

Association of Structural Engineers of Serbia

SYMPOSIUM 2020

13-15 May 2021- ARANDJELOVAC

ASES INTERNATIONAL SYMPOSIUM PROCEEDINGS



IN COOPERATION



Република Србија
Министарство
просвете, науке и
технолошког развоја

SUPPORTED BY



PLATINUM SPONSORS

Metal **ink** ara

ŠIRBEGOVIĆ®
INŽENJERING

DELTA
REAL ESTATE

baldini
studio

INTERNATIONAL

STRABAG

TEAMS WORK.

PUT INŽENJERING

GOLD SPONSORS



Marko Radišić¹, Mira Petronijević²

PRIMENA ARDUINO PLATFORME ZA MERENJE MEHANIČKIH VIBRACIJA

Rezime:

U ovom radu prikazana je primena softvera i hardvera otvorenog koda za merenje mehaničkih vibracija. Objašnjen je postupak izrade akvizicionog sistema za merenje vibracija sačinjenog od Arduino UNO R3 ATmega328P mikrokontrolera i Analog Devices ADXL335 akcelerometra. Program za prikupljanje podataka napisan je u programskom jeziku C++, dok je za obradu signala korišćen programski jezik Python. Vibracije su merene na čeličnoj gredi sa prepustima. Dobijeni rezultati upoređeni su sa rezultatima izmerenim pomoću akvizicionog sistema MGCplus i akcelerometra Silicon Design 2240-002.

Ključne reči: Arduino, merenje vibracija, otvoreni kod, C++, Python, obrada signala

APPLICATION OF ARDUINO PLATFORM FOR MEASURING MECHANICAL VIBRATIONS

Summary:

This paper presents the usage of open source hardware and software for measuring mechanical vibrations. The process of constructing the vibration measurement system including the Arduino UNO R3 ATmega328P microcontroller and Analog Devices ADXL335 accelerometer is described. The program for data acquisition is written in C++. The program for signal processing is written in Python. Vibrations are measured on the steel beam with overhangs. The obtained results are compared with the results measured with the MGCplus data acquisition system and Silicon Design 2240-002 accelerometer.

Key words: Arduino, vibration measurement, open source, C++, Python, signal processing

¹ PhD, Docent, Građevinski Fakultet Univerziteta u Beogradu, Bulevar kralja Aleksandra 73, mradisic@grf.bg.ac.rs

² PhD, Redovni profesor u penziji, Građevinski Fakultet Univerziteta u Beogradu, Bulevar kralja Aleksandra 73, pmira@grf.bg.ac.rs

1. INTRODUCTION

The evolution of technological gadgets led to development of sensors intended for every day use. A single smartphone could be observed as a box of sensors including humidity sensor, thermometer, barometer, touchscreen sensor, ambient light sensor, proximity sensor, magnetometer, gyroscope, and accelerometer. Needless to say, these kind of devices are made to be affordable for personal usage.

The beginning of Arduino [1], an open-source hardware and software company, starts with the beginning of the 21st century. The main idea was to make an easy-to-use hardware and software aimed at students without a background in electronics and programming. Today there is a worldwide community of Arduino users including students, artists, programmers, engineers, either hobbyist or professionals. Arduino platform could be used as a microcontroller [2, 3] as well as a data acquisition system. Among other electronic devices, Arduino board could be paired with accelerometers in order to detect and measure vibrations. Varanis et al [4] assembled a signals acquisition system for mechanical vibrations teaching purposes involving Arduino and sensors as accelerometer, gyroscope and ultrasound. Ribeiro and Lameiras performed a study of using low-cost MEMS accelerometers for structural health monitoring [5].

In this paper, we are building the vibration measurement system using Arduino UNO R3 board [6] as a data acquisition system and Analog Devices ADXL335 accelerometer [7]. It is an open source system affordable for personal usage what makes it a great tool for teaching and learning, but it could be also used in practice. The performance of the system is measured on the simply supported steel beam with overhangs. At the same time, we measured the vibrations of the beam using MGCplus data acquisition system [8] with Silicon Design 2240-002 accelerometer [9]. The natural frequencies of the beam are derived from the power spectral density of the signals and the results are compared.

2. THE VIBRATION MEASUREMENT SYSTEM

The vibration measurement system (VMS) described in this paper in detail is built with two major units: Arduino UNO R3 board [6] and Analog Devices ADXL335 accelerometer [7].

The ADXL335, shown in Figure 1, is an accelerometer with micro-electro-mechanical system (MEMS) technology. It has mechanical elements of microelectronics scale. It is a capacitive type of accelerometer. It measures the change in voltage caused by a change in the capacitance of a capacitor. The capacitor plates are made of fixed and movable micromechanical beams. The movable plate is sensitive to external accelerations and oscillates relatively to the fixed part, causing the change of the capacity and therefore, the voltage in the circuit. ADXL335 measures acceleration with a range of $\pm 3g$. The bandwidth of the accelerometer could be altered using the capacitors at the X_{out} , Y_{out} and Z_{out} pins. The bandwidth limits are 0.5 Hz and 1600 Hz for X and Y axes, and 0.5 Hz and 550 Hz for Z axis.

Arduino UNO R3 is a microcontroller board shown in Figure 2. It is known as an affordable yet powerful tool for quick assemble and test of electronic systems prototypes. UNO R3 is equipped with ATmega328P microcontroller, 14 digital Input/Output pins of which 6

provide Pulse-Width Modulation (PWM) output and 6 analog input pins. It could be powered via USB port or by an external power source.



Figure 1 – Analog Devices ADXL335 accelerometer [6]



Figure 2 – Arduino UNO R3 microcontroller board [7]

For this experiment we used the UNO board connected to the computer as a data acquisition system. The circuit of the system is shown on Figure 3. The board analog pins A0, A1 and A3 are connected with the X_{out} , Y_{out} and Z_{out} pins of the accelerometer. The accelerometer is powered using Arduino 3.3V output pin. The UNO board is powered using the USB cable, which is at the same time used for the data transmission between the UNO board and the computer. As soon as we plug in the board, it starts the serial connection with the computer and forwards the data that accelerometer sends to analog pins.

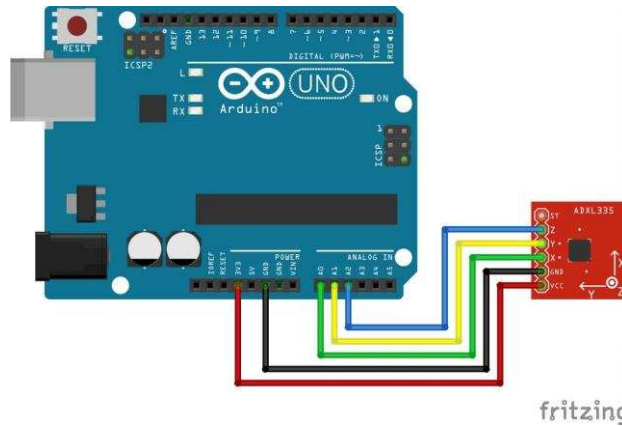


Figure 3 – Vibration measurement system circuit diagram created using Fritzing [10]

3. EXPERIMENT

The experiment is performed on the simply supported steel beam with overhangs. The disposition of the beam and its properties are shown in Figure 4. The additional mass at the ends of both overhangs is provided in order to alter the natural frequencies of the beam. The mass is equally placed on both overhangs.

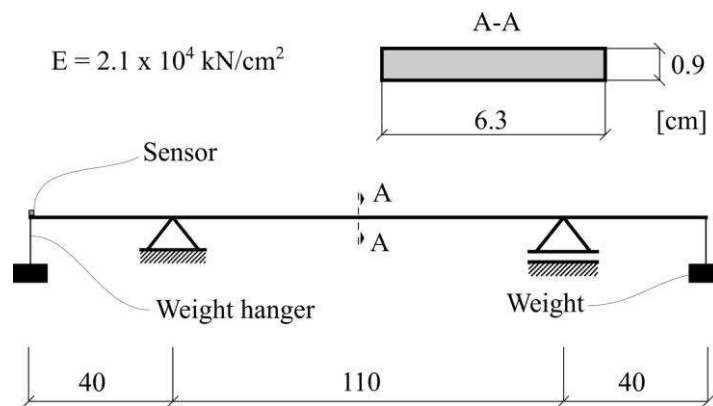


Figure 4 – Disposition of the steel beam with overhangs

The ADXL335 accelerometer is placed on the top face of the left overhang, as shown in Figure 5. The Analog Devices does not provide the housing for the accelerometer. Therefore, the accelerometer is screwed to the plastic box which is glued to the beam. The X axis of the accelerator is parallel to the vertical vibrations of the beam. The Silicon Design 2240-002 accelerometer is glued to the bottom face of the beam, below the ADXL335 accelerometer.

Prior to gluing, both accelerometers are calibrated on the reference table. The Silicon Design 2240-002 accelerometer is calibrated using the software provided by the MGCplus data acquisition system. The calibration of the ADXL335 accelerometer is performed by altering the UNO board program written in Arduino programming language based on C++ [11]. The raw data accelerator sends to the board is the circuit voltage in terms of mV. Since the accelerometer is powered by 3.3V, it is expected to return integer values around 330. Once the minimal and the maximal voltage at rest are obtained, the UNO board program is updated to map the voltage values to acceleration values between -9.81 m/s and +9.81 m/s. The signals are visualized in real time and recorded using Serialplot [12].



Figure 5 – The accelerometers on the beam: ADXL335 (top) and Silicon Design 2240-002 (bottom)

4. RESULTS AND DISCUSSION

The steel beam with overhangs, shown in Figure 4, is excited by introducing the initial velocity at the end of the beam, by simply knocking the beam with the finger. Four cases are considered:

- the beam with no additional mass (M0),
- the beam with mass hangers that weights 1.08kg each (MH),
- the beam with 2kg weights (M2) and
- the beam with 7kg weights (M7).

The signals are measured using the sampling frequency of 500 Hz. Figure 6 shows the accelerations of the beam measured using the Silicon Design 2240-002 accelerometer.

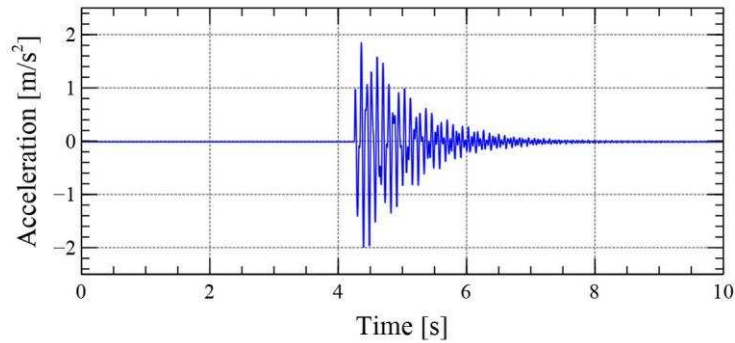


Figure 6 – Accelerations of the beam measured using Silicon Design 2240-002 accelerometer

The postprocessing of the measured signals is done by using the Python [13] script that relies on numpy [14], scipy [15] and matplotlib [16] libraries. The power spectral density of the response is calculated using the scipy periodogram routine that considers Dirichlet window. The resulting power spectral densities are shown in Figure 7. The first two natural frequencies of the beam, F1 and F2, are extracted from the power spectral densities and shown in Table 1. Prefix AD implies the usage of ADXL335. Prefix SD implies the usage of Silicon Design 2240-002. The percent error is calculated relative to the SD values. While the accuracy is high in terms of frequency, Figure 7 shows visible discrepancies of power values. Several reasons could lead to that behaviour. The detail analysis of the measured signals showed that the USB cable cannot provide the reliable sampling rate of 500 Hz. Figure 8 shows the measured signal for the case of the beam with 7kg weights by using AD and SD accelerometers. The resolution of the measured signal is much lower when using the AD accelerometer. Possible improvements are given in Conclusions.

Table 1 – The first two natural frequencies of the beam obtained by using ADXL335 (AD) and Silicon Design 2240-002 (SD) accelerometers and percentage error relative to SD values

	AD F1	SD F1	Error	AD F2	SD F2	Error
M0	12.12	12.14	0.16%	21.44	21.31	-0.61%
MH	9.07	9.06	-0.11%	13.99	14.06	0.50%
M2	6.60	6.64	0.60%	9.81	9.84	0.30%
M7	4.79	4.89	2.04%	6.62	6.63	0.15%

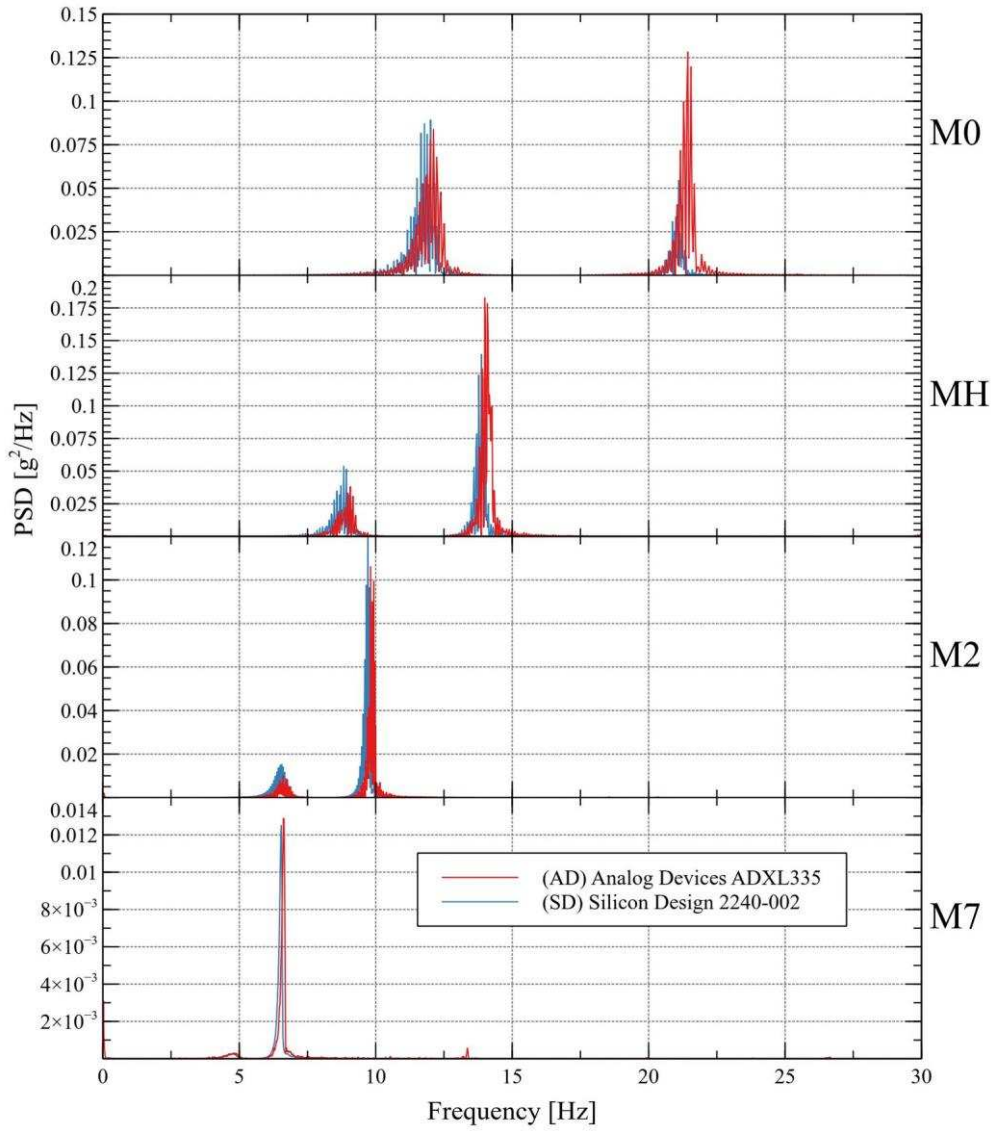


Figure 7 – The power spectral density of the beam (M0), the beam with mass hangers (MH), the beam with 2kg weights (M2) and the beam with 7kg weights (M7)

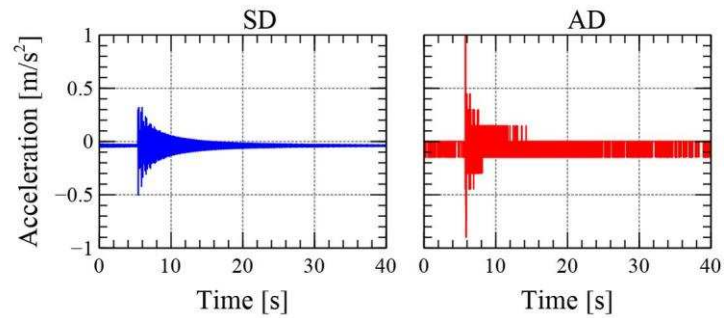


Figure 8 – Measured signal resolution for the beam with 7 kg weights

5. CONCLUSIONS

This paper analyses the performance of the vibrations measurement system (VMS) built with Arduino UNO R3 with ATmega328P microcontroller and Analog Devices ADXL335 accelerometer (AD). The system is open source, hardware and software wise, so it gives a clear insight into the physics of the problem. It is also very affordable for personal usage, what undoubtedly makes it a great tool for teaching and learning. In order to investigate how well the proposed VMS behaves in engineering practice, its performance is compared with the performance of the MGCplus data acquisition system and Silicon Design 2240-002 accelerometer (SD). The measurements are obtained on the simply supported steel beam with overhangs. Additional mass is added to the beam in order to vary the natural frequencies of the system.

The results of the analysis are given in terms of power spectral densities of the measured signals, from which the first two natural frequencies of the system are extracted. The natural frequencies varies from 4.79 Hz to 21.44 Hz. The percentage error between two different VMS, calculated with respect to the one with the SD accelerometer, is 2.04% at most. However, the power values of the signals of two different systems mismatch. The analysis of the measured signals indicated possible problems of the low performance of the proposed VMS.

The data transmission over the USB cable cannot be done reliably with the sampling rate of 500 Hz. The sampling rate could be improved, considering both the stability and the speed, by using the UNO board internal memory or an additional memory card connected directly to the UNO board. The chunks of data could be collected in memory and transferred in to the computer.

The signal measured with the proposed VMS has poor resolution comparing to the signal measured with SD accelerometer. This could be improved by introducing an operational amplifier to the circuit. The amplifier would take advantage of the ADXL335 $\pm 3g$ range that is not fully utilized in the experiment.

The modularity of the proposed VMS should be mentioned. The Arduino board could be used as a data acquisition system for other devices. Besides its small size, it could be coupled with WiFi module and memory card what makes it a portable and easy to install device.

Future research regarding this project would include implementation of proposed improvements as well as testing the performance of other sensors, such as gyroscopes and ultrasound sensors, on measuring mechanical vibrations.

LITERATURE

- [1] What is Arduino? [Online]. Available at: <https://www.arduino.cc/en/Guide/Introduction> [Accessed 9 Dec 2020]
- [2] B. Lahfaoui, S. Zouggar, B. Mohammed, and M. L. Elhafyani, 'Real Time Study of P&O MPPT Control for Small Wind PMSG Turbine Systems Using Arduino Microcontroller', *Energy Procedia*, vol. 111, pp. 1000–1009, Mar. 2017, doi: 10.1016/j.egypro.2017.03.263.
- [3] [F. C. Bolat, S. Basaran, and S. Sivrioglu, 'Piezoelectric and electromagnetic hybrid energy harvesting with low-frequency vibrations of an aerodynamic profile under the air effect', *Mechanical Systems and Signal Processing*, vol. 133, p. 106246, Nov. 2019, doi: 10.1016/j.ymsp.2019.106246.
- [4] M. Varanis, A. Silva, P. Brunetto, and R. Gregolin, 'Instrumentation for mechanical vibrations analysis in the time domain and frequency domain using the Arduino platform', *Revista Brasileira de Ensino de Física*, vol. 38, Mar. 2016, doi: 10.1590/S1806-11173812063.
- [5] R. R. Ribeiro and R. de M. Lameiras, 'Evaluation of low-cost MEMS accelerometers for SHM: frequency and damping identification of civil structures', *Lat. Am. j. solids struct.*, vol. 16, no. 7, p. e203, 2019, doi: 10.1590/1679-78255308.
- [6] Arduino UNO R3 Atmega328P [Online]. Available at: <https://store.arduino.cc/arduino-uno-rev3> [Accessed 9 Dec 2020]
- [7] Analog Devices ADXL335 accelerometer [Online]. Available at: <https://www.analog.com/en/products/adxl335.html> [Accessed 9 Dec 2020]
- [8] MGCplus: The All-Rounder for Data Acquisition [Online]. Available at: <https://www.hbm.com/en/2261/mgcplus-data-acquisition-system/> [Accessed 9 Dec 2020]
- [9] Silicon Designs Product Datasheets [Online]. Available at: <https://www.silicondesigns.com/data-sheets> [Accessed 9 Dec 2020]
- [10] Fritzing [Online]. Available at: <https://fritzing.org/> [Accessed 9 Dec 2020]
- [11] Arduino Programming Language [Online]. Available at: <https://www.arduino.cc/reference/en/> [Accessed 9 Dec 2020]
- [12] SerialPlot: Small and simple software for plotting data from serial port in realtime. [Online]. Available at: <https://hg.sr.ht/~hyozd/serialplot/> [Accessed 9 Dec 2020]
- [13] Python Software Foundation. Python Language Reference, version 3.9. [Online] Available at <http://www.python.org> [Accessed 9 Dec 2020]

- [14] Charles R. Harris et al. Array programming with NumPy, *Nature*, 585, 357–362 (2020), DOI:10.1038/s41586-020-2649-2
- [15] Pauli Virtanen et al. Fundamental Algorithms for Scientific Computing in Python. *Nature Methods*, 17(3), 261-272, DOI:10.1038/s41592-019-0686-2
- [16] John D. Hunter. Matplotlib: A 2D Graphics Environment, *Computing in Science & Engineering*, 9, 90-95 (2007), DOI:10.1109/MCSE.2007.55

ACKNOWLEDGEMENTS

This research is carried out within the Project TR 200092 supported by the Ministry of Science and Technology, Republic of Serbia.

The authors thank to Prof. dr. Zoran Mišković and Siniša Savatović from Department of materials and structures Faculty of Civil Engineering University of Belgrade, for sharing their knowledge and experience as well as the laboratory space, and for providing the testing units and the testing equipment.