ACCELERATION DATA LOGGING SYSTEM FOR STRUCTURALHEALTH MONITORING USING TRIAXIAL MEMS ACCELEROMETER

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ABSTRACT

A structural health monitoring system for midrise structures prototype developed for monitoring building vibration and health is presented. An accelerometer sensor connected to a computer was used for collecting and monitoring acceleration data on structural beams of midrise buildings. The prototype provides information and representation of the acceleration vibration of Z Axes on a midrise structure.

Keywords—Rasberry Pi; acceleration data; vibration monitoring

INTRODUCTION

Structures are built to protect people from the negative effects of a natural disaster. It is important that our buildings are healthy and monitored from severe structure loadings such as earthquakes (Roghaei & Zabihollah, 2014), typhoons (Han et al., 2016; As'ad & Sukiman, 2013), and active daily loading and overloading with heavy contents, which can cause substantial economic loss. Moreover, this can bear continuing damage when structural integrity deteriorates gradually over time (Boudiaf, Djebala, Bendjma, Balaska, & Dahane, 2016; Matsubara & Nagamachi, 1997). With the Structural Health Monitoring (SHM), the high repair costs by monitoring and discovering these detrimental circumstances can be reduced. It has developed into a fundamental instrument that enhances safety and maintains significant infrastructures. The need to develop this technology is essential in keeping structures safe and in generating information to improve future structural designs.

In developing this particular technology, there are different methods, calibration, and measurement techniques that were designed and used to collect, calibrate and measure vibrations on structural health. For example, the experimental design was employed to combine the subwoofer method for frequency response and inclination sensing method of calibration to accelerometers, which resulted to huge accuracy levels. Another calibration technique, the two-point calibration method, was used to a number of temperature sensors, which accounted to not more than 10% percent error. It was considered to be with high data integrity, which was utilized for effective checking and experimenting on structural acceleration, vibration, temperature drifts, and surrounding temperature information from a concrete bridge experiment podium. The method of experimentation on sensing distinctiveness of the sensors facilitated on a winning improvement of the sensing (Lacis, 2016). Another experimental method was used to certify the information output of accelerometers. A shaking stimulator attached to a centrifuge was created that provided synchronized harmonic constant linear accelerations. Its calibration method was used to assess the shaking refinement inaccuracy of the accelerometer (Panin et al., 2017). Another technique was used to investigate the causes of three-axis digital accelerometer MPU6050 errors using the Maximum Likelihood Estimation (MLE) method. This method involves the rotating of the accelerometer, which is set up on one hundred hertz (100hz) data rate on the X, Y, and Z axis. After this process, the computation of acceleration data averages for each axis was done. With recurring procedure, the averages were used as input to the MLE algorithm. As a result, the MLE-based algorithm obtained a high precision estimation in acceleration data (McCann & Forde, 2001). In a similar note, another technique in data gathering method, which decreases the variance of parameter estimation of micro electro-mechanical accelerometer sensors, was the use of optimum experimental design via the auto-calibration model (Moore, Glenncross-Grant, Mahini, & Patterson, 2012). Another method of the calibration was experimented to determine the linear velocity and adjust the untreated data of an accelerometer by means of an encoder utilizing a fuzzy inference systems technique (Bluman, 2009). These modern techniques and methods prove the data integrity in calibrating accelerometer, which can promote the improvement of the qualifications of sensor sensing an acceleration monitoring and frequency response of structures.

Despite the existence of the different methods and calibrating techniques, very few ventured into attaching the equipment on mid-rise buildings. Hence, the goal of this project was to develop an acceleration monitoring system that collects vibration data from structures to help engineers improve safety and structure maintainability. Mainly, this project aimed to calibrate the accelerometer to ensure profound data integrity in structural health monitoring using inclination sensing and subwoofer calibration methods and to test the develop system on a midrise structure.

METHOD

A. System Setup

1) Hardware Setup

The Acceleration Data Logging prototype was fabricated using an industrial-grade plastic container housing the onboard computer and the accelerometer sensor. Figure 4 shows the developed prototype of the acceleration data logging system. The organization of the sensor node, which is, enclosed in an industrial-grade plastic which the ADXL 345 accelerometer and Raspberry Pi 3 Model B+ computer, and an external power supply is attached to the sensor node. The software which runs on the Acceleration Data Logging system was incorporated through the Raspberry Pi platform using the Raspbian Jessie operating system running a python script.

2) Software Setup

The built-in open-source Python Idle on the Linux based Raspbian Jessie operating system of the Raspberry Pi (2) platform was used to program the functions of the system. The Python idle used a processing programming language based on python with user-friendly clean syntax and simple user interface. For program testing and troubleshooting, the Raspberry Pi (2) itself can be connected with peripherals to monitor functions of the components of the system. A Python script was used to read accelerometer (1) data and transfers the data on the CSV file on system memory of the Raspberry pi (2). The system block diagram is shown in figure 1.

Fig. 1. System Block Diagram of Acceleration Data Logging System.

3) *ADXL 345 Accelerometer Sensor*

For the ADXL 345 sensor calibration and acceleration measurements, a program was developed to initiate a calibration procedure. Inclination sensing and subwoofer-setup (Bluman, 2009; Concepcion, 2017) technique were function generator that will be its input, and frequency values will be setup. The accelerometer data, after a minute, will be compared to the input frequency from the function generator. The data from the accelerometer and the function generator did not match. The accelerometer was recalibrated until the value coincide. For the acceleration test, the prototype was exposed to a 1 Hz; 2 Hz: 3 Hz; 4 Hz vibration data and was calculated using a Fast Fourier transform algorithm implemented in Numerical Python.

B. *System Operation*

1) *Control Circuitry and Power Supply*

The system's operation was controlled by Raspberry Pi 3 Model B+ Computer through a python script. The Raspberry Pi-powered the accelerometer and read the sensor data through I2C port and stored acceleration values to the system memory. All the electrical components of the hardware operated on the DC power source.

2) *Data Collection and Data Logging*

The whole system operated on a five-stage methodology, as shown in Figure 2. The Acceleration Data Logging system was installed on a structural beam, specifically midpoints and collected acceleration data. These data were converted waveform outputs, parameter values, and categories in two groups which are data on active load and dead load schedules on ten data points per second monitoring for sensitive acceleration vibration detection.

Active load schedule, typically, is where the building is being used and supporting moving loads most of the time from 7 am to 5 pm schedule; dead load schedules typically lies on the 5 pm to 7 am where least-moving loads are experienced. To verify the active loading vibration, a time series representation of the acceleration vibration was used. Spikes in the time series representation were considered as the active loads acting upon the structure, and the constant vibration were dead load movements.

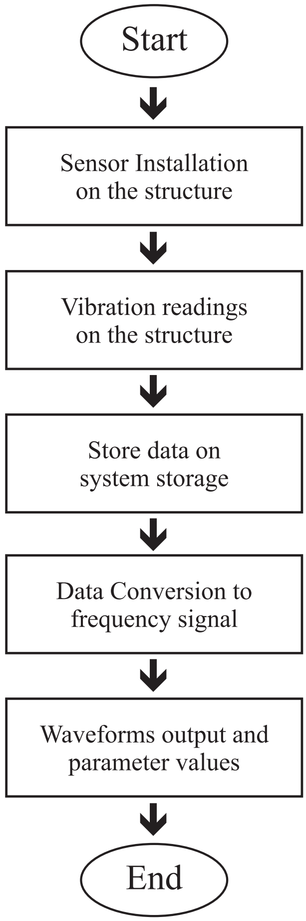

Fig. 2. Acceleration Data Logging methodology.

C. Deployment Site

The deployment site was a 25-year old 3-storey midrise building named Polycarp Building in Cor Jesu College, Digos City, Davao del Sur, Philippines. Shear stress and fatigue of beams on the building storey's gradually decreased storey levels go up, which means that lower stories levels with respect to the ground floor experience more fatigue (Loh, Zimmerman, & Lynch, 2007; Panin, et al., 2017). One of the factors of structural fatigue is service life and exposure to other moving loads (McCann & Forde, 2001; Woo, Kim, Kim, & Kim, 2011). This suggests that the beam on the right side of the older Polycarp Building experiences more fatigue and vibrations induced by the moving loads (Hu, Wang, & Ji, 2013; Weeger, Wever, & Simeon, 2014). Figure 3 shows the older Polycarp Building. The Acceleration Data Logging prototype was deployed at the right side second floor beam of the 25-year-old Polycarp Building for seven days and gathered significant data.

Fig. 3. Polycarp building in Cor Jesu College, Digos City, Philippines

D. *Statistical treatments*

Paired T-test statistical (Moore, Glenncross-Grant, Mahini, & Patterson, 2012) treatment was used to compare the vibrations of the old Polycarp Building, the daily acceleration readings of the active loads, and dead load schedules. The T-statistic formula, as defined in equation 1, is explained, where d as the mean of the difference, S^2 as the standard deviation, n as the sample size, t as the T-statistic, and n-1 as the degrees of freedom.

$$t = \frac{d}{\sqrt{S^2/n}} \quad (1)$$

RESULTS AND DISCUSSION

The method described in section II and Figure 1 were successfully implemented to the prototype, as shown in Figure 5. The prototype was deployed for seven days at a period where the site gave good acceleration vibration. The maximum and minimum acceleration data of the Z-axis were recorded, as shown in Tables 1 and 2. It can be observed that the acceleration vibration varies over the whole duration of deployment in terms of daily building usage levels each day, as observed in a time series representation in Figure 5.

Fig. 4. Final prototype. Accelerometer sensor (1), Raspberry Pi 3 (2)

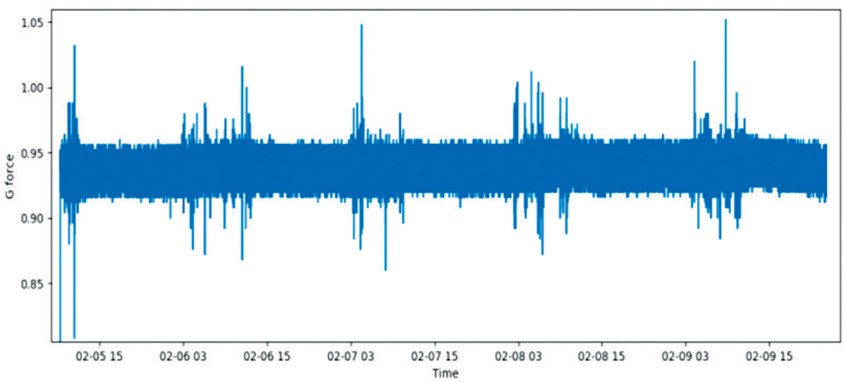

Fig. 5. Time series representation of vibration on the Polycarp building

The time-series representation of the seven-day monitoring of the Polycarp Building using the SHM system with respect to time and g force is shown in Figure 5. The spikes in time series graph indicate active loads moving through in the building, and the constant vibration is the dead loads experienced by the Polycarp Building.

The difference of the maximum and minimum value of the acceleration readings, as shown in Tables 1 and 2, was computed to determine the active load vibration for the Polycarp buildings. It was used T-test statistical treatment to verify the vibration. The null hypothesis was that the active load vibration on Polycarp is equal or no significant difference than the dead load on Polycarp. The alternative hypothesis was that active load vibration on Polycarp is greater than dead load vibration. The null hypothesis H0 and alternative hypothesis Ha are written below, H0 (null hypothesis): if T-statistic<critical value of 1.943, then it is statistically the same.

Ha (alternative hypothesis): if T-statistic> critical value of 1.943, then reject the null hypothesis.

Table 1. Polycarp building difference in Max and Min accelaration readings 7am to 5pm Active load

Day no.	Max acceleration value reading of Z-axis (g)	Min acceleration value reading of Z-axis (g)	Difference in Max and Min acceleration readings of Z-axis(g)
1	1.02982994	0.91782994	0.112
2	1.02182994	0.94782994	0.074
3	1.00382994	0.94382994	0.06
4	1.00982994	0.95782994	0.052
5	1.03982994	0.95582994	0.084
6	0.99982994	0.95582994	0.044
7	0.99382994	0.96782994	0.026

Table 2. Polycarp building difference in Max and Min accelaration readings 5pm to 7am Dead load

Day no.	Max acceleration value reading of Z-axis (g)	Min acceleration value reading of Z-axis (g)	Difference in Max and Min acceleration readings of Z-axis(g)
1	0.99382994	0.96982994	0.024
2	1.00782994	0.94982994	0.058
3	1.03782994	0.95182994	0.086
4	1.01982994	0.94982994	0.07
5	1.02382994	0.95982994	0.064
6	0.99382994	0.96782994	0.026
7	0.99382994	0.96982994	0.024

CONCLUSIONS AND FUTURE WORKS

The study has developed the Acceleration Data Logging system and compared it to the Acceleration vibrations reading of a midrise building named Polycarp. The Polycarp Building has a 0.064571429g acceleration reading on average during an active load, and 0.050285714g acceleration reading on average during dead loads. Statistical treatment using T-test on the difference of the maximum and minimum vibration readings for Polycarp active and dead loads showed a significant difference during the active load. The results revealed the standard deviation of 0.0279 and T-statistic of 2.5406 with 0.05 level of significance. Hence, the null hypothesis was rejected, and alternative hypothesis was accepted. Data suggest that vibration on active was greater than dead loads with a mean difference on the average acceleration readings of 0.014285714g. This implies that the developed monitoring system is working optimally in monitoring vibrations readings. Implementation of the developed system on high-rise buildings and bridges is recommended.

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