LOW COST REAL TIME TEMPERATURE MONITORING SYSTEM FOR CONCRETE USING WIRELESS SENSORS

K Thiruvasagar[1], P Banugoban[2], P Vishnu[3],
KJC Kumara[4] and CS Lewangamage[5]

[1,2,3,5]department of Civil Engineering, University of Moratuwa, Sri Lanka
[4]Department of Mechanical & Manufacturing Engineering, university of Ruhuna, Sri Lanka
[3]*aayilyan1@gmail.com*

Abstract— Structural health monitoring (SHM) has become an inevitable part in a life span of a structure due to its potential to ensure the public safety and to increase the life span of the structure. Monitoring any kind of structures for various parameters, using wireless smart sensors has gained popularity in recent past. This paper discusses the development of low cost real time wireless smart sensor monitoring system to monitor early age concrete temperature in real time. Temperature of two early age concrete mixes (Mix1, Mix2) were measured in real time for 24 hours by using DS18B20 sensors connected with the NodeMcu, which is an open source IoT platform. Temperature measurements were saved and visualized in real time using Thing SpeakTM which is an open IoT online platform with MATLAB analytics. The temperature sensorDS18B20 was selected such that it is suitable to measure temperature readings of the concrete without any interference of the chemical reactions in concrete. Calibration methods and temperature variation with different concrete mixesare also discussed. It could be seen that the wireless temperature monitoring system performed adequately and it can be considered as a better low cost alternative for traditional wired temperature monitoring system.

Keywords - Structural Health Monitoring, Wireless smart sensors, Wireless temperature monitoring system, Concrete, low cost.

I. INTRODUCTION

The safety and durability of any civil infrastructure is mandatory. Structural health monitoring (SHM) is a new paradigm which incorporates automated systems for data acquisition for monitoring, analysing and identification of structural defects (Sun et al. 2010). It enhances the structural safety and significantly reduces lifetime operating costs by early detection of defects for maintenance (Farrar et al. 2007). Data resulting from deploying sensors, could also be used for design optimization, retrofitting and replacement of structures. Dense arrays of sensors were used to monitor structures at the initial stage of the development of such SHM system which was very expensive and non-versatile (Hongki et al. 2010). The attractive features in wireless SHM are real time processing, low cost, easy to install with less space accommodated, and performance similar to that of wired sensing system (Kim et al., 2006). However, such a wireless sensor based real time monitoring system for health monitoring of civil infrastructures has not yet been developed and used in Sri Lanka.

The development of high temperatures in fresh concrete could cause detrimental effects to long-term concrete performance. High concrete temperatures accelerate the rate of hydration and cause the concrete to undergo drying shrinkage cracking(Schindler &Frank Mccullough, 2002). When temperature reduces, the hydration process slows down and concrete does not set properly which would affect the strength of concrete. Increased rate of hydration in thick elements could create higher core temperature within structural element. Higher core temperatures will create temperature differentials when ambient temperature differs from core temperature. Higher temperature differentials could cause cracking, loss of structural integrity, thus shortening the life span by decreasing the strength of the concrete. Higher temperature around 70°C is the key factor for Delayed Ettringite Formation (DEF) which could lead to cracking of concrete with the presence of water in long run and this could be significant when concrete element is larger. Concrete temperature is also used in identification of corrosion of steel reinforcement, which also strengthens the vitality of monitoring temperature.

Main constituent minerals to cement are Tricalcium aluminate (C_3A), Tricalcium Silicate (C_3S),Dicalcium Silicate (C_2S) and tetra calcium alumino ferrite (C_4AF. C_3A) which reacts very fast with water with an exothermic reaction that increases the temperature at a higher rate. In order to slowdown the effect from C_3A, gypsum is added to cement. The presence of OH- and SO_4^{2-} allows the formation of primary ettringite ($C_3A.3CaSO_4.2H_2O.32H_2O$) which is later converted to Mono sulphate hydrate (Dayarathne et al., 2013). Ettringite formation in fresh concrete does not cause any adverse effects because of the plastic nature of concrete. But it can cause significant effect if it forms during hardened stage of concrete. Hence it is important to measure the temperature of concrete at least during first 24 hours to ensure, prevailing temperature of fresh concrete is within the limit 70°C.

II. WIRELESS SMART SENSORS

Wireless smart health monitoring system is a new substitute for the traditional tethered monitoring system (Lynch, 2006). With the introduction of new electronic systems with high processing power and remote sensing ability, wireless monitoring system(WMS) has become an attractive solution for SHM. Noel et al. (2017) compared the advantages and disadvantages of wireless smart sensing method with the traditional tethered method. Traditional wired sensing methods are labour intensive due to its complicated arrangement of long wires, which is a major contributing factor for the higher cost involved. Wired sensing networks usually takes several days to deploy because, running of wires through structure without invasion of space is not an easy task.

Apart from its attractive features, WMS has inherent challenges which is currently overcome with the development technology in electronics and telecommunication. Wireless sensing network has nodes which consists of required sensors connected with PCB, and wireless transmission portion such as Wi-Fi module. These nodes generally run on battery power, which needs regular recharging, thus resulting in regular maintenance requirements. Wireless sensing network has lesser band width compared to wired method, but it does not have significant impact in data transfer because in SHM systems, data transfer rate requirements are lesser. Even with 10bits resolution of data with data acquisition frequency 1kz the data transfer rate would be 125Bytes/s.

$$\frac{1000\ samples}{second} X \frac{10\,bits}{sample} X \frac{1Byte}{8\ bits} = 125\ bytes/s$$

In other words, it would only be 0.125kB/s whereas modern transmission wireless protocols can even transfer in a rate of 100 MB/s. Another main challenge in wireless monitoring is synchronization of data, due to its lesser speed whereas wired monitoring systems are much more reliable as far as synchronization is concerned.

Wireless smart sensing technology suits Civil engineering structures well, due to its easiness of handling and long range transmission of data. The first ever structure with high number of sensor nodes with proper PCB designs and network protocol is Golden Gate Bridge(Noel et al., 2017) which was successfully monitored irrespective of its size. Data were collected at a sample rate of 1 kHz where the sensitivity of accelerometer was 500 μG. The data collected were impressively synchronized with 10 μs jitter.

Since this research only consider one node and the parameter monitored was temperature, there were not any significant invasive disturbances for the readings taken.Silveira and Bonho (2016)implemented a wireless temperature monitoring system using IEEE 802.15.4 (Wi-Fi) protocol where data was successfully transferred in the range of 50m out door and 20m indoor. Using Wi-Fi makes higher data transfer possible. Wi-Fi is suitable for local area networks and it is now incorporated with day to day devices such as smart phones, which makes the data transfer to cloud data base easier and fast. Storing data in cloud not only secures the data but also it allows to monitor the data from anywhere of the world along with analytical graphs and other interactive features.

Wireless smart sensors could be an attractive solution. However, the success of that depends on the way it is connected with sensors, nature of sensors, electronic design, power supply, telecommunication protocol etc. (Norberto B. et al., 2013) describes some main challenges faced when a wireless temperature and humidity sensing unit was deployed in real structures. In addition to afore mentioned factors there were some other challenges such as inability of temperature sensor to sustain with the alkaline environment and selecting a proper casing for the monitoring system to protect PCB and transmission unit in order to prevent current leakages and short circuiting.

III. METHODOLOGY

SHM includes many common steps irrespective of the parameters and the structures we monitor. The flow chart below (Figure 1) depicts the critical steps in monitoring a structure for a given parameter, which is identified to be critical. In this particular research the flow starts from identification of concrete specimens and ends with the real time online visualization.

Monitoring of temperature of concrete is important in Sri Lankan context because Concrete is widely used in construction industry in Sri Lanka. In this experiment, Fresh concrete samples were selected at their plastic stage. Appropriate mix proportion is essential to meet the concrete strength and the durability requirements. Two types of concrete Sample mixes (Mix1 and Mix2) were selected with different cement contents, in order to observe clear difference in peak temperatures. Cement content of Mix2 was selected such that it is higher than Mix1. Table1 shows the mix proportions of Mix1 and Mix2.

In the next step, proper sensor was selected in order to meet the accuracy level required. Several wireless temperature sensors such as SHT15, SHT21S, SHT71, BOTDR, Raman OTDR, Rayleigh OFDR/OBR, FBG, and DS18B20 were considered. In order to select an appropriate sensor several factors such as cost, ability to perform in severe environments, power supply and range of temperature that the sensor can sustain, were considered. Since the temperature measurements are related to concrete, high accuracy is not required. An accuracy of 0.5^{o}C with the range of 10^{o}C to 80^{o}C is sufficient for monitoring of concrete temperatures.

Temperature sensor, DS18B20 was selected to monitor the temperature because of its casing which ensures the protection from severe alkali environment. This sensor can measure temperatures in the range from -55°C to +125°C (-67°F to +257°F) with ±0.5°C accuracy in the range of 10°C to +85°C. DS18B20 sensor can be powered by an external

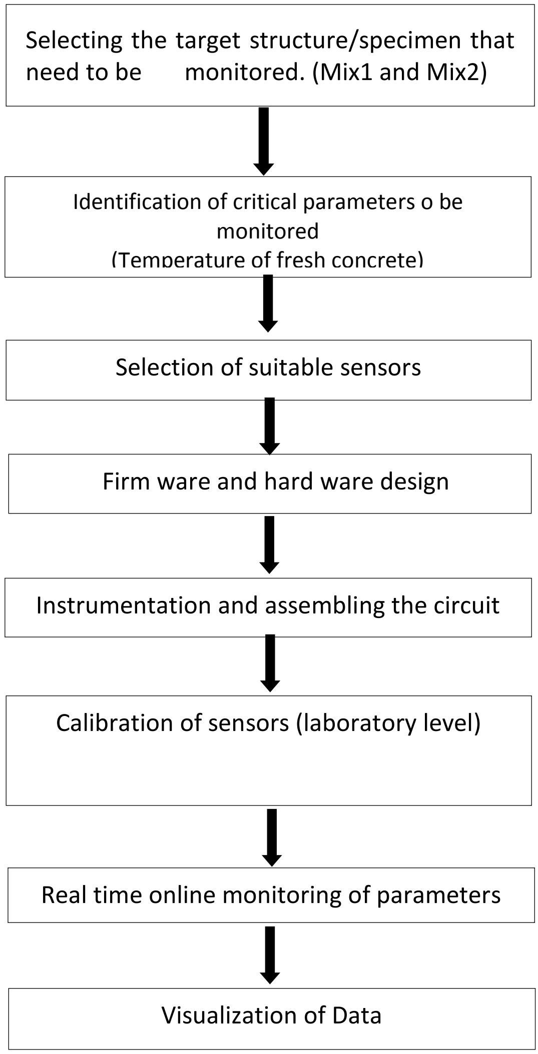

Figure 1: Methodology of the experiment

Table 1. Mix proportion for Mix1 and Mix2.

Material used	Mix1 (kg/m^3)	Mix2 (kg/m^3)
Cement	385	711
Water	154	284
Coarse Aggregate	1291	1007
Fine Aggregate	859	681

supply on the Vcc pin. External power supply was used to power the sensor because power supply using USB is not reliable in higher temperatures. DS18B20 does not sustain communications due to the higher leakage currents which exist at these temperatures. For applications in which high temperatures are likely, it is strongly recommended to use direct power supply. DS18B20 was very cheap compared to the other aforementioned sensors. Table 2shows the specifications of the DS18B20 sensor.

Table 2. Specifications of DS18B20

Specifications	Range
Voltage supply	3V -5.5 V
Sensing temperature	-55°C ~ 125°C
Accuracy - Highest (Lowest)	±0.5°C
Sensor type	Digital
Mounting type	Surface Mounting

The typical method used in Sri Lanka to monitor temperature of concrete is thermo-couple based data logging system. Thermocouples are tethered with data loggers using wires. This method is very expensive because of the higher cost involved with data loggers and man hours required to install and onsite collection of data.

Figure 2: Typical data logging systems used in temperature monitoring.

Table3 compares the cost involved in both thermocouple based data logging system and WMS used in this research. Another attractive feature in WMS was, it consumed less current at the node level which could also be powered by a battery.

According to the system design, electricity consumption for one sensor operation unit annually is calculated as follows:

Monitoring interval	=	10minutes.
Then per one hour	=	6 data.
Per one day (6 x 24)	=	144 data.
Power consumption per day	=	0.048mAh.
Sleeping mode	=	2.3999mAh.
Annual power consumption	=	893.505mAh.

Table 3. Cost comparison (Main components only) of dense wired method and wireless monitoring method.

Thermocouple based wired data logging system	
Data logger	Rs. 600,000
Thermocouple wire k-Type 4m	Rs. 800
Total	Rs. 600,800
Wireless system	
Sensor(DS 18B20)	Rs.150
Node MCU	Rs.900
Other Circuit components	Rs.800
Total	Rs.1,850

Once the sensor type is selected the circuit was designed with the main components. The main components in the circuit contains sensor, micro controller, communication units and power supply to the circuit. The collected data flows as depicted in Figure 3 below. Instrumentation and assembling the circuit with the actual components carried out after the completion of the circuit design. NodeMcu version 1.0 (*NodeMCU* Documentation, 2018) is selected as a master controller since it contains the specified Wi-Fi module in itself. NodeMcu is programmed using Aruduino IDE (Integrated development environment). Figure 4 shows the connected DS18B20 sensor with NodeMcu. The setup was later encompassed in proper casing. PCB board was not required because of the simplicity of the experiment set up and bread board was used in order to implement the circuit design. Figure5 shows the final product after encompassing circuit where dual data channel was used in order to collect two different flows of data. The yellow colour wire indicates where the data cable of the sensor should be connected whereas red and black indicate the power supply and ground, respectively. The WMS was calibrated using thermocouple based temperature monitoring system before monitoring concrete temperature. Then, it was used to measure the temperature of Mix1 and similarly another set of 3 wires and a sensor were connected to the system in order to take measurements of Mix2. It was programmed so that the data from each mix could be collected alternatively in 10 minute intervals assuming the concrete temperature does not vary significantly during this interval. Then obtained results were initially established within a local network and an online open source plate form Thingthinkspeak.com (*IoT Analytics - ThingSpeak Internet of Things, 2017*) was used to monitor the temperature variations in real time online. Figure 6 shows both Mix1 and Mix2 samples being monitored for temperature using WMS.

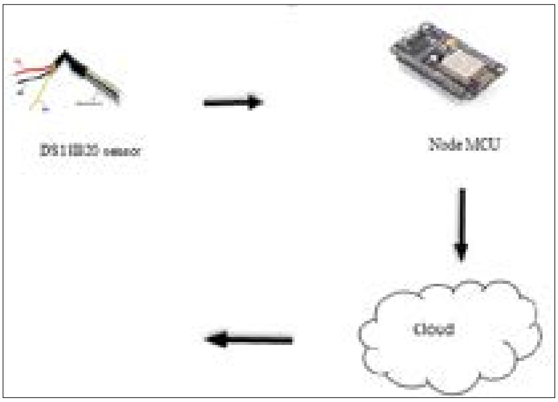

Figure 3: Sensed Data flow

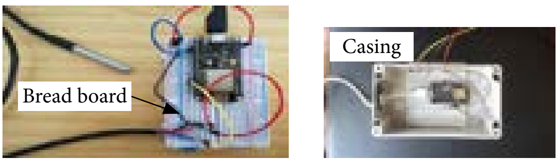

Figure 4.NodeMcu connected with temperature sensor and full setup with casing.

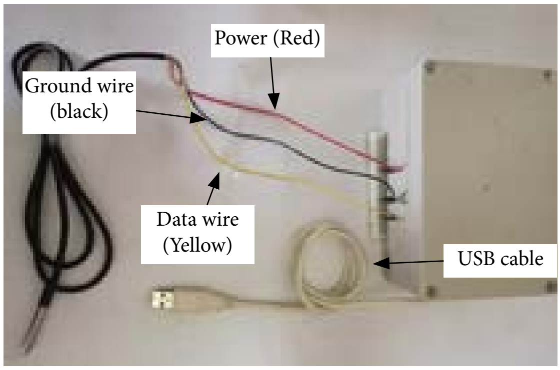

Figure 5. Dual data channel wireless temperature monitoring system.

Figure 6. Laboratory test set up of monitoring temperature of samples using wireless system.

The experiment was carried out for continuous 24 hours in order to monitor the concrete temperature during plastic stage and hardened stage.

IV. RESULTS AND DISCUSSION

Temperature of both types of mixes were visualized in real time in Thingspeak blocks. Then the data were extracted and combined in order to compare. Table 4shows the inner temperature reading of concrete obtained using WMS for both Mix1 and Mix2 for 24 hours, using calibrated wireless temperature monitoring system. Figure 7 shows how the temperature of Mix1 and Mix2 vary against time.

Table 4. Reading obtained using wireless monitoring system(WMS) for 24 hours period

Time (minute)	Temperature of Mix1 (°C)	Temperature of Mix2(°C)
0	30	30.5
120	29.05	29
240	29.31	29.5
360	29.95	31.25
480	30.57	33.15
600	30.75	33.38
720	30.3	32.75
840	29.8	31.25
960	29.5	30.5
1080	29.25	30.12
1200	30.05	31
1320	30.25	31.125
1440	30.2	31.25

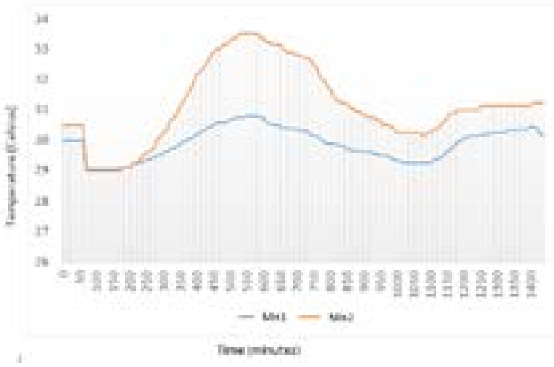

Figure7. Compares the temperature between two grades of concrete.

The results of the calibration tests displayed that the initial temperatures monitored using the DS18B20 and thermocouple based temperature monitoring system was more or less same for both grade of concrete, with a maximum variation of only 0.3 oC throughout the experiment.

As expected, the temperature of Mix2 was always higher than that of Mix1, due to the higher cement content in Mix2.Maximum temperature difference observed was 2.63oC.The absolute maximum temperature measured during the experiment was 33.38 o C (Mix2).The observed temperature rise values were not that significant since the size of tested concrete elements were small in size.

V. CONCLUSION

This paper discussed about a low cost wireless temperature monitoring system for concrete developed using DS18B20 temperature sensor and Nodemcu IoT platform. Data visualization has been carried out on thing speak IoT online application. This system was calibrated using thermocouple based temperature monitoring system at laboratory level. It has been shown that proposed low cost wireless system performed adequately and could be used as a replacement for wired temperature monitoring system.

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