Accelerometer sensor data analysis of bridge structural health monitoring system

A A Hapsari¹*, E Supriyanto², A Hasan² and A Suharjono²

¹ School of Graduate Studies, Management and Science University, Shah Alam, Malaysia
² Departement of Electrical engineering, Politeknik Negeri Semarang, Semarang, Indonesia

*012018020311@sgs.msu.edu.my

Abstract. The use of Wireless Sensor Network (WSN) for monitoring systems continues to grow, as it is required data analysis of a sensor node in which there is an accelerometer, use WSN system intended for structural health monitoring application. This monitoring system prototype, built by integrating software and hardware with device microcontroller and sensor. The node sensor produces data and processed with a microcontroller, the resulting data is then immediately transmitted to the cloud by internet network using MQTT. The system was built with a firmware-based Internet of Things (IoT) and this verified using accelerometer sensor node. The data has also been explored and analyzed in the time domain and frequency domain using FFT. Using MQTT, data can be sent directly to the internet in the form of raw data or graph data over time. And in this paper authors do an analysis of the raw data of the output sensor accelerometer ADXL345 and applied to monitor the bridge. From experiments, conducted output accelerometer sensor can vary depending on the sensitivity of the values.

1. Introduction

The bridge is one of the very important infrastructures for road transport. Along with the progress of the times, bridge construction built increasingly long and pretentious. However, the bridge looks strong, sturdy and stately could just become very fragile and dangerous for the users. Therefore, there are required monitoring system to find out the cause of the damage to the structure of the bridge which can cause the collapse [1]. Used of Structural Health Monitoring System (SHMS), structure analysis can be performed to detect and identify the presence of damage or degradation of the structure of the bridge so that it could prolong the service bridge because it can find out the cause of the damage [2]. Factors cause damage and a reduction in the strength of the structure of the bridge such as the presence of overload, earthquake, vibrations, collisions, and the degradation of the quality of construction of the bridge. By placing a sensor node on the bridge can be known of the condition of the bridge and the observable parameters must not exceed the limits specified service (Serviceability Limit State) [3].

Several other studies on Structural Health Monitoring System to observe communication system and find out the most appropriate topology used for monitoring bridge structure when used on large bridges [4].

For the analysis of data generated by the sensor on the system can use a Fast Fourier Transform algorithm and wavelet transform to produce clearer data for further analysis [5].
Research on Structural Health Monitoring System using Wireless Sensor Network mode has been there one of them using Arduino, ATmega32, and Zigbee is quite expensive sensors are on each node. Because of it, we needed a more efficient alternative system.

Based on the reasons in the background. The author conducting research on Structural Health Monitoring System with the design of a simpler hardware and system with cheap and efficient technology. We propose Accelerometer Sensor Data Analysis of Prototype Bridge Structural Health Monitoring System Prototype with Internet of Things. And we use the internet of things based firmware that can display the data directly from the sensor to the internet with cheaper hardware.

2. Related works
On research about Structural Health Monitoring System on Single Degree of Freedom Bridge [6]. Deals with monitoring bridges with sensors and accelerometer sensors Wight in Motion. This research is already using the method of WSN. And the data is displayed in some form, namely time and frequency. But the accelerometer data is not yet in the show on the internet. Wireless Sensor Networks Technology for Bridge Health Monitoring [7] describes the research on monitoring the bridge with WSN. This research data further discusses the power consumption and power on the system. But data from the sensors are not shown in this study. And just discuss power supply is needed on WSN system.

Next research [8], already using WSN method. And use multiple sensors. This research uses a sensor device is relatively expensive and not yet explained how the data is analyzed. The sensor data is still in the form of graphs in the time domain. And not explained how the generated sensor data, and how to process data from the sensor.

Research about Structural Health Monitoring Measurements under Train Speed Changing [9]. In this research are described and illustrated the influence of train speeds towards the railway bridge structure with accelerometer sensor. The device can monitor displacement when trains pass. The data in this paper is a comparison of the data fast and slow trains train when passing the bridge. Already using WSN method and a few sensors deployed directly on the bridge but the data haven't been uploaded or displayed directly on the internet.

Based on related works that are already described in this research will be designed a system with sensor and accelerometer node MCU ESP8266 which is the firmware for the application of the technology of the Internet of Things on a prototype monitoring system health structures of the bridge. The data on this system can be seen anywhere by internet network as it uses MQTT. So it will be a frugal and efficient system. The resulting data will be uploaded directly to the cloud using the MQTT protocol, saved by the database using node.js and the data saved in the database. And data can be viewed by subscribers wherever and whenever.

3. System description
On this research built a prototype of health monitoring system bridge with wireless sensor network. This study uses several interconnected sensors node can be sending data from the accelerometer sensor reading of results. Draft and a general overview of the health monitoring system of the bridge structure is shown in Figure 1.
Figure 1. Architecture design of the SHM system.

The workings of this system, starting with the determination of the reference or indication that will be applied. The sensor used in these tools namely accelerometer and sensors will be installed in the body section of the prototype structure of the bridge. Data from the accelerometer sensor can be analyzed and compared the results. Several nodes comprising sensors, accelerometer and sensor node MCU will be installed at some point and can monitor the condition of the bridge simultaneously. With each node connected with Wi-Fi networks that are generated by the node MCU ESP 8266, connected with a Wi-Fi modem that is connected to the internet. Data can be displayed in the form of a real-time graph. The system is designed with a highly efficient. The creation of this system is divided into two parts, namely the manufacture of hardware and software.

3.1. Hardware

Wireless sensor nodes are composed of four components, a processing unit, a transceiver unit, a battery unit, and a sensor unit. This research uses the node MCU ESP 8266 as data processing. And node MCU ESP 8266 already there is a wireless module with Wi-Fi 802.11 b/ g/ n, so it can instantly transmit wireless data. Node MCU ESP 8266 working on the resolution 32 bit [10]. In this paper, the structural vibration is sampled by an accelerometer sensor. Accelerometer sensor used is the ADXL 345 type that has a pretty cheap price. Not only low-cost but also have low-power 3-axis accelerometer with a measurement range of ±16 g. Node MCU and accelerometer sensors work on the voltage of 3.3 volts. Sensor output data has ADXL 345 with the digital format. The minimum resolution that can be read by the accelerometer sensor is of 4mg/ LSB.

Figure 2. The hardware of wireless sensor node.
3.2. Software
The sensor nodes are configured with the program so that the sensor can work and produce data. Used the Arduino IDE software to upload programs to the node MCU ESP 8266. Upload the program to the node MCU esp8266 with the Arduino IDE that has been previously installed library from node MCU ESP8266 version.

![Flow diagram of the program for the node sensor.](image)

The configuration for Wi-Fi and wireless connections, as well as on the program via Arduino IDE. And then configure the program for the connection with MQTT. The flow of the program can be seen in Figure 3. In this system using five sensors to sample the real data from the board. The system used MCU with a wireless module to send the data sampled from the bridge prototype. All of the node sensors sends the sampled data to the cloud using MQTT. The data that appear and then saved into a database using the node.js program. The data acquired and stored in the database is subsequently carried out further analysis. It also carried the serial data retrieval, to do an analysis of the data of the accelerometer sensor is still in the form of raw data.

3.3. Digital accelerometer sensor data
The experiment can be seen in the comparison of the data from the accelerometer sensor by performing different sensitivity settings and compare with the datasheet from the sensor being used. Accelerometer digital has raw data output data that can be converted to mg or g [11]. Sensitivity on digital sensors related to the value of the bit of the sensor. The value of g from digital accelerometer sensor can be determined based on the value of the LSB of the data that can be spelled out with formula one, and the value of the LSB can be searched with the formula two [12].

\[
g = \frac{\text{data LSB value}}{1000} \tag{1}\]
It can be viewed and compared with the results of existing data on the datasheet the sensor to be used. The value of LSB vary depending on the value of bit sensors are used. Digital accelerometer has different bits of resolution depending on the type.

\[
\text{One LSB} = \frac{\text{Full g-range}}{\text{Number of counts}}
\]  

(2)

4. Experiment results

This study observed how the data generated by the accelerometer sensors on a prototype bridge. previously seen how the data generated by the sensor node. Data over time can be seen live with MQTT applications and can also be stored in the database is next on to draw in the shape of the graph. The first experiment to see if the sensor has been successfully transmitted data directly with MQTT. And the result can be seen on the graph of fig 4. Displaying sensor data sent wireless and online using MQTT.

The next test is taking the sampling data resulting from a reading of the accelerometer sensor node in place on the body of the prototype model of the bridge. experiment with changing the values of the sensor sensitivity accelerometer ADXL 345 and compare with the datasheet. the raw data generated from the sensor output accelerometer sensitivity differently when in settings with different values. but from the resulting data would be worth approaching when computed using the formula (1).

By laying the same sensor that is horizontally aligned right at the Earth's surface and produce a value of 0 g on the X-axis, 0 g on the Y-axis, and 1 g on the Z axis, that can be seen in Table 1.

![Accelerometer Chart](image)

**Figure 4.** Live data sensor with X, Y, Z axis from accelerometer.

![Experiment set up on bridge model](image)

**Figure 5.** Experiment set up on bridge model.
Table 1. Data values to g accelerometer sensors with different sensitivity.

| Sensitivity | x (g)   | y (g)   | z (g)   | LSB |
|-------------|---------|---------|---------|-----|
| 2           | -0.0585 | 0.0507  | 1.0491  | 3.9 |
| 4           | -0.0624 | 0.0546  | 1.0452  | 7.8 |
| 8           | -0.0624 | 0.0468  | 1.0296  | 15.6|
| 16          | -0.0630 | 0.0315  | 1.0395  | 31.5|

Then do the experiment by giving objects to move above the bridge, it generates data read out sensor as shown in Figure 6. It can be seen from the graph that there are changes to the reading of data sensors accelerometer in the time domain and then do the conversion with FFT.

On Figure 6 there are shows the graph of the experimental data, and describe the form of the output signal from the sensor is x, y, z-axis. Figure a shows the output signal which is read by a sensor node and later changed into the form of FFT on the graph b. And look a peak magnitude values on the graph of the FFT. from the resulting data shown graph FFT on each axis x, y, and z.

Figure 6. Three-axis sensor node data response node 1 (a) graph time sensor node with FFT (b).

Test on the model of the bridge is done by taking the sensor data when given a load moving and not given a load moving. When the constituent components of the bridge like a bolt that is still attached to the full and is not complete. then carried out observations on the outcome of the reading of the sensor. Shown in figure 7 and 8.

Figure 7. Three-axis sensor node data response when mounting bolts tight (a) data response when the bolt loose (b).
Figure 8. FFT graph when bolts tight (c), FFT graph when bolt loose (d).

The accelerometer sensor node is set with a 10 ms delay and an analysis of 1000 data inputs is performed. The higher peak value difference is generated on the “x” and “y” node axes when there is a change in the bridge structure at the maximum value with the FFT computation of the node 4 sensor data which detects the state of the bridge at the time of the bolt nut condition removed, and with a complete bolt nut condition.

Node 4 is the sensor node that is placed closest to the location of the nut and bolt release on the bridge model. The maximum output value of sensor node 4 can be seen in Table II.

Table 2. Output maximum value of data sensor node 4.

| Condition      | LSB | X (g)   | Y (g)   | Z (g)   |
|----------------|-----|---------|---------|---------|
| Complete bolt  | 31.2| 0.5616  | 1.3416  | 2.496   |
| Lost bolt      | 31.2| 3.1824  | 1.0296  | 4.056   |

Figure 9. Graph of amplitude maximum FFT axis x,y,z data sensor when bolts tight and loose.

When the model of the bridge is passed through the moving load, the accelerometer sensor installed produces a different data change output similar to that of the bridge model body. The change is also obtained by reading the different sensor output values. The peak value of the resulting FFT is in the range of 0-1 Hz. And when the bridge model changes by removing the nuts and bolts, there is an increase in data readings as can be seen in the average FFT peak value graph in Figure 9.
5. Conclusion

From the research that has been done, it can be seen that the output data from the accelerometer sensor in the form of raw data, the analysis needs to be done first, and calibrate the sensor and match the datasheet of the sensor used. The raw data generated by the sensor is analyzed by converting it according to the sensor datasheet into units of "g" or "mg" so that it can be used further. And after observation, knows that the raw output value of the sensor data obtained still meets the value of g as found in the datasheet of the accelerometer sensor ADXL 345 when the sensor is still and the bridge is not passed through the load.

When there is a moving load across the bridge it appears that the accelerometer sensor readings are changing. And in the result seen at the maximum sensor reading value has a higher value when the bolt release.

From some tests that have been done known that FFT can be done on accelerometer sensor data. FFT is performed on each axis. And the faster of sensor readings are used the higher the sampling frequency. Accelerometer sensor can be used as vibration detector and also displacement at bridge monitoring system. The FFT process is performed on the accelerometer data to know the value in the real of frequency.

Acknowledgment

Thanks to Mr Sudarmono for support at Politeknik Negeri Semarang, for the bridge prototype.

References

[1] Kawchuk G N, Hartvigsen J, Edgecombe T, Prasad N and Van Dieen J H 2016 Structural health monitoring (vibration) as a tool for identifying structural alterations of the lumbar spine: a twin control study Nat. Publ. Gr. 6–11
[2] Bassett K and Bassett K 2010 Vibration Based Structural Health Monitoring for Utility Scale Wind Turbines By
[3] Yang J, Chang F and Derriso M M 2013 Structural Health Monitoring Struct. Heal. Monit.
[4] Setijadi E, Bp S and Suprobo P 2013 Design of Large Scale Structural Health Monitoring System for Long-Span Bridges Based on Wireless Sensor Network 169–174
[5] Shome S K, Sen S, Mondal K and Datta U 2016 Development and Performance Analysis of Wireless Sensor Node for Structural Health Monitoring using Fast Fourier and Wavelet Transform 491–495
[6] Putra S A, Trilaksono B R, Harsoyo A and Imam A 2016 Agent-based structural health monitoring system on single degree of freedom bridge: A preliminary study 2015 Int. Conf. Inf. Technol. Syst. Innov. ICITSI 2015 - Proc.
[7] Zhou G D and Yi T H 2013 Recent developments on wireless sensor networks technology for bridge health monitoring Math. Probl. Eng.
[8] Niu J, Deng Z, Zhou F and Cao Z 2009 A Structural Health Monitoring System Using Wireless Sensor Network 2–5
[9] Kaloop M R, Hu J W and Sayed M A 2016 Yonjung High-Speed Railway Bridge Assessment Using Output-Only Structural Health Monitoring Measurements under Train Speed Changing
[10] Skraba A, Kolozvari A, Kofjac D, Stanovov V and Semen E 2016 Streaming Pulse Data to the Cloud with Bluetooth LE or NODEMCU ESP8266 428–431
[11] Setiawan I, Setiyono B and Susilo T B 2009 Hasil Uji Kalibrasi Sensor Accelerometer e-Journalundip 118–122
[12] Description G, Ideas A and Specifications K 2009 MMA7455 3-Axis Accelerometer Module (#28526) Package and Pin Descriptions + Z + X 8333(916) 1–7