
3.	14.0	15.91	150.6	159.1	8.5	-1.91
4.	15.0	18.58	181.5	185.8	4.3	-3.58
5.	17.5	20.85	203.4	208.5	5.1	-3.35
6.	19.0	22.08	219.8	220.8	1.0	-3.08

7.	20.0	23.42	229.6	234.2	4.6	-3.42
8.	22.0	23.44	230.0	234.4	4.4	-1.44
9.	23.5	24.60	244.3	246.0	1.7	-1.10
10.	24.0	24.68	243.5	246.8	3.3	-0.68
11.	24.5	25.30	249.8	253.0	3.2	-0.80
12.	24.5	25.50	252.5	255.0	2.5	-1.00
13.	24.5	25.51	251.2	255.1	3.9	-1.01
14.	25.0	26.10	254.1	261.0	6.9	-1.10
15.	28.0	28.42	278.3	284.2	5.9	-0.42
16.	33.5	34.00	336.1	340.0	3.9	-0.50
17.	50.0	51.35	497.0	503.5	6.5	0.65
18.	99.5	101.56	994.8	995.6	6.0	1.44

* θ_A: Analogue temperature reading
* θ_D: Digital temperature reading

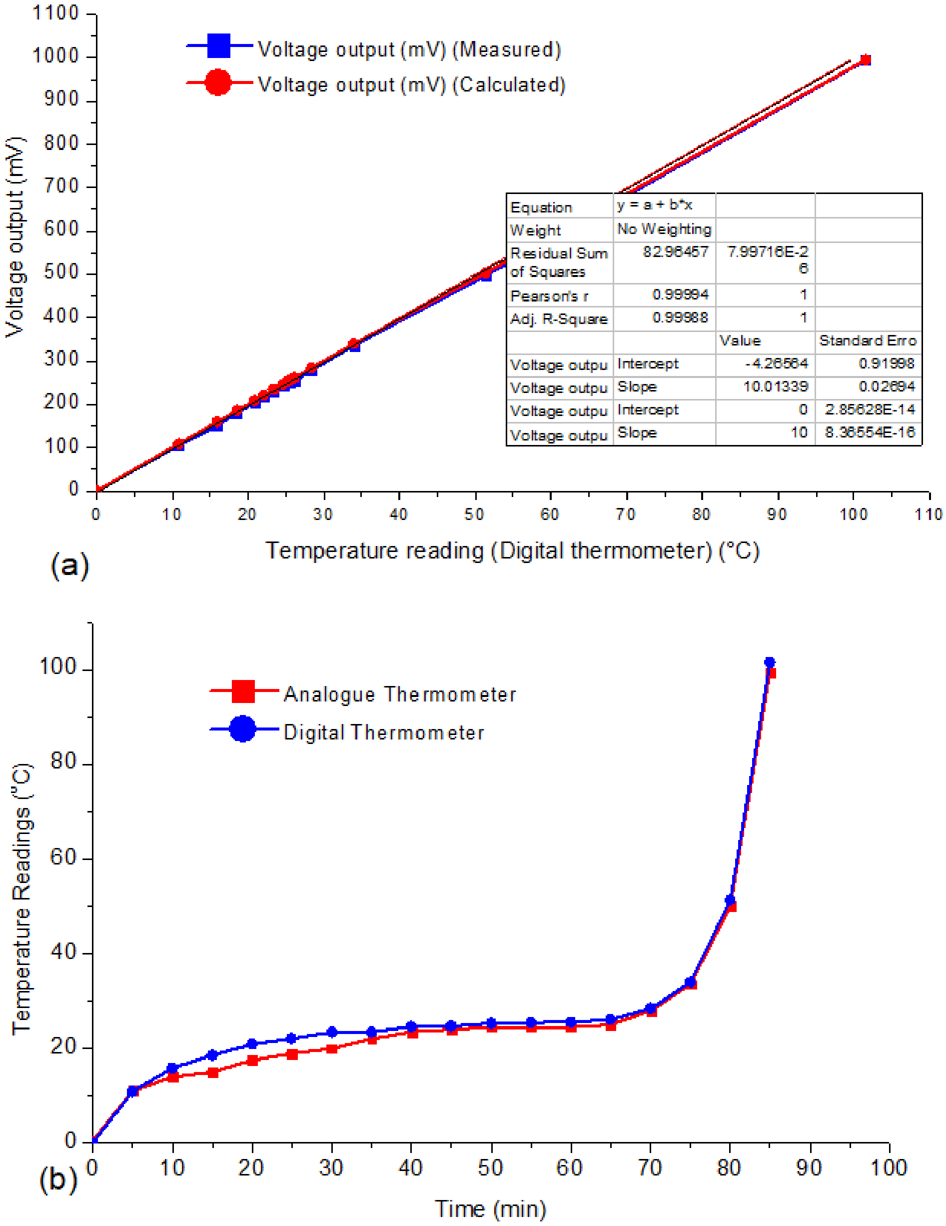
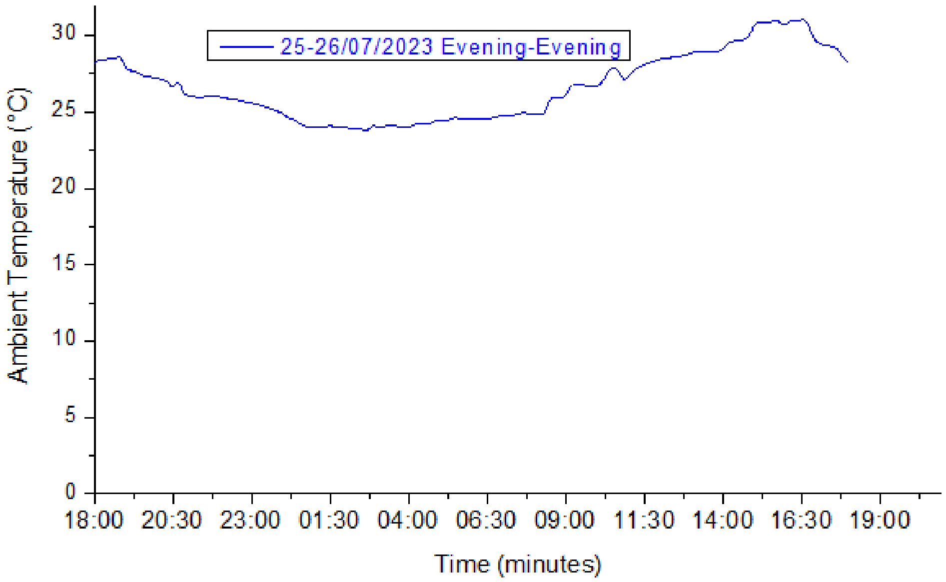
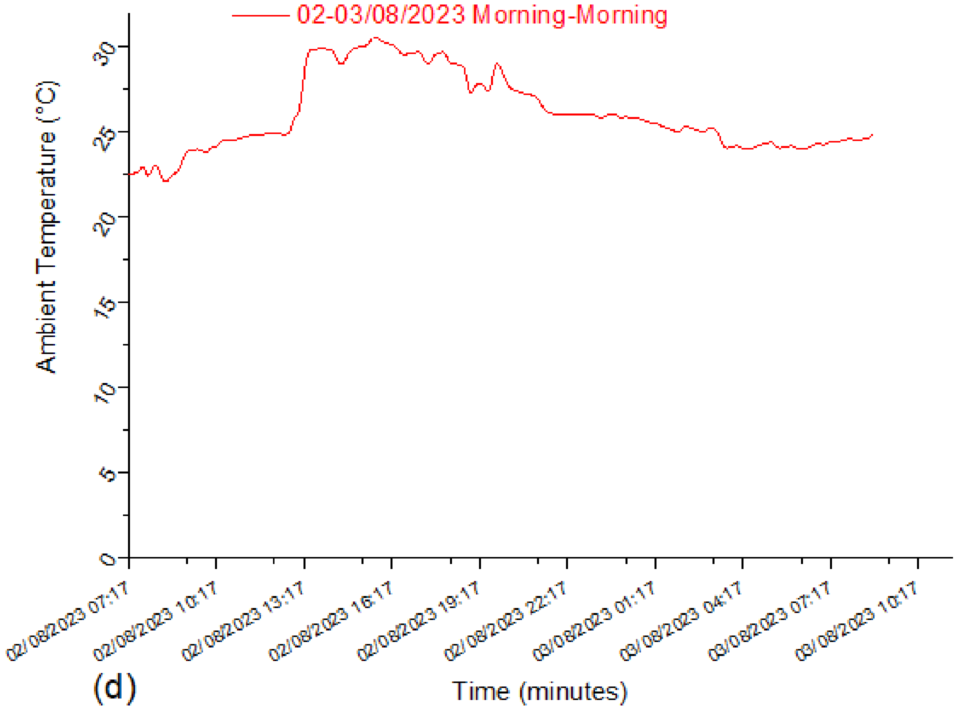


Figure 3: (a) Voltage-Temperature Response of the Implemented Thermometer (b) Stress Test Graph of Implemented Thermometer



(c)



(d)

Figure 4: (c & d) 24-Hour Ambient Temperature Graphs of the Implemented Thermometer

Table 2: 24-Hour Ambient Temperature Readings of Implemented Temperature Sensor (LM35A) *(25th -26th July, 2023 and 2nd- 3rd August, 2023)*

S/No	Time (min)- *July*	Temperature (°C)	Time (min)-*August*	Temperature (°C)
1	25:07:2023:18:00	28.20	02:08:2023:07:17	22.47
2	25:07:2023:18:10	28.43	02:08:2023:07:27	22.56
3	25:07:2023:18:20	28.43	02:08:2023:07:37	22.49
4	25:07:2023:18:30	28.45	02:08:2023:07:47	23.26
5	25:07:2023:18:40	28.48	02:08:2023:07:57	22.07
6	25:07:2023:18:50	28.69	02:08:2023:08:07	23.00
7	25:07:2023:19:00	27.77	02:08:2023:08:17	23.05
8	25:07:2023:19:10	27.69	02:08:2023:08:27	22.00
9	25:07:2023:19:20	27.62	02:08:2023:08:37	22.00

10	25:07:2023:19:30	27.41	02:08:2023:08:47	22.56
11	25:07:2023:19:40	27.32	02:08:2023:08:57	22.49
12	25:07:2023:19:50	27.23	02:08:2023:09:07	23.26
13	25:07:2023:20:00	27.20	02:08:2023:09:17	23.98
14	25:07:2023:20:10	27.10	02:08:2023:09:27	23.89
15	25:07:2023:20:20	27.01	02:08:2023:09:37	23.97
16	25:07:2023:20:30	26.38	02:08:2023:09:47	23.90
17	25:07:2023:20:40	27.26	02:08:2023:09:57	23.68
18	25:07:2023:20:50	26.12	02:08:2023:10:07	24.18
19	25:07:2023:21:00	26.04	02:08:2023:10:17	24.00
20	25:07:2023:21:10	26.00	02:08:2023:10:27	24.50
21	25:07:2023:21:20	25.95	02:08:2023:10:37	24.55
22	25:07:2023:21:30	26.00	02:08:2023:10:47	24.51
23	25:07:2023:21:40	26.04	02:08:2023:10:57	24.55
24	25:07:2023:21:50	26.01	02:08:2023:11:07	24.59
25	25:07:2023:22:00	26.00	02:08:2023:11:17	24.72
26	25:07:2023:22:10	25.91	02:08:2023:11:27	24.76
27	25:07:2023:22:20	25.80	02:08:2023:11:37	24.76
28	25:07:2023:22:30	25.80	02:08:2023:11:47	24.79
29	25:07:2023:22:40	25.74	02:08:2023:11:57	24.84
30	25:07:2023:22:50	25.62	02:08:2023:12:07	24.96
31	25:07:2023:23:00	25.54	02:08:2023:12:17	24.86
32	25:07:2023:23:10	25.54	02:08:2023:12:27	24.84
33	25:07:2023:23:20	25.38	02:08:2023:12:37	24.82
34	25:07:2023:23:30	25.24	02:08:2023:12:47	24.80
35	25:07:2023:23:40	25.15	02:08:2023:12:57	25.94
36	25:07:2023:23:50	25.04	02:08:2023:13:07	25.91
37	26:07:2023:00:00	24.90	02:08:2023:13:17	28.51
38	26:07:2023:00:10	24.56	02:08:2023:13:27	29.89
39	26:07:2023:00:20	24.49	02:08:2023:13:37	30.80
40	26:07:2023:00:30	24.26	02:08:2023:13:47	30.85
41	26:07:2023:00:40	24.07	02:08:2023:13:57	30.89
42	26:07:2023:00:50	24.00	02:08:2023:14:07	30.79
43	26:07:2023:01:00	24.05	02:08:2023:14:17	30.90
44	26:07:2023:01:10	24.00	02:08:2023:14:27	30.96
45	26:07:2023:01:20	24.00	02:08:2023:14:37	30.89
46	26:07:2023:01:30	24.12	02:08:2023:14:47	30.54
47	26:07:2023:01:40	23.99	02:08:2023:14:57	30.87
48	26:07:2023:01:50	23.96	02:08:2023:15:07	31.00
49	26:07:2023:02:00	23.98	02:08:2023:15:17	31.08
50	26:07:2023:02:10	23.89	02:08:2023:15:27	31.00
51	26:07:2023:02:20	23.97	02:08:2023:15:37	31.50
52	26:07:2023:02:30	23.90	02:08:2023:15:47	31.53
53	26:07:2023:02:40	23.68	02:08:2023:15:57	30.30
54	26:07:2023:02:50	24.18	02:08:2023:16:07	30.23
55	26:07:2023:03:00	24.00	02:08:2023:16:17	31.15
56	26:07:2023:03:10	24.03	02:08:2023:16:27	29.13
57	26:07:2023:03:20	24.10	02:08:2023:16:37	29.48
58	26:07:2023:03:30	24.19	02:08:2023:16:47	29.56
59	26:07:2023:03:40	24.02	02:08:2023:16:57	29.56
60	26:07:2023:03:50	23.93	02:08:2023:17:07	29.65
61	26:07:2023:04:00	24.00	02:08:2023:17:17	29.72
62	26:07:2023:04:10	24.14	02:08:2023:17:27	28.88
63	26:07:2023:04:20	24.27	02:08:2023:17:37	29.01
64	26:07:2023:04:30	24.25	02:08:2023:17:47	29.65
65	26:07:2023:04:40	24.22	02:08:2023:17:57	29.62
66	26:07:2023:04:50	24.43	02:08:2023:18:07	29.71
67	26:07:2023:05:00	24.44	02:08:2023:18:17	28.88

68	26:07:2023:05:10	24.44	02:08:2023:18:27	28.98
69	26:07:2023:05:20	24.50	02:08:2023:18:37	28.91
70	26:07:2023:05:30	24.64	02:08:2023:18:47	28.92
71	26:07:2023:05:40	24.48	02:08:2023:18:57	26.87
72	26:07:2023:05:50	24.59	02:08:2023:19:07	27.70
73	26:07:2023:06:00	24.50	02:08:2023:19:17	27.87
74	26:07:2023:06:10	24.55	02:08:2023:19:27	27.77
75	26:07:2023:06:20	24.51	02:08:2023:19:37	26.97
76	26:07:2023:06:30	24.55	02:08:2023:19:47	28.90
77	26:07:2023:06:40	24.59	02:08:2023:19:57	29.10
78	26:07:2023:06:50	24.72	02:08:2023:20:07	28.20
79	26:07:2023:07:00	24.76	02:08:2023:20:17	27.62
80	26:07:2023:07:10	24.76	02:08:2023:20:27	27.41
81	26:07:2023:07:20	24.79	02:08:2023:20:37	27.32
82	26:07:2023:07:30	24.84	02:08:2023:20:47	27.23
83	26:07:2023:07:40	24.96	02:08:2023:20:57	27.20
84	26:07:2023:07:50	24.86	02:08:2023:21:07	27.10
85	26:07:2023:08:00	24.84	02:08:2023:21:17	27.01
86	26:07:2023:08:10	24.82	02:08:2023:21:27	26.38
87	26:07:2023:08:20	24.80	02:08:2023:21:37	26.12
88	26:07:2023:08:30	25.97	02:08:2023:21:47	26.04
89	26:07:2023:08:40	25.94	02:08:2023:21:57	26.00
90	26:07:2023:08:50	25.94	02:08:2023:22:07	26.00
91	26:07:2023:09:00	25.91	02:08:2023:22:17	25.95
92	26:07:2023:09:10	26.89	02:08:2023:22:27	26.00
93	26:07:2023:09:20	26.75	02:08:2023:22:47	26.04
94	26:07:2023:09:30	26.72	02:08:2023:22:57	26.01
95	26:07:2023:09:40	26.70	02:08:2023:23:07	26.00
96	26:07:2023:09:50	26.70	02:08:2023:23:17	25.91
97	26:07:2023:10:00	26.87	02:08:2023:23:27	25.77
98	26:07:2023:10:10	27.70	02:08:2023:23:37	25.94
99	26:07:2023:10:20	27.87	02:08:2023:23:47	26.00
100	26:07:2023:10:30	27.77	02:08:2023:23:57	26.00
101	26:07:2023:10:40	26.97	03:08:2023:00:07	25.74
102	26:07:2023:10:50	27.35	03:08:2023:00:17	25.91
103	26:07:2023:11:00	27.79	03:08:2023:00:27	25.80
104	26:07:2023:11:10	27.93	03:08:2023:00:37	25.80
105	26:07:2023:11:20	28.10	03:08:2023:00:47	25.74
106	26:07:2023:11:30	28.23	03:08:2023:00:57	25.62
107	26:07:2023:11:40	28.33	03:08:2023:01:07	25.54
108	26:07:2023:11:50	28.45	03:08:2023:01:17	25.54
109	26:07:2023:12:00	28.48	03:08:2023:01:27	25.38
110	26:07:2023:12:10	28.56	03:08:2023:01:37	25.24
111	26:07:2023:12:20	28.56	03:08:2023:01:47	25.15
112	26:07:2023:12:30	28.65	03:08:2023:01:57	25.04
113	26:07:2023:12:40	28.72	03:08:2023:02:07	24.90
114	26:07:2023:12:50	28.88	03:08:2023:02:17	25.38
115	26:07:2023:13:00	28.88	03:08:2023:02:27	25.24
116	26:07:2023:13:10	28.98	03:08:2023:02:37	25.15
117	26:07:2023:13:20	28.91	03:08:2023:02:47	25.04
118	26:07:2023:13:30	28.92	03:08:2023:02:57	24.90
119	26:07:2023:13:40	28.90	03:08:2023:03:07	25.24
120	26:07:2023:13:50	29.10	03:08:2023:03:17	25.15
121	26:07:2023:14:00	29.51	03:08:2023:03:27	25.04
122	26:07:2023:14:10	29.65	03:08:2023:03:37	24.03
123	26:07:2023:14:20	29.62	03:08:2023:03:47	24.03
124	26:07:2023:14:30	29.71	03:08:2023:03:57	24.10
125	26:07:2023:14:40	29.89	03:08:2023:04:07	24.19

126	26:07:2023:14:50	30.80	03:08:2023:04:17	24.02
127	26:07:2023:15:00	30.89	03:08:2023:04:27	23.93
128	26:07:2023:15:10	30.79	03:08:2023:04:37	24.00
129	26:07:2023:15:20	30.90	03:08:2023:04:47	24.14
130	26:07:2023:15:30	30.96	03:08:2023:04:57	24.27
131	26:07:2023:15:40	30.89	03:08:2023:05:07	24.25
132	26:07:2023:15:50	31.54	03:08:2023:05:17	24.45
133	26:07:2023:16:00	31.87	03:08:2023:05:27	24.03
134	26:07:2023:16:10	31.00	03:08:2023:05:37	24.03
135	26:07:2023:16:20	31.08	03:08:2023:05:47	24.10
136	26:07:2023:16:30	31.00	03:08:2023:05:57	24.19
137	26:07:2023:16:40	29.93	03:08:2023:06:07	24.02
138	26:07:2023:16:50	29.53	03:08:2023:06:17	23.93
139	26:07:2023:17:00	29.40	03:08:2023:06:27	24.00
140	26:07:2023:17:10	29.35	03:08:2023:06:37	24.14
141	26:07:2023:17:20	29.23	03:08:2023:06:47	24.27
142	26:07:2023:17:30	29.14	03:08:2023:06:57	24.25
143	26:07:2023:17:40	28.44	03:08:2023:07:07	24.22
144	26:07:2023:17:50	28.27	03:08:2023:07:17	24.43
145	26:07:2023:18:00	28.20	03:08:2023:07:27	24.44
146			03:08:2023:07:37	24.44
147			03:08:2023:07:47	24.50
148			03:08:2023:07:57	24.64
149			03:08:2023:08:07	24.48
150			03:08:2023:08:17	24.50
151			03:08:2023:08:27	24.59
152			03:08:2023:08:37	24.59
153			03:08:2023:08:47	24.91

Discussion of Result

The LM35 is a popular temperature sensor that provides a linear output voltage proportional to the temperature being measured and has very low current consumption of about 60µA as well as self-heating (0.08^{o}C) (Oluleke *et al*., 2017). The temperature sensitivity of the LM35 is the coefficient representing the change in output voltage per degree Celsius change in temperature. It indicates how sensitive the sensor is to temperature variations. From Figure 3(a), the implemented temperature sensor has a sensitivity of (10.1339±0.91998)mV/^{o}C - (4.26564 ± 0.02694) compared to the design specified value of 10.0mV/^{o}C (datasheet). This offset factor is however negligible hence the temperature readings of the sensor are adjudged accurate within the purview of experimental considerations. The comparative stress test of the sensor vis-à-vis an analogue laboratory thermometer (standard sensitivity 0.1^{o}C) (Figure 4b) shows slight deviations at temperatures between 15 and 35 ^{o}C with the implemented digital thermometer in lead. The possible reason for the slight difference in the measured temperatures is that, 12-bit ADC values were not rounded up during digital conversion by the controller thus enhancing the accuracy of the system by 0.01°C. The measured temperatures therefore are likely to have error of ± 0.01 ^{o}C from the actual value which is more advantageous than the 0.1^{o}C accuracy in the analogue or conventional 10-bit digital thermometers. Moreover, the percentage error is insignificant within the fundamental intervals examined (Morris and Langari, 2012). Hence the LM35 sensor is suitable for deployment in ambient temperature monitoring as shown in Figure 4 (c) and (d). The 24-hour temperature readings recorded on the University Campus (25th-26th July, 2023 and 2nd-3rd August, 2023) are consistent with the average daily temperature readings of Makurdi town within the period (Akaahan et al., 2017).

Conclusion

This paper successfully implemented the development and testing of a logger-based digital thermometer using LM35 sensor, integrated with a dsPIC30F4013 digital signal processing controller, an LCD, a real-time clock (DS1307), and other essential components. The sensor's sensitivity and its response under both stress and non-stress temperature conditions have been tested and adjudged good. The findings thus indicate that the sensor's output closely follows the theoretical sensitivity, with a negligible offset, ensuring accurate temperature measurements. Hence the thermometer could be usefully deployed in environmental temperature monitoring in both temperate and arid zones of interest.

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