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A STUDY OF MECHANICAL PROPERTIES OF REINFORCED CONCRETE BEAM USING ARDUINO MICROCONTROLLER

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Abstract: This paper presents the use of an open source-based technology, Arduino microcontroller, which is used for free vibration test by using accelerometer ADXL345 comparing with one of common accelerometer and data-logger. The test was carried out in 3 variations: pre-loading, elastic damage (L/240), and inelastic damage (L/120). This research used reinforced concrete beam as specimens with 3000 mm length, 150 mm width, and 250 mm depth. Specimen was installed by 2 monitoring system, Arduino equipped with accelerometer ADXL345 and commercial data-logger NI equipped with commercial accelerometer KISTLER. The results show that relative error between ADXL345 to KISTLER is less than 5% for mode shape 1, 2, and 3 except in case inelastic damage for mode shape 3 is almost 10%.

Keywords: Arduino; Open-source; Accelerometer; ADXL345; Free vibration.

1. Introduction

Construction industry is one of the sectors that play a role in economic development. Oxford Economics has showed that construction will be an economic driver over the medium term with growth averaging 4.5% in 2020-2025 period, which is 2.75 times higher than the previous period, 2015-2020 (Marsh, 2021). Higher construction activity leads to higher safety risk. The risk to public safety associated with the deteriorating condition of civil infrastructures has fuelled research on structural condition assessment and has led to the development of the structural health monitoring system (SHMS) (Dragos & Smarsly, 2017).

Septinurriandiani et al., (2011) stated SHMS is a process of monitoring information on the health condition of a construction structure, such as buildings, bridges, dams, etc. by using special instruments. The structural health monitoring (SHM) plays an important role in load testing and rating for bridges, train rail systems, dams, buildings and other structures (steel, concrete, timber, composite-fiber material) throughout live load tests and several long-term tests (Nguyen et al., 2018). However, the procurement and operational costs are quite expensive. This is also one of the challenges on SHMS implementation.

Sensors and data logger are two main instruments used in the SHMS. There are several types and functions of sensors (Moreu et al., 2018), but the most common sensor used in SHMS is accelerometer. Traditionally, bridge displacement is measured using Linear Variable Differential Transformers (LVDT) sensor. However, the problem in the field is the absence of a fixed reference point so that standard displacement measuring sensors such as LVDT can no longer be used (Hester et al., 2017). As an alternative method, it is preferable to use accelerometer and double-integrates to calculate displacements. However, as explained by Thong et al. (2004), the amplification of low-frequency noise that is inevitably present in real acceleration data is the challenge of the method.

In the industry 4.0 era, open-source technology spread rapidly due to simple and free of charge software. This kind of technology would be a good solution to reduce costs for any fields of industry. Arduino microcontroller is a fairly well-known open-source electronics platform that uses hardware and software that is quite easy for laypeople to access. The Arduino board is capable of reading inputs in the form of sensors, buttons, Twitter messages and turning them into outputs such as activating motors, turning on LEDs, even publishing something online, etc. Arduino can be set up to do whatever it wants by sending a set of instructions to the microcontroller in the Arduino IDE software and then uploading them to the Arduino board hardware (Arduino, 2018). The specification of Arduino microcontroller is presented in Table 1.

Table 1. Arduino microcontroller specification (Mahbub, 2019)

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

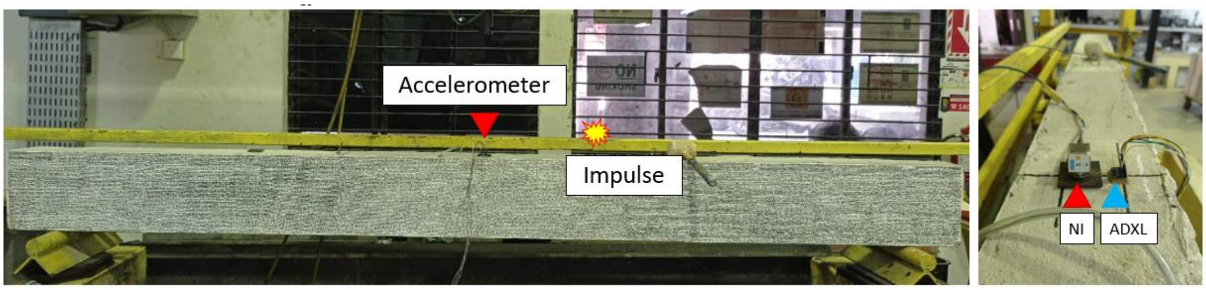
Arduino has several connection types, the way it communicates with other devices, two of them called SPI and I2C. SPI is a synchronous serial data protocol commonly used for communication between microcontrollers and one or more peripherals over short distances quickly (Mallari, 2020b). Meanwhile, I2C is also known as a two-wire interface, which means it is a simple data exchange system, using two lines between the controller and the peripherals (Mallari, 2020a).

With the flexibility of Arduino, it can be utilized in various activities. Several research have studied the application of Arduino, for examples: Study of strain and deformation measurement using the Arduino microcontroller and strain gauges devices to measure internal strain due to bending and torsional action (Silva et al., 2019), A low-cost Arduino-based platform for long-term indoor environment data collection (Ali et al., 2016). Some other application are presented in: On the uses of low-cost arduino based microcontroller and adxl 345 accelerometer for geotechnical instrumentation (Oetomo, 2020), Cognitive sensor technology for structural health monitoring (Serov, 2017); Design and calibration of an innovative ultrasonic, arduino based anemometer (Allotta et al., 2017); An arduino-based EIS with a logarithmic amplifier for corrosion monitoring (Angelini et al., 2014); Vibration measurement & analysis using arduino based accelerometer (Hasibuzzaman et al., 2020); Low-cost Arduino based wire extensometer for earth flow monitoring (Guerriero et al., 2017), Arduino wireless system for concrete beam monitoring (Aditama & Wedyantadji, 2020), Arduino based modern SHM (Abruzzese et al., 2020).

Regarding to the SHMS, Arduino microcontroller can be used as a data logger that acquire the data read by the sensors. Unfortunately, the construction industry has been quite slow in implementing it. The objective of this study is to learn the effectiveness of Arduino in comparison to commercial data logger. In addition, this study also compared 2 different accelerometers. Experiments were carried out by using 2 sets of monitoring systems; Arduino equipped with ADXL345 accelerometer and commercial data-logger (NI) equipped with commercial accelerometer (KISTLER).

2. Materials and methods

The specimen used in the free vibration test is a reinforced concrete beam 3000 mm length, 150 mm width and 250 mm depth. The specimen is installed with 2 types of acceleration sensors which are placed side by side in the middle of the span. The variation of the test is on different specimen conditions such as non-damage (pre-loading), elastic damage (after being loaded up to L/240 deflection), inelastic damage (after being loaded to L/120 deflection). Three tests were carried out by giving an impulse load in the direction of gravity with a distance of 30 cm to the right of the sensor (as seen in the **Figure 1** and **Figure 2**). The two sensors are set to have relatively the same sampling rate, around 2000 data/second. The accelerations compared in the Z-direction (vertical) parallel with gravity. Natural frequency of specimen calculated by using Fast Fourier Transform method of the acceleration data collected from both sensors. Data plotted in the graphic to compare in the certain range of frequency.



(a) (b)

Figure 1. Sensor and impulse position in front view (a), KISTLER (NI), ADXL345 position in side view (b)

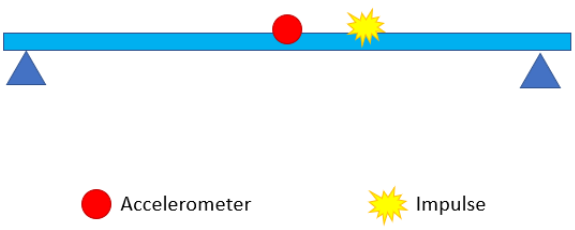


Figure 2. Illustration of the sensor and impulse location

In this study, the connection used on Arduino is SPI with 6 wiring connection, as showed in **Figure 3**. ADXL345 transferred the data to Arduino board as data acquisition, then Arduino was connected to computer/laptop using USB connection to transfer the data and to energize the system. Program or script of instruction built into the Arduino IDE must be uploaded to the Arduino board prior to data recording.

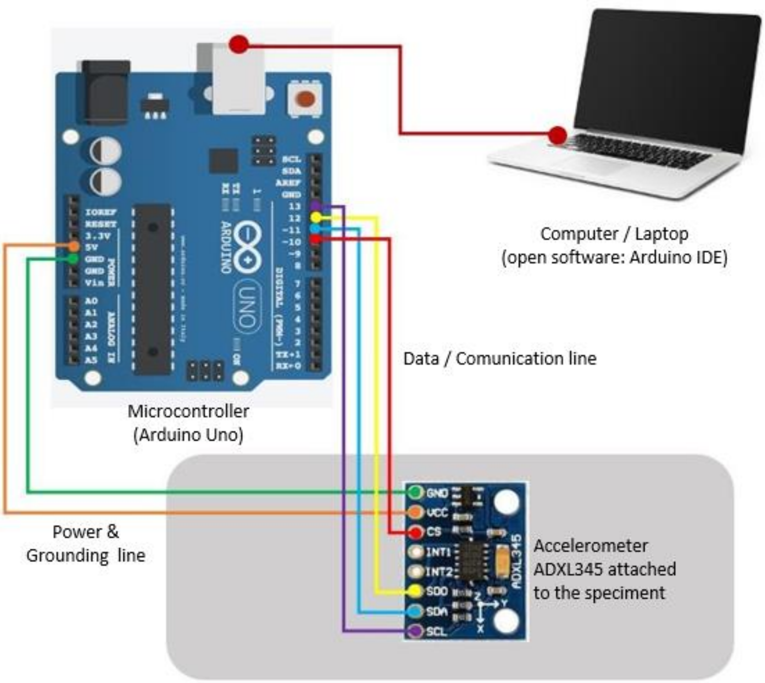


Figure 3. Illustration of the Arduino and accelerometer ADXL345 installation

3. Results & Discussion

3.1. Noise Comparison Test

Comparison of two monitoring system and sensor, ADXL345 and KISTLER, are placed on the specimen at steady state condition. **Figure 4** shows that ADXL345 has a higher noise level than KISTLER. To quantify the level of noise, it will describe as standard deviation of each system. Standard deviation of ADXL345 is 0.028 g and KISTLER is 0.001 g.

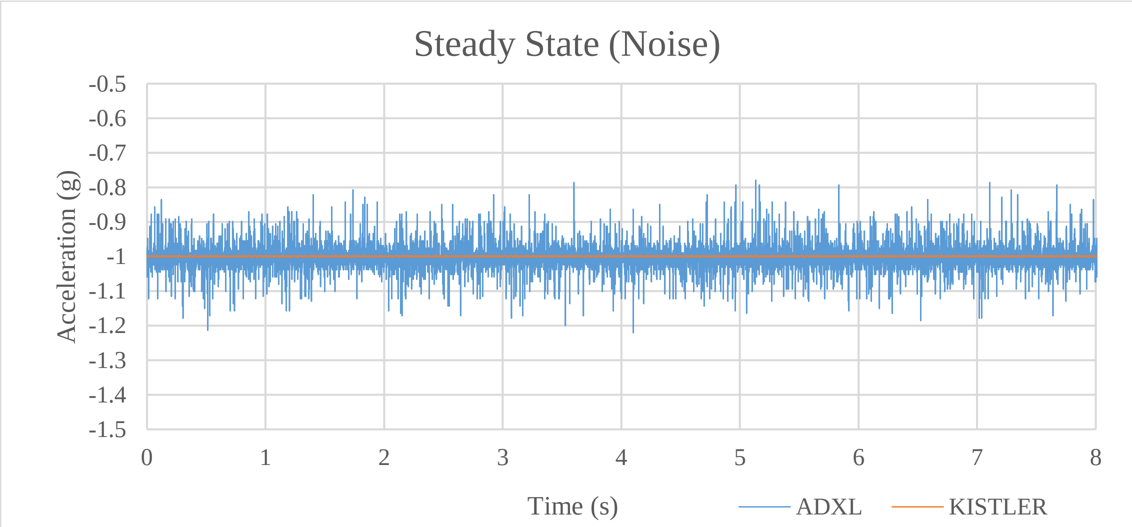


Figure 4. Comparison of acceleration data recorded by ADXL345 vs KISTLER at steady state condition

3.2. Non-Damage (Pre-Loading)

The first test is carried out on the condition before the specimen is being loaded. Accelerometer ADXL345 & KISTLER are installed on the top of the specimen. After the impulse load applied to the specimen, it triggered the free vibration on Z-axis (vertical) and then the acceleration of specimen is being recorded. **Figure 5** shows the acceleration record obtained from both sensors.

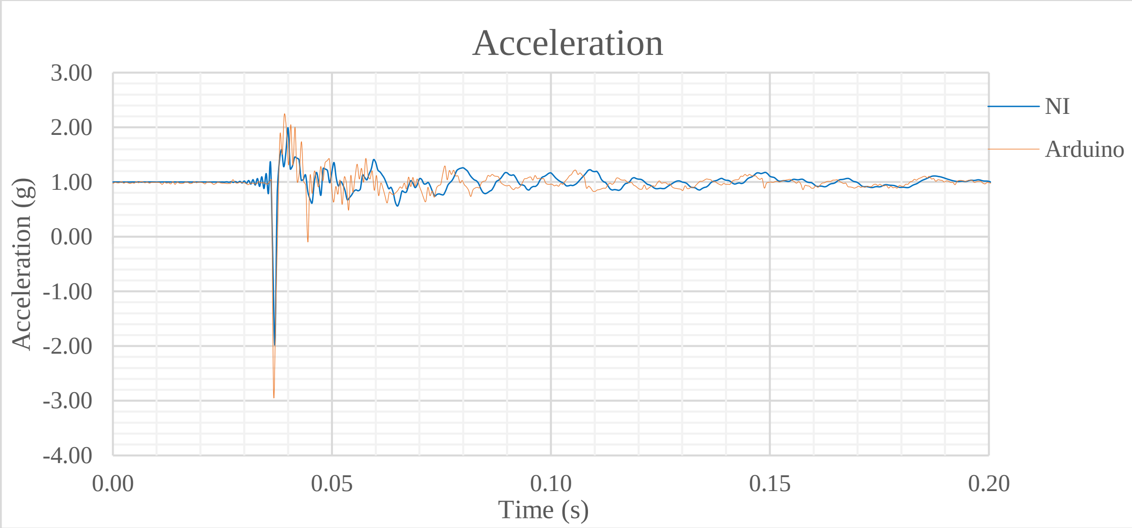


Figure 5. Time history of free vibration in non-damage (pre-loading)

Afterwards, the FFT analysis was performed for the two data above based on the frequency domain to show the natural frequency of the specimen. **Figure 6** shows comparison of the FFT results on the two measurements. The FFT results in mode 1, 2 and 3 have quite similar result between the ADXL345 and KISTLER accelerometers with relative errors are less than 5%.

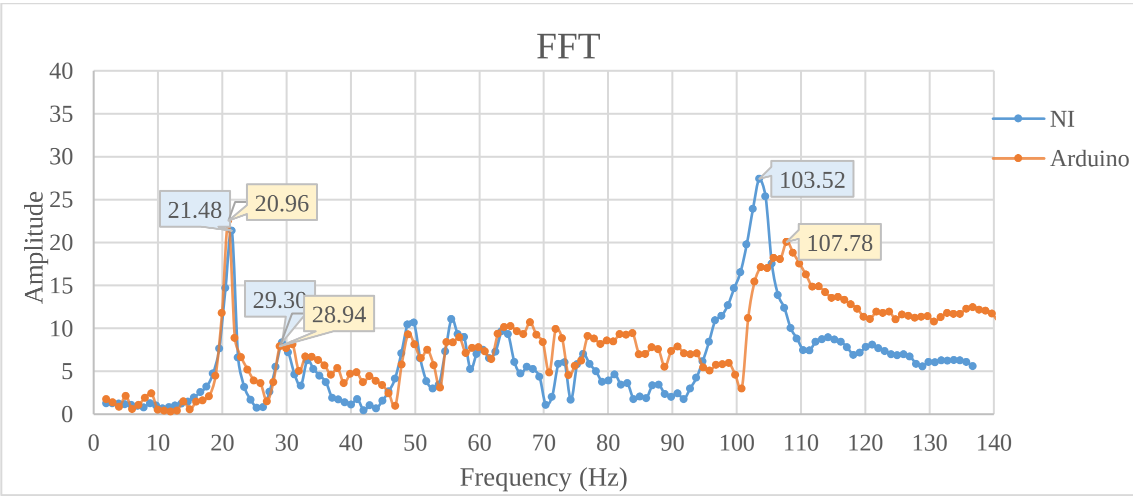


Figure 6. FFT of free vibration in non-damage (pre-loading)

3.3. Elastic Damage (L/240)

After obtaining data from the free vibration test under non-damage condition, the specimen is loaded until it reaches a deflection of 11.6 mm (L/240). Afterwards, the accelerometer was re-installed on the specimen and the free vibration test was carried out. **Figure 7** shows the acceleration data recorded by both sensors.

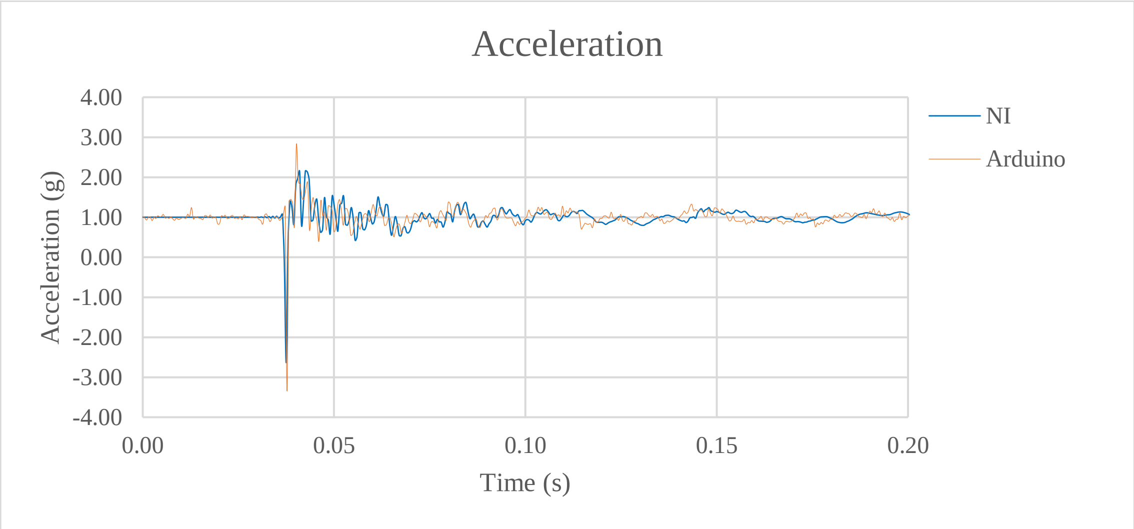


Figure 7. Time history of free vibration in elastic damage (L/240)

The following is a comparison of the results of the FFT on two measurements of acceleration against time in condition of the elastic damage specimen (**Figure 8**). **Figure 8** shows that ADXL345 and KISTLER have similar FFT results on mode 1, 2 and 3 with less than 5% of relative errors.

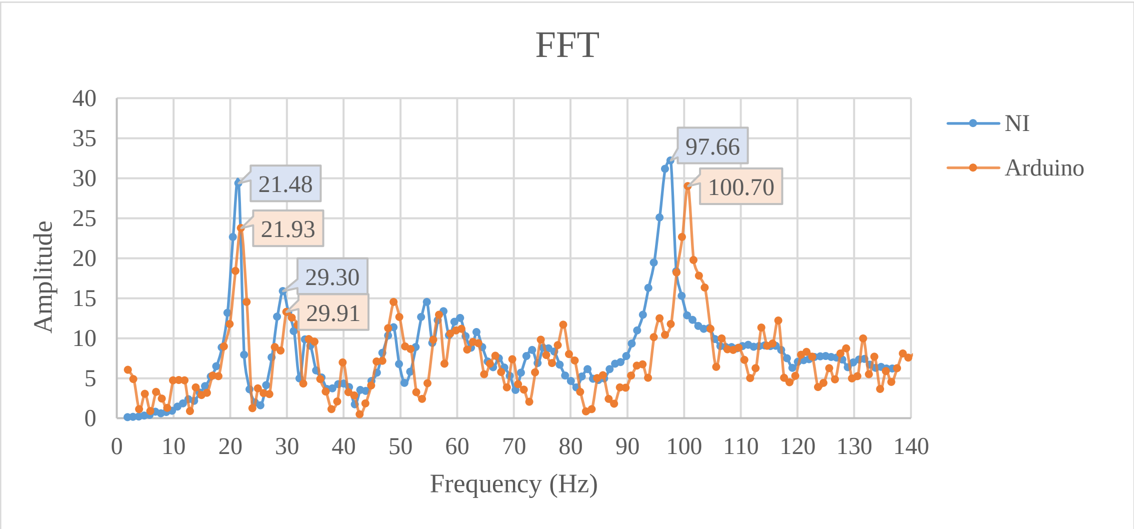


Figure 8. FFT of free vibration in elastic damage (L/240)

3.4. Inelastic Damage (L/120)

After obtaining data from the free vibration test under elastic damage conditions, the specimen is loaded until it reaches a deflection of 23.2 mm (L/120). Then the accelerometer is re-installed in previous location and free vibration test is carried out. **Figure 9** shows the acceleration data recorded by both sensors.

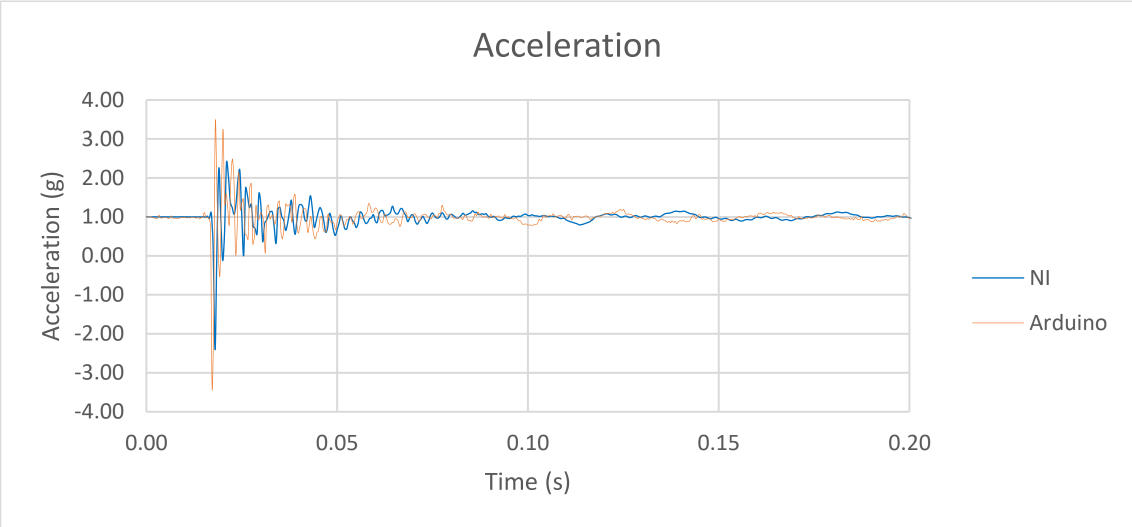


Figure 9. Time history of free vibration in inelastic damage (L/120)

Figure 10 shows the comparison of the FFT results on two measurements of acceleration against time on the condition of inelastic damage specimen.

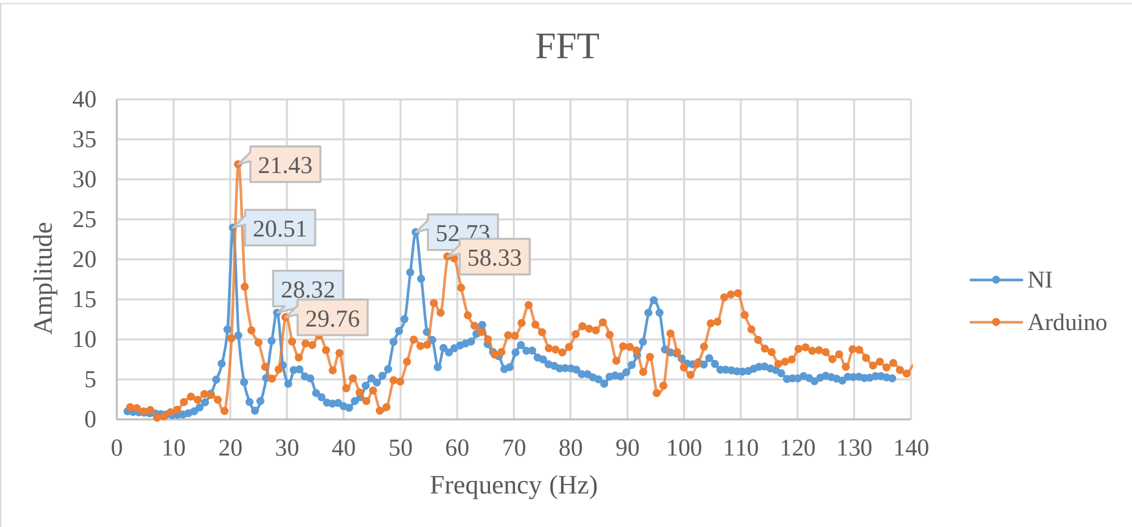


Figure 10. FFT of free vibration in inelastic damage (L/120)

Figure 10 shows that mode 3 are shifted to lower frequency due to crack developing and impacted to the natural frequency of specimen. Nevertheless, FFT results of ADXL345 & KISTLER still show similar pattern.

The relative errors size of FFT results obtained is not more than 5% on mode 1, 2, 3 for each case, except on mode 3 for inelastic damage case which has relative error of almost 10%. In general, both of sensors have shown similar result with acceptable relative error. Table 2 shows a summary of the results of all tests carried out.

Table 2. Comparison of free vibration test using Arduino (ADXL345) vs commercial accelerometer (KISTLER)

Case	**Mode 1**			**Mode 2**			**Mode 3**		
	ADXL (Hz)	**NI (Hz)**	**Relative Error (%)**	**ADXL (Hz)**	**NI (Hz)**	**Relative Error (%)**	**ADXL (Hz)**	**NI (Hz)**	**Relative Error (%)**
Pre-loading	21.0	21.5	2.4%	28.9	29.3	1.2%	107.8	103.5	4.1%
Damage L/240	21.9	21.5	2.1%	29.9	29.3	2.1%	100.7	97.7	3.1%
Damage L/120	20.5	21.4	4.3%	28.3	29.8	4.8%	52.7	58.3	9.6%

4. Conclusion

The results of this study indicate that the free vibration test measurements carried out on 3 different conditions of the specimens shown relatively similar results. The pattern between the Arduino equipped with ADXL345 and the Data logger NI equipped with accelerometer KISTLER is similar. However, noise levels between them are quite significant.

As a suggestion for further study, the noise level of Arduino equipped with ADXL345 could be reduced to decrease the size of relative error. Other than that, the experiments could also be conducted by using low tolerance level of resistor, strain gauge or using fibre optic cable. Maintain the error level of each component will reduce the general error of system.

References

Abruzzese, D., Micheletti, A., Tiero, A., Cosentino, M., Forconi, D., Grizzi, G., Scarano, G., Vuth, S., & Abiuso, P. (2020). IoT sensors for modern structural health monitoring. A new frontier. *Procedia Structural Integrity*, *25*, 378–385. https://doi.org/10.1016/J.PROSTR.2020.04.043

Aditama, V., & Wedyantadji, B. (2020). Deteksi Jarak Jauh Keruntuhan Beton Bertulang Berbasis Arduino. *Jurnal Sondir*, *4*(2), 63–69.

Ali, A. S., Zanzinger, Z., Debose, D., & Stephens, B. (2016). Open Source Building Science Sensors (OSBSS): A low-cost Arduino-based platform for long-term indoor environmental data collection. *Building and Environment*, *100*, 114–126. https://doi.org/10.1016/J.BUILDENV.2016.02.010

Allotta, B., Pugi, L., Massai, T., Boni, E., Guidi, F., & Montagni, M. (2017). Design and calibration of an innovative ultrasonic, arduino based anemometer. *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 1–6. https://doi.org/10.1109/EEEIC.2017.7977450

Angelini, E., Corbellini, S., Parvis, M., Ferraris, F., & Grassini, S. (2014). An Arduino-based EIS with a logarithmic amplifier for corrosion monitoring. *2014 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) Proceedings*, 905–910. https://doi.org/10.1109/I2MTC.2014.6860873

Arduino. (2018). *What is Arduino?*

Dragos, K., & Smarsly, K. (2017). *Decentralized infrastructure health monitoring using embedded computing in wireless sensor networks* (pp. 183–201). https://doi.org/10.1007/978-3-319-56136-3_10

Guerriero, L., Guerriero, G., Grelle, G., Guadagno, F. M., & Revellino, P. (2017). Brief Communication: A low-cost Arduino®-based wire extensometer for earth flow monitoring. *Natural Hazards and Earth System Sciences*, *17*(6), 881–885. https://doi.org/10.5194/nhess-17-881-2017

Hasibuzzaman, Md., Shufian, A., Shefa, R. K., Raihan, R., Ghosh, J., & Sarker, A. (2020). Vibration Measurement & Analysis Using Arduino Based Accelerometer. *2020 IEEE Region 10 Symposium (TENSYMP)*, 508–512. https://doi.org/10.1109/TENSYMP50017.2020.9230668

Hester, D., Brownjohn, J., Bocian, M., & Xu, Y. (2017). Low cost bridge load test: Calculating bridge displacement from acceleration for load assessment calculations. *Engineering Structures*, *143*, 358–374. https://doi.org/10.1016/J.ENGSTRUCT.2017.04.021

Mahbub, M. (2019). Automated control signal reception acknowledgement system using Nrf24l01p wireless transceiver module and arduino. *Journal of Applied Science & Process Engineering*, *6*(1).

Mallari, J. (2020a). *How to setup I2C communication on the Arduino?*

Mallari, J. (2020b). *How to use SPI communication on the Arduino?*

Marsh, M. (2021). *Future of construction global construction outlook*.

Moreu, F., Li, X., Li, S., & Zhang, D. (2018). Technical specifications of structural health monitoring for highway bridges: New Chinese structural health monitoring code. In

Frontiers in Built Environment (Vol. 4). Frontiers Media S.A. https://doi.org/10.3389/fbuil.2018.00010

Nguyen, C. D., Huynh, Q. H., Phan, C. B., Tran, V. M., Nguyen, C. M., Pham, B. T., & Ngo, K. N. (2018). *Low-cost vibration measurement for behavior of small-scale steel modeling using MEMS, Raspberry Pi-3 and Arduino Mega 2560*. https://www.researchgate.net/publication/326032887

Oetomo, J. J. (2020). On the uses of low-cost arduino based microcontroller and adxl 345 accelerometer for geotechnical instrumentation. *24th Annual National Conference on Geotechnical Engineering Jakarta*.

Septinurriandiani, P., Penelitian, P., Pengembangan Jalan, D., Jembatan, D., Penelitian, B., & Pengembangan, D. (2011). *Sistem monitoring kesehatan struktur-penilaian kondisi dan kriteria peralatan monitoring*. www.pusjatan.pu.go.id

Serov, A. (2017). Cognitive Sensor Technology for Structural Health Monitoring. *Procedia Structural Integrity*, *5*, 1160–1167. https://doi.org/10.1016/J.PROSTR.2017.07.027

Silva, A. L., Varanis, M., Mereles, A. G., Oliveira, C., & Balthazar, J. M. (2019). A study of strain and deformation measurement using the Arduino microcontroller and strain gauges devices. *Revista Brasileira de Ensino de Fisica*, *41*(3). https://doi.org/10.1590/1806-9126-RBEF-2018-0206

Thong, Y. K., Woolfson, M. S., Crowe, J. A., Hayes-Gill, B. R., & Jones, D. A. (2004). Numerical double integration of acceleration measurements in noise. *Measurement*, *36*(1), 73–92. https://doi.org/10.1016/J.MEASUREMENT.2004.04.005