Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 3-Issue 2, Paper 11, August 2020

WSN BASED STRUCTURAL HEALTH MONITORING SYSTEM

Kukkala Naga Vamsi Manikanta Reddy
SRM Institute of Science and Technology, Ramapuram

Abstract*— The focus of this project is to understand the aspects of a Structural Health Monitoring (SHM) scheme, and how it can be applied to structures. The Wireless Sensor Network based Structural Health Monitoring scheme based on accelerations and is carried out to understand the effects of vibrations on a structure to identify damage. It has been widely applied in various engineering sectors due to its ability to respond to adverse structural changes, improving structural reliability and life cycle management. Various methods in SHM are presented in this chapter such as energy utilization, system reliability, methodology, sensory information, and so on.*

SHM can be related to the monitoring of someone's heart through the use of an Electrocardiograph monitor. When someone has heart problems and a diagnosis is needed, doctors connect electrodes or sensors to the person in key spots to record the person pulse. If a change in the persons pulse has occurred then it can be measured using the Electrocardiograph monitor. This same technology is used in SHM; the development of a network of sensors shows you a real time "pulse" of the structure. If an earthquake or accident occurs around the bridge then you would know almost immediately whether or not the structure was safe.

SHM is an area of growing interest and worthy of new and innovative approaches. The United states spends more than $200 billion each year on the maintenance of plant equipment and facilities. Maintenance and repair represent about a quarter of commercial aircraft operating costs. Out of approximately 576,600 bridges in the US national inventory, about a third are either "structure deficient" and in need of repairs, or "functionally obsolete" and in need of replacement.

I. INTRODUCTION

Structural Health Monitoring (SHM) is a process of detecting damages in Engineering structures in order to reduce the frequency of collapse of buildings. In this work, an expert system was incorporated to SHM for monitoring residential buildings. The developed system used a Wireless Sensor Network (WSN) based on 2.4GHz Radio Frequency (RF) band. The developed expert system is based on fuzzy inference and decision-making process also based on British Standard (BS): 7385 – Evaluation and measurement for vibration in building and BS 13670:2009. From performance evaluation result, the system's reliability was calculated to be decreasing from 99% to 50% over a space of 100 years. Energy utilization result showed that the system has the capability to operate with 30% of its energy saved, thereby working for longer hours. The developed system showed a remarkable level of reliability and the energy saving capability is good. Hence, the system is adequate for SHM.

There has been several incident of collapse of buildings allHK7 over the world and this has claimed several lives. Collapse of building can be described as the inability of the building components not to perform what is expected of them. A study showed that 139 houses collapsed between 1974 and 2012 with major occurrences in Lagos and Abuja. One of the noticeable collapses of building is the Lekki Garden building in Lagos which a five stored building under construction collapsed and claimed 30 lives. The causes of collapse of buildings in Nigeria include bad design, faulty construction, use of substandard materials, hasty construction, foundation failure and lack of proper supervision.

II. WORKING PROCESS

Structural Health Monitoring (SHM) is a process of detecting damages in Civil Engineering structures. It is a necessary measure that has been identified by the Structural Engineering Community. SHM systems are designed to reliably test and monitor the health performance of structures such as buildings, bridges,

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 3-Issue 2, Paper 11, August 2020

sewage and turbines by employing sensors placed at strategic locations where it can give measurement needed in determining the safety of the structures. An SHM requires the use of sensors, data transmission and receiving mode, computational power and processing ability. To transmit the structural parameters, recent SHM are configured in Wireless Sensor Network (WSN) mode. WSN is a combination of a number of battery-powered sensor nodes deployed to acquire parameters for monitoring phenomena. Each node consists of different sensor types to monitor different parameters and transmit the data wirelessly between one another to the sink (static or mobile) using any of the existing routing protocols. When a mobile sink is employed, the topology changes from time to time and is managed by a topology management protocol.

III. STEPS OF STRUCTURAL HEALTH MONITORING

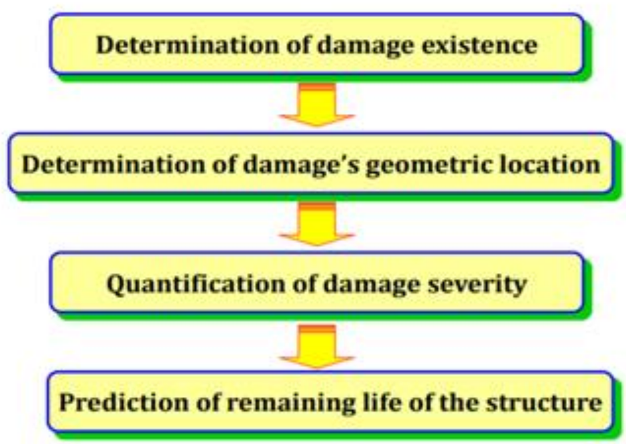


Fig. 1 Structural Health Monitoring

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 3-Issue 2, Paper 11, August 2020

IV. SUCCESS OF ONGOING HEALTH MONITORING

Infrastructure	2005	2013
Aviation	D+	D ↓
Bridge	C	C+ ↑
Dams	D	D
Drinking Water	D-	D ↑
Energy	D	D+ ↑
Hazardous Waste	D	D
Inland Waterways	D-	D-
Ports	C-	C ↑
Public Parks and Recreation	C	C- ↓
Rail	C-	C+ ↑
Roads	D	D
Schools	D	D
Solid Waste	C+	B- ↑
Transit	D+	D ↓

Grade	Implication
A	Exceptional (fit for the future)
B	Good (adequate for now)
C	Mediocre (requires attention)
D	Poor (at risk)
E	Failing (unfit for purpose)

	2005	2013
Estimated Investment needed	1.6 trillion (by 2010)	3.6 trillion (by 2020)
Overall Condition	D	D+

V. ENERGY UTILIZATION RESULT

In order to optimize the energy consumption of the system, the system was designed to work for five minutes and power down the next five minutes in a loop process. A comparison was made between when the system works without power down and power down. This was carried out every five minutes for one hour. The result obtained is shown in Table 1 and Table 2. The power and energy of the system were calculated using equation 3 and 4. The percentage change of energy utilized is calculated using equation 5.

$$\text{Power, } P = V \times I \quad (3)$$

$$\text{Energy, } E = P \times t \quad (4)$$

$$\text{\% change of energy utilized} = ((EA - EB)/EA) \times 100 \quad (5)$$

where V= Voltage, I = Current, t = Time, EA = Energy utilized for Table 1, EB = Energy utilized

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 3-Issue 2, Paper 11, August 2020

Table 1. Result of energy utilization of the system

Time (mins)	Voltage (V)	Current (mA)	Power (W)	Energy (J)
5	4.78	132	0.63	0.0525
10	4.61	133	0.61	0.1017
15	4.81	135	0.65	0.1625
20	4.66	140	0.65	0.2167
25	4.80	142	0.68	0.2833
30	4.69	141	0.66	0.3300
35	4.80	141	0.68	0.3967
40	4.70	141	0.66	0.4400
45	4.82	139	0.67	0.5025
50	4.69	137	0.64	0.5333
55	4.84	137	0.66	0.6050
60	4.69	134	0.63	0.6300

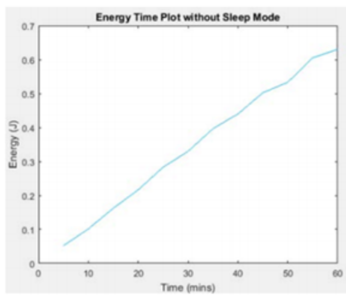


Figure 4: Energy Time Plot without sleep mode

Table 2. Result of energy utilization of the system

Time (mins)	Voltage (V)	Current (mA)	Power (W)	Energy (J)
5	4.71	132	0.62	0.0517
10	4.61	49	0.23	0.0383
15	4.80	133	0.64	0.1600
20	4.61	52	0.24	0.0800
25	4.81	135	0.65	0.2708
30	4.59	56	0.26	0.1300
35	4.81	140	0.67	0.3908
40	4.62	67	0.31	0.2067
45	4.82	139	0.67	0.5025
50	4.61	61	0.28	0.2333
55	4.83	140	0.68	0.6233
60	4.64	64	0.30	0.3000

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 3-Issue 2, Paper 11, August 2020

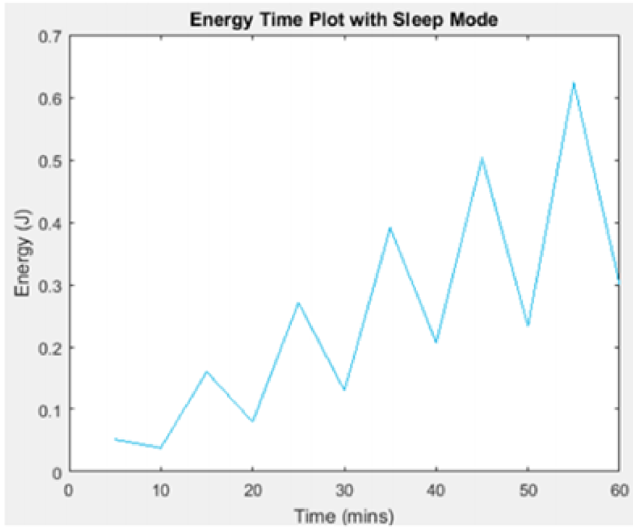


Figure 5. Energy Time Plot with sleep mode

For the result in Table 2, 30% of energy is saved and this enables the system to work for longer hours. The energy time plot of the system for Table 1 is shown in Figure 4. As the time increases, the energy consumed by this system also increases. The energy time plot of the system for Table 2 is shown in Figure 5. When the sleep mode is activated, energy reduced and increases immediately sleep mode is deactivated.

VI. SYSTEM RELIABILITY RESULT

The reliability of the system was calculated (forecasted) in months, and decades. The reliability was forecasted using equation 6. The forecasted result of the system reliability in months and its graph is shown in Table 3 and Figure 6 (a) respectively. From the table, it is shown that the change in the reliability of the system in months is very small. At some points, the reliability of the system is constant Reliability,

$$Rt = e\text{-}\lambda t$$

where λ= Failure rate,
t= Time

Table 3. Reliability of the system in months

Months reliability		Decades reliability	
Time (Months)	Reliability, R_t	Time (years)	Reliability, R_t
1	0.999	10	0.93
2	0.998	20	0.87
3	0.998	30	0.81
4	0.997	40	0.76
5	0.997	50	0.71
6	0.997	60	0.66
7	0.996	70	0.62
8	0.995	80	0.58
9	0.994	90	0 (b)
10	0.994	100	0
11	0.994		
12	0.993		

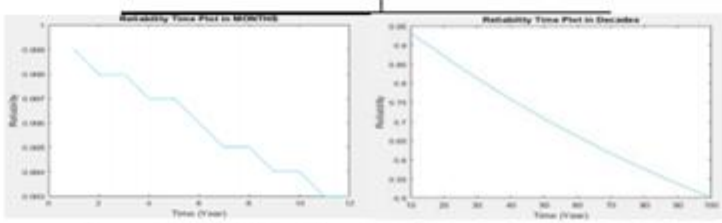


Figure 6. Reliability Time Plot(a) months (b)decades

The result of the calculation of the system reliability in decades and its graph is shown in Table 3 and Figure 6(b) respectively. From the table, it is shown that the reliability of the system decreases as the year increases linearly. No decade has the same reliability. This follows the true curve of life.

VII. METHODOLOGY

The methods adopted for this paper is depicted in Figure 1. It shows the interrelationship between the various components of the system. The system block diagram has two modules: Transmitter modules and the Receiver Module. Using this block diagram, the system can be divided into three sections: data acquisition, data conditioning and transmission, and data reception and processing.

Data Acquisition

The arduino nano is interfaced with the piezo vibration sensor and LM35 sensor. These sensors acquired the vibration and temperature of the building and communicate the data to the arduino nano in which they are connected to.

Data Conditioning and Transmission

At this stage, the data acquired by the sensors is processed by the arduino nano. The processed data is shown on the LCD to ensure accuracy of data at both the transmitting and receiving end. Data is being communicated to the nRF24L01 module from the arduino nano and further transmitted into the network.

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 3-Issue 2, Paper 11, August 2020

Data Reception and Processing

The transmitted data is received at the receiver. The received data from the two transmitters is averaged based on equation 1 and 2. Then, the average data is rendered to fuzzy logic incorporated into arduino nano for decision making process. The expert system was implemented after the data has been processed.

Tempt value = (t1 +t2)/2

Vibration value = (v1 +v2)/2

Where, $t1$= Value of temperature sensor 1, $t2$= Value of temperature sensor 2, $v1$= Value of vibration sensor 1, $v2$= Value of vibration sensor 2

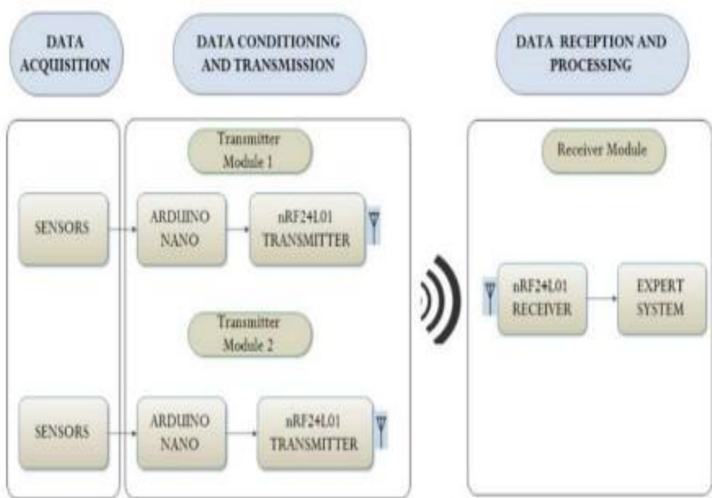
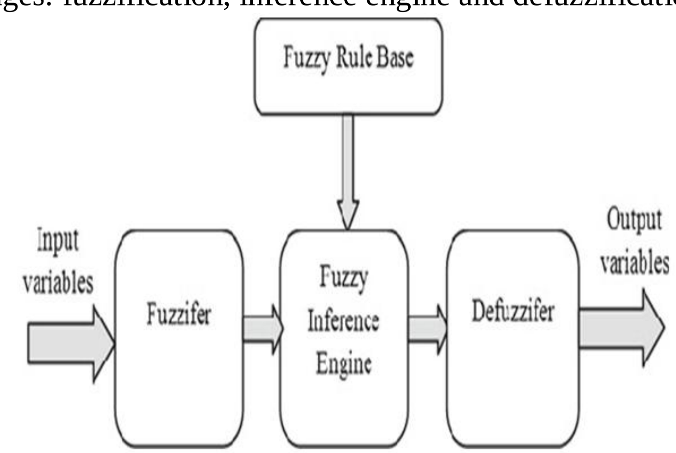


Figure 1. Block diagram of the system

Design of the Expert System

The expert system was designed using fuzzy logic. Fuzzy logic is an Artificial Intelligence Technique Capable of making decision. The fuzzy logic system was designed as shown in Figure 2. The system has two inputs; temperature and vibration, and an output; status. Figure 2 shows the fuzzy logic system. Fuzzy logic design involved 3 stages: fuzzification, inference engine and defuzzification.



Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 3-Issue 2, Paper 11, August 2020

PROS

- Allow damage detection as well as damage location
- May be even used to assess the damage type and to estimate the structure remaining life
- Do not require high user expertise
- Free from modelling assumption induced errors
- Take into account uncertainties inherently present in SHM
- Reliable service for long period of time

CONS

- Require high user expertise
- Affected by modelling assumptions (e.g boundary conditions, number of DOFs)
- Often too many unknowns
- Usually computationally expensive
- Without a physical model, can at most reach the second level of the damage detection hierarchy

VIII. Collection of Sensory Information

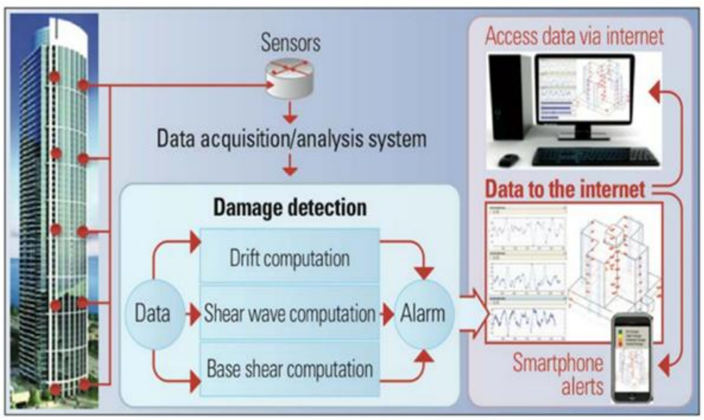
Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 3-Issue 2, Paper 11, August 2020

IX. STUDY: LONG BEACH PUBLIC SAFETY BUILDING, CALIFORNIA (2006)

Mode	Freq before Retrofit	Freq after Retrofit	% change
1	0.94 Hz	2.09 Hz	122.34 %
2	1.20 Hz	2.52 Hz	110.00%
3	1.47 Hz	2.87 Hz	95.24%
4	3.00 Hz	5.21 Hz	73.67%
5	4.25 Hz	7.60 Hz	78.82%

- Six stored rectangular steel building built in 1950s, having a plane dimension of 82.3mx22.3m.
- Due to Northridge Earthquake this facility need significant seismic mitigation measure.
- So health of the structure was monitored and it was retrofitted.
- The ambient vibration collected before, during, and after the structural retrofit.

X. FUTURE OF SHM



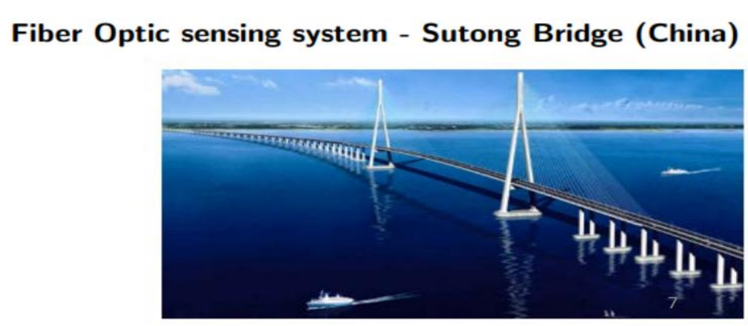
XI. WORLD WIDE MONITORING PROJECTS

Egnantia Highway - Greece

Stork Bridge Outdoor Deployment - Winterthur

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 3-Issue 2, Paper 11, August 2020



XII. CONCLUSION AND FUTURE WORKS

The system's reliability was calculated to be decreasing from 99% to 50% over a space of 100 years. Energy utilization result showed that the system has the capability to operate with 30% of its energy saved, thereby working for longer hours. The developed system showed a remarkable level of reliability and the energy saving capability is good. Hence, the system is adequate for Structural Health Monitoring. It is highly recommended that the system should be integrated into buildings especially residential buildings so as to enable the residents to know the status of their buildings at all time. This paper focused on the monitoring of residential structures only, future work would extend it to industrial structures. Also, improvement can further be made to reduce the energy utilization the system.

REFERENCES

[1] https://www.sciencedirect.com/topics/engineering/structural-health-monitoring

[2] https://www.researchgate.net/publication/343179661_Wireless_Sensor_Network_based_Structural_Health_Monitoring_Expert_System

[3] https://web.wpi.edu/Pubs/E-project/Available/E-project-053113-093601/unrestricted/Structural_Health_Monitoring-final.pdf