Comparative Analysis of Temperature Sensors and Selection of Temperature Sensor for Concrete Temperature Monitoring to Study Concrete Maturity in Civil Structure

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Abstract : This paper presents the laboratory results of comparative analysis of three temperature sensors inserted into liquid state.The selection of suitable temperature sensor on the basis of this analysis, which would be useful for concrete temperature monitoring to study concrete maturity in civil structure. Different types of temperature sensors can be used for this.Concrete temperature plays an important role to study concrete maturity and strength of civil structure during curing and maturation period. The selection of proper temperature sensor is very important to find out reliable and accurate concrete maturity and strength in the civil structure. This paper presents comparative study of three type of temperature sensors to monitor the temperature of water using Arduino Uno hardware platform, ZigBee wireless communication, and JAVA software tool. This paper also compared results from the pairs of LM35 temperature sensors, K-Type thermocouple sensors and DS18B20 sensors based on its accuracy, response, range, reliability, size, and cost. The statistical analysis results show that the DS18B20 temperature sensorto be the most suitable sensor for concrete temperature monitoring**.**

***Keywords: Maturity, civil structure, thermocouple, Arduino platform, ZigBee*.**

I. INTRODUCTION

Sensors are essential part of an embedded system which used to sense the change in the physical parameters/quantity and converts it into a proper signals with the help of signal conditioning circuit. Failures in embedded system is mainly due to improper selection of sensors. Therefore, in order to prevent system failure, it is essential to select the proper sensor. The proper selection of temperature sensor is very important to predict compressive strength of the concrete in civil structure. These sensors embedded into the concrete structure plays an important role to predict compressive strength of in-place concrete at early ages. After concrete work, the temperature inside the concrete structure varies during curing process and it will be below 60^0C-80^0C. In-situ estimation of compressive strength of concrete in real-time, the different types of temperature sensors are used with different type of wireless communication techniques [6, 9, 10]. This paper shows comparative analysis of received temperature information from the pair of three type of temperature sensors viz. LM-35, K-Type thermocouple and DS18B20 sensor which were embedded into water. This paper also indicates studies and classification of these sensors on the basis of accuracy, response, range, reliability, complexability in signal conditioning, size and cost.

II. RELATED WORK

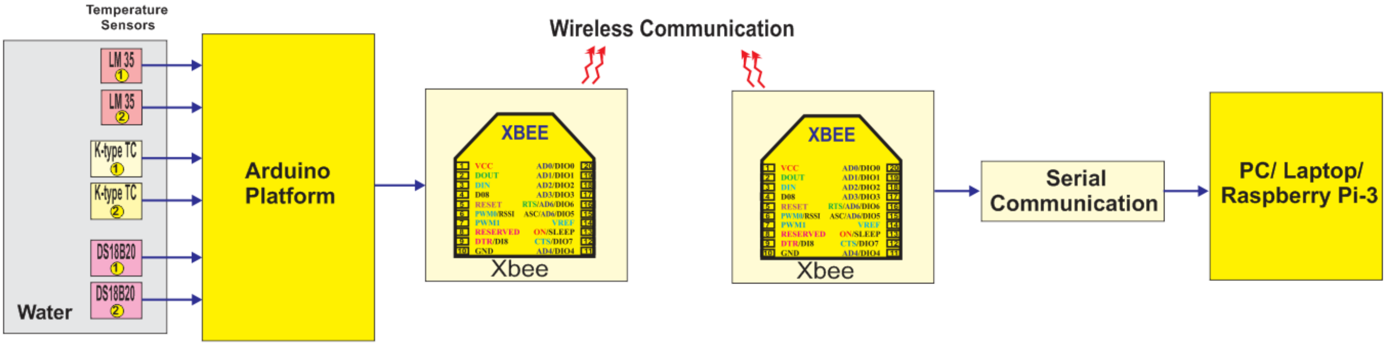
In the structural health monitoring of the concrete structure at early ages, the main emphasis on the prediction of in-situ concrete compressive strength by measuring and recording concrete curing time and temperature [4, 6, 8]. The temperature sensors play an important role to calculate and find out the maturity index for prediction of compressive strength of concrete. Therefore, it is very essential to comparative study the different type of temperature sensor based on wireless embedded system.

In the present survey, the embedded systems are based on Thermocouples, Dallas Semiconductor iButton®, NomadicsintelliRock™ and Identec Solutions i-Q Tag devices. But these systems are bulky, costly, and limited channel with limitations in Software [8, 12].

This survey indicates that researchers have attempted different methods, way and different types of temperature sensors to sense and measured the concrete temperature to predict the compressive strength of the concrete. After going through the extensive literature survey and analyzing obtainable work, it is understood that there is a lot of work done related to concrete temperature monitoring and measurement using different types of temperature sensors, but have a scope to develop cost effective wireless temperature sensor networks system for structural health monitoring. We develop compact and portable Arduino platform based wireless temperature sensors network using ZigBee S2C to measured water temperature with respective to time for pair of 3-type of temperature sensor and Java programmed based graphical user interface (GUI) with PC to monitor water temperature in real-time.

III. Block Diagram of System

Figure 1. Show the block diagram of microcontroller basedwireless temperature monitoring and recoding system.



a. Transmitter Section b. Receiver Section

Figure 1. Block diagrams of wireless temperature monitoring and recoding system.

The system setup is design for the comparative study of the three-type of temperature sensors. It can be divided into two main sections:a. Transmitter section and b. Receiver sections. This experimental setup used for comparative study of the 3-type of temperature sensor along with thermometer. The components of each section are as follows.

A. Transmitter section: It consists of temperature sensors, Arduino Uno platform using Atmega 328P Microcontroller andZigbee (Xbee S2C).

A.1. Temperature Sensors

In the designed system setup, pair of 3-type of temperature sensors viz. LM35, k-type Thermocouple and DS18B20 are used. The details are as follows.

i. LM 35 Temperature Sensor

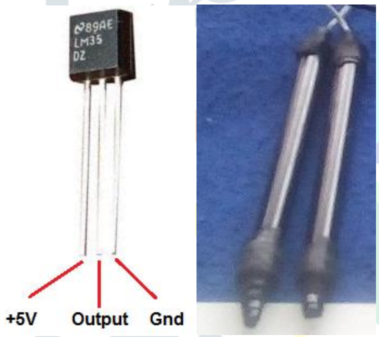


Figure-2: LM 35 Temperature Sensor

LM35 is a 3-terminal IC-based temperature sensor used to measure temperature. The measure temperature range for this IC is between -55°C to 150°C. It does not require any external calibration technique or trimming circuitry to provide accuracy. It has low-output impedance and linear output, can be operated used with single power supplies, or with plus and minus supplies, and also gives an analog voltage output proportional to the senses' temperature. The sensitivity of LM35 is 10mV/°C [ ]. In the experimental setup, LM35 temperature sensors are used with the plastic coating such that only sensing point is uncovered which is contact with the liquid for the temperature measurement.

ii. Thermocouple:

Figure-3: K-Type Thermocouple Sensor

It is one of the most versatile, cheap, rugged and low cost temperature sensor. It is most widely used due to its simplicity, ease of use and small size. It consists of two dis-similar metals joined together at one end while other ends are used for measurement. Thermocouple works on Seebeck effect. Thermocouples has the widest temperature range of all the temperature sensors from -200^{0}C upto 2000^{0}C. Thermocouple are made using different materials as per temperature range. E-type (-200 to 900^{0}C) ,J-type (0 to 750^{0}C), K-type (-200 to 1250^{0}C) ,N-type (0 to 1250^{0}C), and T-type (-200 to 300^{0}C) are the types of thermocouples with temperature range. The measure temperature range for k-type thermocouple is between -200^{0}C to 1250^{0}C. The output voltage of k-type thermocouple is small, may be in micro-volts. Therefore signal conditioning circuit using AD595 is needed to enhance the voltage range with respect to the temperature. With AD595 K-type thermocouple sensitivity is 10mV/^{0}C[1,13, 14].In the experimental setup, simplex k-type thermocouple temperature sensor probes are used with sheath of stainless steel such that only junction point tip is sensitive which is contact with the liquid for the temperature measurement.

iii. DS18B20 sensor

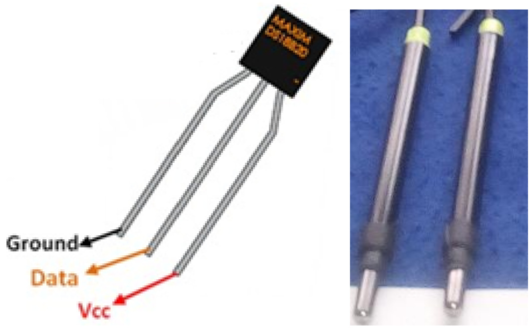


Figure-4: DS18B20 Temperature Sensor

DS18B20 is smart temperature sensor manufactured by DALLAS Semiconductor Company. It is a 3-terminal one-wire digital temperature sensor used to measure temperature with a minimal amount of hardware. The measure temperature range for this IC is between -55°C to 125^{0}C. Its output is in digital form and can be directly connected to development board without the need of any data converter. These are available in different form such as simple stand-alone DS18B20, waterproof DS18B20 and high temperature DS18B20 sensor. These sensors are handy and works very well in wet conditions. The accuracy of DS18B20 is ±0.5^{0}C from -10^{0}C to +85^{0}C for 9 to 12 bit [13]. Multiple sensors can connect to one digital pin for communication on sharing basis.In the experimental setup, waterproof DS18B20 temperature sensor probes are used with sheath of stainless steel such that only junction point tip is sensitive which is contact with the liquid for the temperature measurement.

A.2. Arudino Uno platform using Atmega 328P Micro-controller

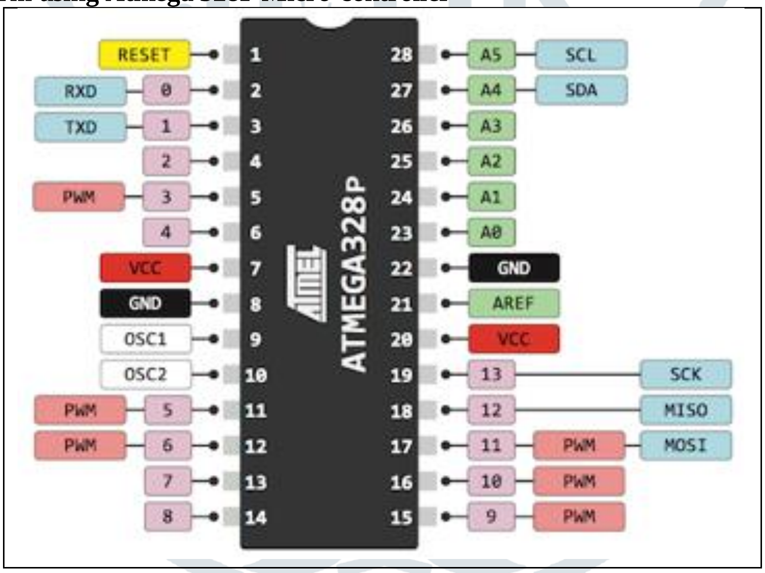


Figure-5: Arduino Uno Platformusing Atmega-328P Micro-controller

In Arduino Uno Platform, ATmega-328P microcontroller is used. It is single chip, 8-bit microcontroller manufactured by ATMEL.

It has Harvard architecture [14]. Its specifications are

- It is RISC based 8-bit microcontroller
- 32 KB ISP Flash memory
- 1KB EEPROM & 2KB SRAM
- Total 23 general purpose I/O pins
- 32 GPR , 3-Timers/Counters
- 10-bit ADC converters
- Serial programmable USART

In the experimental setup, ATmega-328P microcontroller is used for receiving the temperature information from the different types of sensors and wireless route this information toward the receiver section.

A.3. ZigBee S2C Transmitter

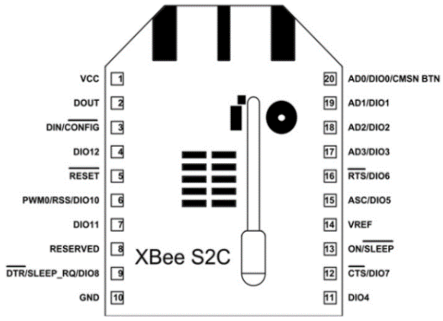


Figure-6: ZigBee S2C pin diagram

The ZigBee (XBee Series)S2Cis IEEE 802.15.4 based protocol used for the wirelesscommunication as shown in figure 6. It operates on an ISM 2.4 GHz band with transmission range up to 100 meters with 240 KBPs transmission speed. It can be configured in three modes i.e. coordinator, router, and end device and can be fitted in peer-to-peer, point-to-point, and mesh network topology. It is commonly applied in low-cost, low-power wireless sensor networks. The configuration of ZigBee S2C has done through the X-CTU software by Digi International [5, 8, 9]. It is configured in point-point communication topologies within 100mtr. In the experimental setup,for Transmitter 1stXBee S2C configure as an End Device and for Receiver 2ndXBee S2C configure as Co-ordinator.

The information transmission flow of XBee commences from the DIN pin's reception of the microcontroller signal, and the data is stored in a TX register until all information is received. After the microcontroller's information is received, the RF switch is activated to switch to transmission mode. Using the transmitter, the information in the TX register is communicated wirelessly to the XBee receiver.

B. Receiver section: It consists of Zigbee (Xbee S2C) receiver, serial communication unit and PC based GUI using JAVA

B.1. ZigBee S2C Transmitter

The XBee receiver accepts the information from transmitter and stores it in the RX registry.During receiving no data is sent to microcontroller. Once the entire information is received then only it will be communicated tothe computer through the DOUT pin of serial communication unit.

B.2. Serial communication unit

XBee S2C is interface to computer through serial communication unit.Received temperature information/data from transmission section which is connected to LM35, K-type thermocouple, DS18B20 temperature sensors are store in computer. This time-temperature information/datawill be used for displaying and analysis of concrete maturity.

B.3. GUI using Java

Received temperature information from the LM35, K-type thermocouple, DS18B20 temperature sensors are display in a digital format on the computer screenand then record it in the PC for further analysis with the help of graphical user interface (GUI) using JAVA programming software [15].

IV. Experimental Setup

Figure 7(a) and (b) shows the experiment setup used for comparative study of the 3-type of temperature sensor along with thermometer. Figure 8(a) and (b) shows the screen-shot of JAVA based GUI for analysis and selection of proper temperature sensor for concrete temperature monitoring to study concrete maturity in civil structure.

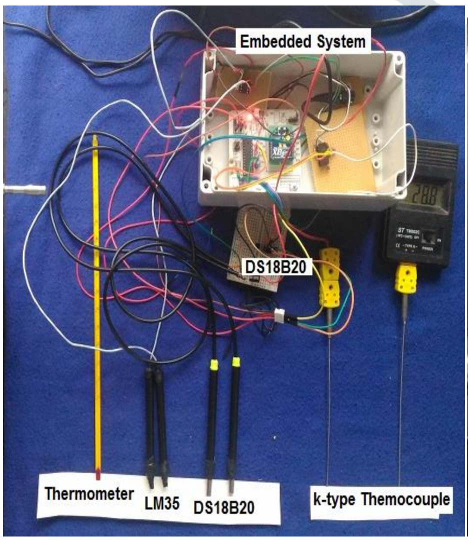


Figure 7(a): Embedded System with temperature sensors

Figure 7(b): Temperature Sensors embedded in water bath

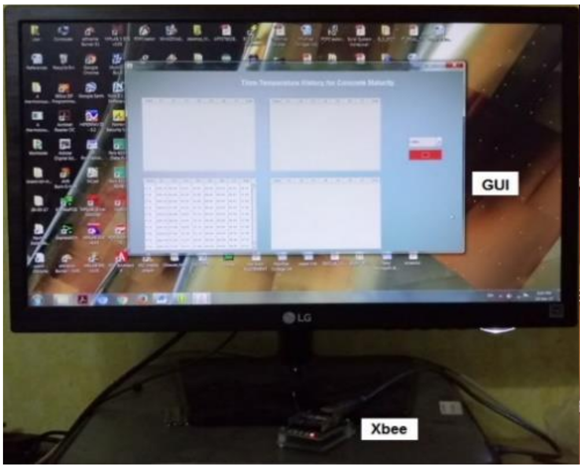


Figure 8(a): Zigbee based Receiver section with 4-Nodes

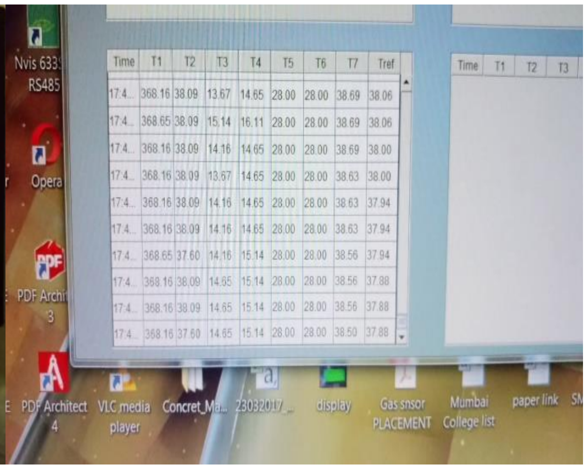


Figure 8(b): Data received from all Temperature Sensors

The pair of LM35, K-type thermocouple, DS18B20 temperature sensors are installed into the water along with thermometer and stand-alone K-type thermocouple temperature display system. The temperature of water varies using water heating coil arrangement. There outputs of 3-types of temperature sensor are attached to signal conditioning circuit and then to Microcontroller ATmega-328P and ZigBee-S2C. The water temperature variation is sense by each temperature sensor and transmitted to PC through the ZigBee S2C communication except thermometer and stand-alone temperature display system for k-type thermocouple. Here the ZigBee S2C configured as Router/END device at Transmitter. ZigBee S2C configured as Coordinator device to receive the temperature information coming from different 3-types of temperature sensor and then record it in the PC.

The transmitter section uses the internal ADC of the ATmega-328P to convert analog information about the temperature which is sense by the LM35 sensors, k-type Thermocouples and SPI mode of the Arduino platform ATmega-328P to transfer digital information about the temperature which is sense by digital temperature sensor DS18B20. ZigBee S2C connected to the micro-controller ATmega-328P for wireless communication. The sense temperature information were converted into display format using microcontroller coding and then sent through the ZigBee S2C to transmit temperature information in a digital format to the computer.

V. RESULTS AND DISCUSSION

A. Correlation analysis of Temperature Sensors

Table 1: Pearson correlation of three-type of Temperature sensor

		Time	Water_LM35_1	Water_LM35_2	Water_K_type TC_1	Water_K_type TC_2	Water_DS18B20_1	Water_DS18B20_2
Time	Pearson Correlation	1	.189	-.476	-.055	-.067	-.877**	-.917**
	Sig. (2-tailed)		.517	.085	.853	.819	.000	.000
	N	14	14	14	14	14	14	14
Water_LM35_1	Pearson Correlation	.189	1	-.061	.041	-.047	-.036	.038
	Sig. (2-tailed)	.517		.837	.889	.874	.903	.897
	N	14	14	14	14	14	14	14
Water_LM35_2	Pearson Correlation	-.476	-.061	1	.049	.024	.604*	.438
	Sig. (2-tailed)	.085	.837		.867	.934	.022	.117
	N	14	14	14	14	14	14	14
Water_K_typeTC_1	Pearson Correlation	-.055	.041	.049	1	.980**	-.094	-.089
	Sig. (2-tailed)	.853	.889	.867		.000	.750	.762
	N	14	14	14	14	14	14	14
Water_K_typeTC_2	Pearson Correlation	-.067	-.047	.024	.980**	1	-.102	-.115
	Sig. (2-tailed)	.819	.874	.934	.000		.730	.696
	N	14	14	14	14	14	14	14
Water_DS18B20_1	Pearson Correlation	-.877**	-.036	.604*	-.094	-.102	1	.942**
	Sig. (2-tailed)	.000	.903	.022	.750	.730		.000
	N	14	14	14	14	14	14	14
Water_DS18B20_2	Pearson Correlation	-.917**	.038	.438	-.089	-.115	.942**	1
	Sig. (2-tailed)	.000	.897	.117	.762	.696	.000	
	N	14	14	14	14	14	14	14

Table 1. shows Pearson's r is .980 for K-type TC 1st and 2nd temperature sensor which is close to 1 means that both K-type TC temperature sensor gives the same performance in liquid state (water) at 5% level of significance.Table1. alsoshows Pearson's r is .942 for DS18B20 1st and 2nd temperature sensor which is close to 1 means that both DS18B20 temperature sensor gives the same performance in liquid state (water) at 5% level of significance.

B. Variance analysis of temperature sensors using One-Way ANOVA

Table 2. Variance analysis of 3-type of Temperature Sensors

Anova: Single Factor						
Ho : The three type of temperature sensor are behave same in liquid state i.e. water H1: The three types of temperature sensor are not behave same in liquid state i.e. water						
SUMMARY *Groups*	*Count*	*Sum*	*Average*	*Variance*	*S.E.*	*CV*
Water_LM35	28	748.11	26.71821	1.622674	0.240734	4.767693
Water_K_typeTC	28	1208.47	43.15964	695.2794	4.983112	61.09446
Water_DS18B20	28	786.79	28.09964	**0.116529**	**0.064512**	**1.214835**
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	4657.637	2	2328.818	**10.02334**	**0.000129**	**3.109311**
Within Groups	18819.5	81	232.3395			
Total	23477.14	83				

Temperature information obtained from the 3-temperature sensor in the liquid state (water) is very important for the detection of accurate and reliable water temperature. To reduce the measurement error from the temperature sensor, they were analyzed statistically for finding the best temperature sensor. Analysis of variance using Anova technique was used for selection of reliable and accurate temperature sensor. On applying ANOVA: single factor on all the 3-type of temperature sensor having P value less than 0.05 ($P<0.05$) were obtained as shown in Table 2.F > F Critical and p-value < 0.05. Hence, Reject Ho.

The 3- temperature sensor types are not equally behave in liquid state i.e. water. The standard error (S.E.) of DS18B20 is 0.064512 and it is very less as compare to the LM35 and K-type TC temperature sensor. The coefficient of variation (CV) of DS18B20 is 1.21835 and it is less as compare to the LM35 and K-type TC temperature sensor. Hence, DS18B20 temperature is gives consistent performance and more suitable for the measurement of Concrete temperature.

C. Post- hoc T-test performance analysis of temperature sensors using post hoc truth-table

Table 3. T-test performance analysis of LM35 and K-type TC temperature sensor

Ho:$\mu1=\mu2$ H1: $\mu1\neq\mu2$		
t-Test: LM35 and K-type TC Assuming Equal Variances		
	Water_LM35	***Water_K_typeTC***
Mean	26.71821429	43.15964286
Variance	**1.622674471**	695.2793665
Observations	28	28
Pooled Variance	348.4510205	
Hypothesized Mean Difference	0	
df	54	
t Stat	**-3.295586366**	
P(T<=t) one-tail	**0.000869586**	p-value
t Critical one-tail	1.673564907	
P(T<=t) two-tail	**0.001739172**	p-value
t Critical two-tail	2.004879275	
	Bonferroni corrected alpha	
p-value<0.05	**0.016666667**	
Reject Ho		

p-value< 0.05 Hence, Reject Ho

Coefficient of variation (CV) of LM35 is 1.62267 and it is less as compare to K-type TC temperature sensor. Hence, LM35 temperature sensor gives consistent performance in the liquid state (water).

Table 4. T-test performance analysis of K-type TC and DS18B20 temperature sensor

Ho:μ2=μ3 H1:μ2≠μ3		
t-Test: K-type TC and DS18B20 Assuming Equal Variances		
	Water_K_typeTC	***Water_DS18B20***
Mean	43.15964286	28.09964286
Variance	695.2793665	**0.116529497**
Observations	28	28
Pooled Variance	347.697948	
Hypothesized Mean Difference	0	
Df	54	
t Stat	3.021954533	
P(T<=t) one-tail	**0.001917221**	p-value
t Critical one-tail	1.673564907	
P(T<=t) two-tail	**0.003834443**	p-value
t Critical two-tail	2.004879275	
	Bonferroni corrected alpha	
p-value<0.05	**0.016666667**	
Reject Ho		

p-value< 0.05 Hence, Reject Ho

Coefficient of variation (CV) of DS18B20 is 0.116529497and it is less as compare to K-type TC temperature sensor. Hence, DS18B20 temperature sensor gives consistent performance in the liquid state (water).

Table 5. T-test performance analysis of LM35 and DS18B20 temperature sensor

Ho:μ1=μ3 H1:μ1≠μ3		
t-Test: LM35 and DS18B20 Assuming Equal Variances		
	Water_LM35	***Water_DS18B20***
Mean	26.71821429	28.09964286
Variance	1.622674471	**0.116529497**
Observations	28	28
Pooled Variance	0.869601984	
Hypothesized Mean Difference	0	
Df	54	
t Stat	-5.542838067	
P(T<=t) one-tail	**0.000000456**	p-value
t Critical one-tail	1.673564907	
P(T<=t) two-tail	**0.0000009117**	p-value
t Critical two-tail	2.004879275	
	Bonferroni corrected alpha	
p-value<0.05	**0.016666667**	
Reject Ho		

p-value< 0.05 Hence, Reject Ho

The coefficient of variation (CV) of DS18B20 is 0.116529497and it is less as compare to LM35 temperature sensor. Hence, DS18B20 temperature sensor gives consistent performance in the liquid state (water).

T-test performance analysis of temperature sensors from Table 3. Table 4. and Table 5.shows that coefficient of variation (CV) of DS18B20 is 0.116529497and it is less as compare to LM35 and K-type TC temperature sensor. Hence, DS18B20 temperature sensor gives consistent performance in the liquid state (water).

VI. Conclusion:

In the presented work, LM 35, DS18B20 and K-Type thermocouples were interfaced with Arduino Platform and studied. The statistical analysis of received temperature data concludes that, all the temperature sensors are not responding as per requirement in the liquid state (water). The statistical analysis and experiment result indicates that DS18B20 temperature sensor is more suitable and gives consistent performance in wireless water temperature. So, it will be convenient and robust to embed in concrete structure to predict concrete maturity by monitoring time-temperature factor (TTF).

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