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Design, Construction and Calibration of a Multi-Scale Digital Thermometer

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Abstract
Background: *This work elucidates the simple design method of a low cost multi-scale digital thermometer based on PIC16F77A Microcontroller and temperature sensor LM35. LM35 is an analog sensor that converts the surrounding temperature to a proportional analog voltage. The sensor's output is connected to one of the Analog to Digital Converter (ADC) channel inputs of the Microcontroller to originate the equivalent temperature value in digital format. Ten digital values of temperature are stored and computed within a short duration to have maximum, minimum and average temperatures. Thereafter, the calculated forms of temperature are displayed in a 16×4 character LCD in four different scales correspondingly.*
Results: *This design process is more convenient than others as it is more economical, efficient and straightforward.*
Conclusion: *The constructed multi-scale digital thermometer was used to measure the temperature of two media at 1 minute interval for 5 minutes and values compares reasonably well with values obtained from an analog thermometer.*
Keywords: *Microcontroller, Sensor, LCD, Circuit board, Construction and Calibration*

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I. Introduction

The name thermometer is coined from the Greek words thermo, meaning "warm" and meter"to measure"[1]. Thermometers measure temperature by using materials that change in some way when they are heated or cooled [2]. The invention and creation of the first working thermometer have been credited variously to Abu Ali Ibn Sina, Cornelius Drebbel, Robert Fludd, Galileo Galilei and Santorio Santorio [3,4,1].

Modern thermometers are calibrated in standard temperature units such as Fahrenheit or Celsius and Kelvin. A thermometer has two essential elements: the temperature sensor in which some physical change occurs with temperature, plus some means of converting this physical change into a numerical value [1]. The temperature precision or resolution of a thermometer is simply to what fraction of a degree it is possible to do a reading.

Overall, this feature, in particular, dramatically extends the applicability of our digital thermometer. The temperature-range interrupt feature could enable this device as a control unit that drives an air conditioner, fan, or heater in a climate-controlled environment. It could send a control signal to turn – on a sprinkler system if the upper threshold is passed.

II. Materials And Methods

The temperature controller is an automated device constructed to detect, measure, record, and control a particular place's temperature condition based on user settings. In this work, the temperature is sensed, displayed and compared with a defined value set. If the measured temperature is greater/less, it controls the heating element's heat by changing its supply current. The ON-OFF type temperature controller method was implemented in this work. PIC16F877A was used as the controller and the cooling fan as an actuator. The materials and component used in the construction of the temperature controller includes: PIC16F877A microcontroller, Crystal Capacitor (4MHZ), Ceramic Capacitor (33pf), Button Switch, LM35 (Temperature Sensor), Rectifier diode (1N4007), Resistor (1kΩ, 10kΩ), LCD (LM016L), 7-Segment display, S8050 (NPN Transistor), Electrolytic Capacitor (1000µf, 35V) and LM7805 (Voltage regulator). This work is divided into four (4) segments, namely: Temperature sensor unit, Microcontroller/Logic unit, Display unit and Power supply unit. The block diagram of the work is as shown in Figure 1 below.

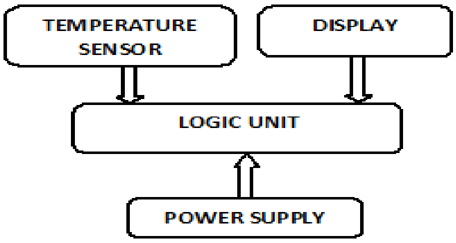

Fig. 1**:** Block Diagram of the Design

Temperature sensor unit

Every form of automation requires sensors to monitor parameters, as for the automatic fan regulator, the sensor is a temperature sensing IC called LM35 made by national semiconductors. This IC can monitor temperature between -55^{0}C to 150^{0}C. It represents one degree with 10mV. This signal is what the Microcontroller receives and digitizes with its ADC. The temperature sensor of the device works in conjunction with the ADC of the Microcontroller (PIC16F876A). LM35 picks up the temperature of the room and convert it to an electrical signal, which is coupled to the channel zero (RA0) of the ADC of the Microcontroller as shown in figure 2.

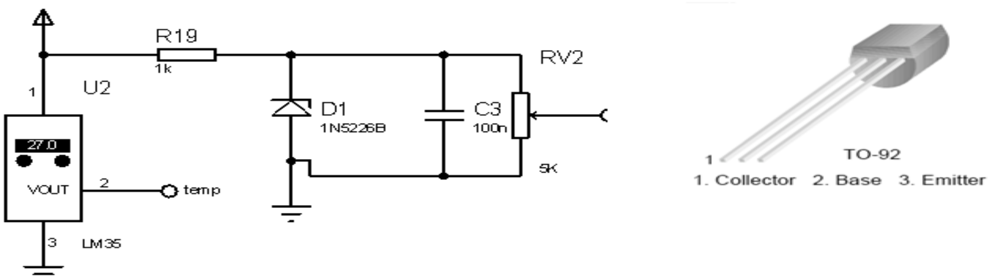

Fig. 2: Temperature Sensor LM35 and its calibration

The IC is powered with a 5V DC supply which automatically measures the temperature of its environment. The ADC converts the analog signal from the temperature sensor into its digital representation with respect to the reference voltage (1.023V) set with the potentiometer (variable resistor), RV1. The reference voltage is measured against a ground datum. The ADC of the Microcontroller in use is of 10 bit resolution. This means that it has 1024 different digital representations for voltages between the two reference points. The reference voltage in this design is set to 1.023V. This means that the ADC will divide the 1.023V into 1024 different levels with 0 as the 0V and 1024 as 1.023V. The variable resistor (RV1) is used to adjust the voltage drop across the 3.3V Zener diode (D1). This voltage through a variable resistor is set to 1.023V, which is the reference voltage to the ADC of the Microcontroller. The digitization will remain accurate so long as the reference voltage is accurate and stable. This is the reason for the filtration of the reference voltage with capacitors C3 and C4.

The Microcontroller/logic unit

The logic unit is the thinking faculty of the system. It is the central processing unit of the automatic fan regulator or controller, [5]. The microcontroller PIC16F877A, as shown in figure 3 is the heart of this unit. A microcontroller is a programmable logic IC capable of performing many functions within its design with the help of written instruction called a program. The Microcontroller in this design is the PIC16F877A; it has an inbuilt 10-bit resolution ADC. With its RAM, ROM, Ports and CPU, it can be mighty, bringing all the advantages of microcontroller technology into the design. This can emulate logic functions through the skills of the programmer and thereby reduce circuit complexity.

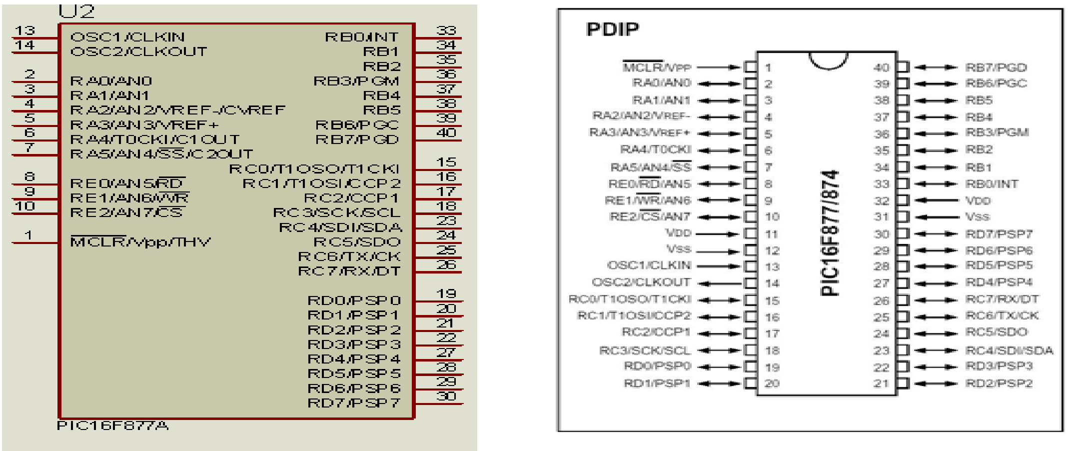

Fig. 3: PIC 16F877A Pin assignment

Display Unit

The display unit is the means through which the temperature controller's monitors the fan's activity and its current state and setting. The LCD used is the Hitachi 2x16-matrix, as shown in figure 4, which is used to display the user's set temperature. The design communicates to the LCD with six communication lines, four of which are the data line, while the other two are for state indication. 1KΩ resistors are used to limit the current through these lines. The LCD is powered through its Vdd and Vss lines with a 5V DC power source. The LCD has a backlight, which is activated by pushing the backlight button. The LCD constantly monitors temperature around the measurement field/range of the temperature sensor LM35 and displays the same on LCD module. This module makes it extremely easy to add an LCD to any project with its built in character set and easy command structure [6].

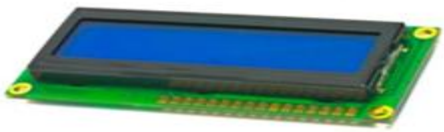

Fig.4: Circuit and hardware representation of an LCD (LM016L)

Power supply unit

The circuit power is sourced from the mains AC power line. This input is expected to be 50Hz, 220V. The fan uses this voltage directly, but the current is as allowed by the selected speed. The control circuit operates at 5V DC. This is achieved with the use of a transformer to step down the 220V to 12V. A bridge rectifier made with four diodes is used to rectify the signal.

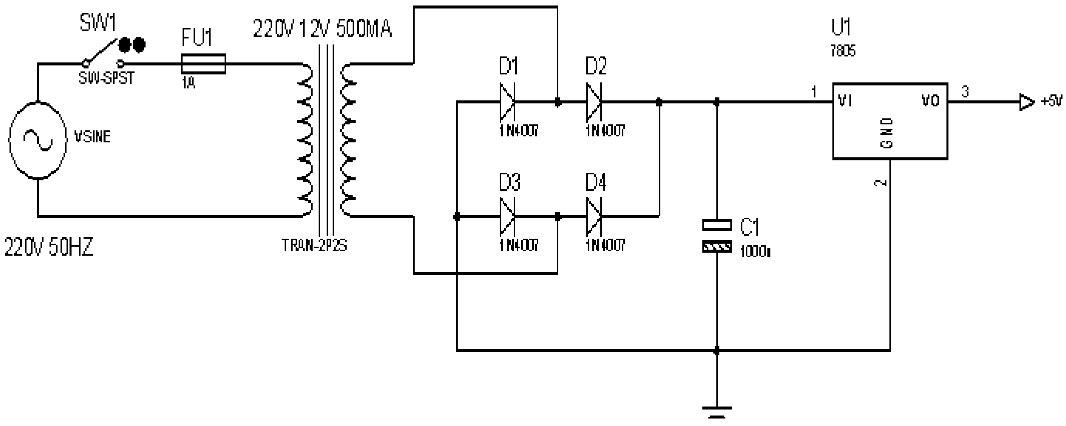

Fig. 5: The power circuit

After the rectification, the output voltage is a pulsating signal with double its original frequency. This is filtered with a filtering capacitor to produce a DC voltage which at this point is slightly higher than 11V. A voltage regulator (LM7805) is used to regulate the voltage at 5V. This regulator's maximum current capacity is 1A, and its output is used to power the logic unit, display, sensor, and speed relays. The power circuit is as shown in figure 5 above. Figure 6 shows the complete circuit diagram while figure 7 is the 3D representation module.

Power Unit Analysis and Design

The rectified output DC voltage (Vdc) can be obtained as; $V_{dc} = \frac{2V_m - 2V_a}{\pi}$ (1)

When the values are substituted into equation (1), it gives that; Vdc = (2 x 12 - 2 x 0.7)/3.142 = 22.6/3.142 = 7.19V. Where Vm = voltage from the secondary winding of the transformer, Va = Voltage drop across each diode, Vdc = Rectified DC voltage and π = 3.142.

To determine the capacitance value, C, we must consider the required ripple percent in the output DC voltage. The Capacitor must be able to withstand twice the DC voltage to avoid being over stressed.

Vcap = 1.5 to 3times Vpeak = (3 x Vm)/2

Vm = 12 volts as read from the output of the step-down transformer.

Vcap = (3 x 12 x 1.414)/2 = 25.452V $\simeq$ 25V

Therefore, a capacitor of a 25V rating was selected where the capacitance is derived from;

Vr = Idc/2Fc, where Vr = ripple voltage, F = mains frequency = 50Hz and Idc = load current which was assumed that maximum load current of 1Amps, therefore, Vr = 1/(2x50xC).

For a ripple factor of 5 percent, 0.05 = Vr/Vdc, therefore, Vr = 0.05x 7.19V = 0.3595V

C = 1/(2 x 50x 0.3595V) = 1/35.95 = 0.027816 = 27816 μf and we used 22000μf/25V capacitor.

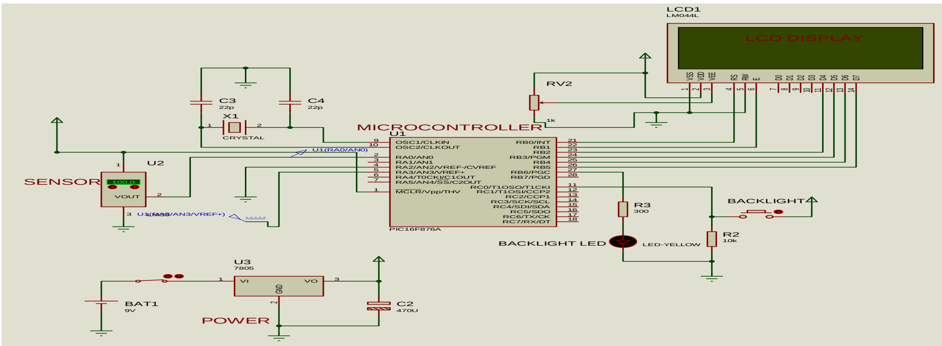

Fig.6: Project Complete Circuit Diagram

Fig.7: 3D representation module

III. Testing And Results

Microcontroller Unit: This is the heart of the automatic function that coordinates all other units' activities. The main component of this function is the PIC16F877A. This is a 40-pin microcontroller with many essential peripherals used to construct the temperature controller's automatic operation. The Microcontroller is programmed using the MikroC pro compiler v6.0.0. The circuit diagram is designed using Proteus (ISIS version 7.8), and the PCB (Printed circuit board) is designed using the ARES PCB designer. The Microcontroller software program is tested, simulated, and modeled using a Proteus circuit simulator, while the MikroC pro compiler was used to compile and debug the program software.

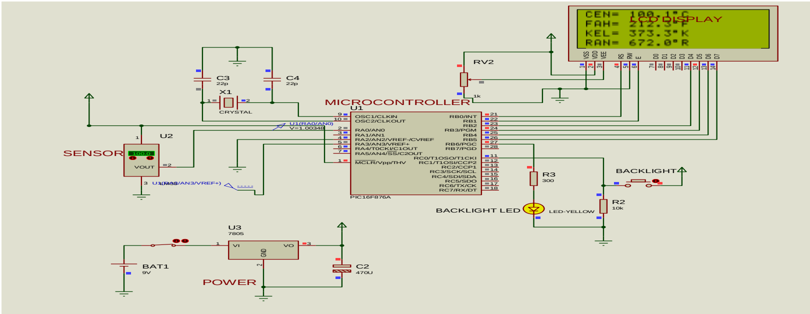

Fig.8: Circuit Simulation of the Microcontroller Unit

Temperature Sensor Unit: The temperature sensor is an electronic device used to convert electrical signals into digital signals that the Microcontroller then interprets into the system's automatic function[7]. The temperature sensor used is the LM35; this sensor can measure temperature (0-150)^{0}C. The sensor is programmed using the Microcontroller analog pin1 and the ADC register to interpret electronic signals into temperature. The accuracy and efficiency of the temperature were set using the RV1 variable resistor and 3.3V Zener diode to set the reference voltage used for the calibration of the sensor to 1024 bit of resolution. The temperature sensor was tested using the hot air from a soldering iron, and it was observed that the temperature on the 7-segment display increased as long as the soldering iron was still ON near the temperature sensor.

Fig. 9: Circuit Simulation of the Sensor Unit

Display Unit: The type of display used in this project is the LCD and the 7-segment display. These displays are the electronic device used to convert the electronic signals into numeric and alphanumeric characters. The LCD is used to display the user set temperature while the 7-segment display displays the current room temperature. All temperature information is channeled by the sensor digitally through the analogue channel (pin 2 of the Microcontroller to the Microcontroller for processing. After the processing, the result is displayed on the 7-segment display. At the same time, the set temperature and the fan speed are displayed on the LCD[8]. This unit is tested by changing the set temperature and the room temperature by using hot air from the soldering iron to cause a change the room temperature.

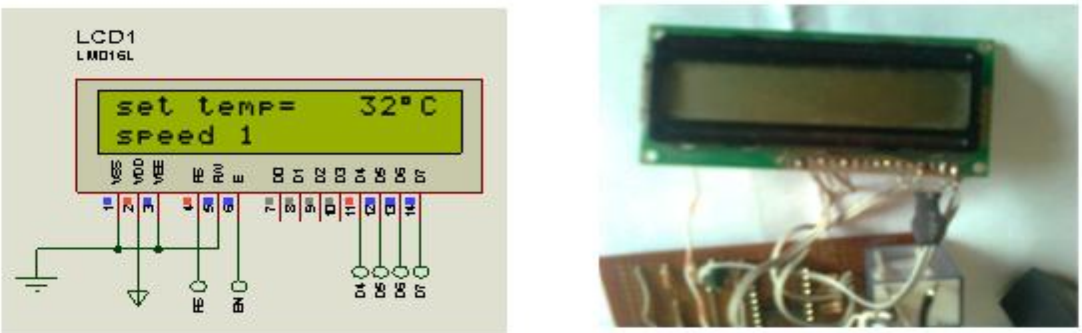

Fig.10: Display Unit

Software Test

The software is written, compiled, debugged, and simulated using the MikroC pro compiler shown in figure 11.Mathematically; Room temperature (T), Temp (T) = KS, Temp (T) = temperature measured in ^{0}C,S =sources of heat and K = Temperature Coefficient.

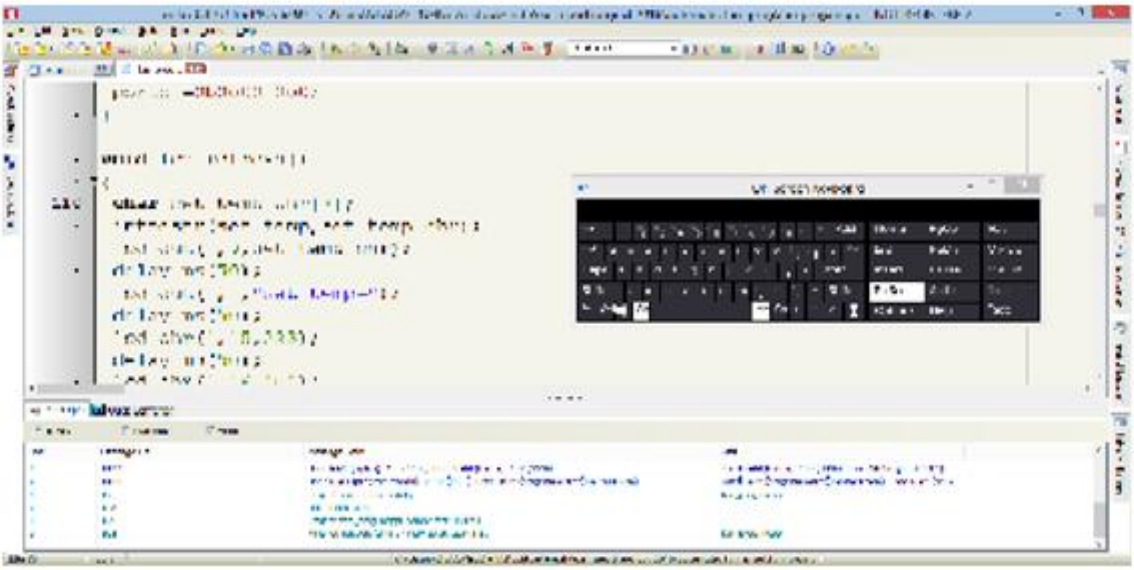

Fig.11: Software test diagram

IV. Discussions

A digital thermometer is an instrument used to measure the temperature of a substance or the surroundings automatically. In this work, a multi-scale digital thermometerconstructed had three main parts namely; sensor, Microcontroller and LCD parts. A DC voltage was developed as the output of the sensor (LM 35) which depended on the body's temperature to be measured. For every increase of 1^{0}C of temperature, 10mV voltage at the sensor output was found.We could measure the magnitude of temperature ranging from 0 to 102 degrees. Table 1 shows the result of taking the temperature of liquids (water and kerosene) with a stopwatch at intervals of 1 minute for 5 minutes using digital thermometer while Table 2 shows the result of taking the temperature of liquids (water and kerosene) with a stopwatch at intervals of 1 minute for 5 minutes using the analogue thermometer.

Table 1: Temperature of Liquids(Water and Kerosene) Using Digital Thermometer

Time (min)	^{o}C Water	Kero.	^{o}F Water	Kero.	^{o}R Water	Kero.	K Water	Kero.
0.0	60.80	60.2	141.44	140.36	601.11	600.03	333.95	333.35
1.0	59.40	55.9	138.92	132.62	598.59	592.29	332.55	329.05
2.0	57.60	52.2	135.68	125.96	595.35	585.63	330.75	325.35
3.0	55.30	49.1	131.54	120.38	591.21	580.05	328.45	322.25
4.0	53.80	46.2	128.84	115.16	588.51	574.83	326.95	319.35
5.0	51.40	43.6	124.52	110.48	584.19	570.15	324.55	316.75

Table 2: Temperature of Liquids (Water and Kerosene) Using Analog Thermometer

Time (min)	^{o}C Water	Kero.	^{o}F Water	Kero.	^{o}R Water	Kero.	K Water	Kero.
0.0	60.4	60.00	140.72	140.00	600.39	599.67	333.55	333.15
1.0	57.6	56.08	135.68	132.94	595.35	592.61	330.75	329.23
2.0	55.3	55.98	131.54	132.76	591.21	592.43	328.45	329.13
3.0	53.4	54.68	128.12	130.42	587.79	590.09	326.55	327.83
4.0	51.8	51.48	125.24	124.66	584.91	584.33	324.95	324.63
5.0	50.5	49.98	122.90	121.96	582.57	581.63	323.65	323.13

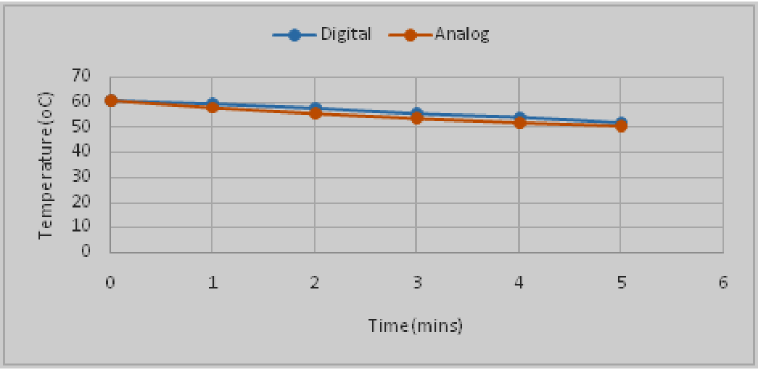

Fig. 12: Graph of Temperature of Water with Time Using Analog and Digital Thermometer

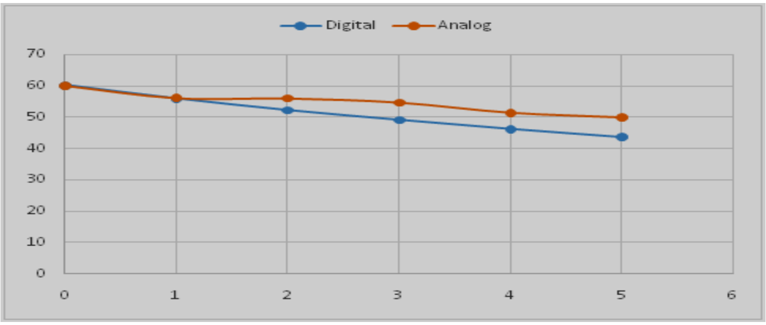

Fig. 13: Graph of Temperature of Kerosene with Time Using Analog and Digital Thermometer

Analysis of the graph of Figure 12 using Anova

Step 1:H_o: Group (digital and analogue) means are equal, **H_1:** Group means are not equal.

Step 2: F-ratio and Critical value

ANOVA: Single Factor (One way ANOVA)

Description

Groups	Count	Sum	Mean	Variance	SS
Digital	6	338.3	56.3833	12.5536	62.7683
Analog	6	329	54.8333	13.7787	68.8933

AnovaTable			Alpha	0.5		
Sources	SS	Df	MS	F-ratio	P-value	F-critical
Between Groups	7.2075	1	7.2075	0.5474	0.47638	0.4897
Within Groups	131.6617	10	13.1662			
Total	138.8692	11	12.6245			

Step 3: Result

From the above ANOVA table, Since **F-Critical<F-ratio,** we reject the null hypothesis (H_o) and conclude that the group means for Digital and Analog in water are not the same at a confidence interval of **50%**.

Analysis of the graph of Figure 13 using Anova

Step 1:H_o: Group (digital and analogue) means are equal, **H_1:** Group means are not equal.

Step 2: F-ratio and Critical value

One way Anova

Description

Groups	Count	Sum	Mean	Variance	SS
Digital	6	307.2	51.2	38.252	191.26
Analog	6	328.2	54.7	12.856	64.28

ANOVA Table			Alpha	0.1		
Sources	SS	Df	MS	F	P-value	F critical
Between Groups	36.75	1	36.75	1.4381	0.2581	3.2850
Within Groups	255.54	10	25.554			
Total	292.29	11	26.57181818			

Step 3: Result

From the above ANOVA table,Since **F-Critical**<**F-ratio,** we reject the null hypothesis (H_o) and conclude that the group means for Digital and Analog in Kerosene are not the same at a confidence interval of **90%.**Compared with commercially available analog thermometers, our device measures very well in accuracy and precision as depicted in Figures 12 and 13.

V. Conclusion

In conclusion, the multi-scale thermometer makes it very easy to measure the temperature of a given substance given the corresponding value in four different scales, making it very easy to convert from one scale to the other depending on the desired scale. It is easy to install and simple to use.Automation makes home and industrial appliances easy to use. There are many sensors for sensing different natural sensations and with the availability of digital and analogue electronic components, automation can be made possible. This automatic fan regulator is a typical example of a controller system using microcontroller. Some already automated devices can still be improved upon to enhance their performance and make life much better. The way this automatic fan regulator works can be further enhanced to make it better or cheaper through; incorporating a time base system whereby a time for operation can be programmable; creating a form of storage or database/temperature data logger that keeps a record of all previous records of temperature settings and their behaviors for easy referencing and analysis of a particular geographical area's weather condition; and incorporating a temperature and humidity visual display system that shows all temperature measured by the sensor and one set by the user.

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