Jurnal Materi dan Pembelajaran Fisika
Volume 14, Number 2, pp. 72-80 2024
Website : https://jurnal.uns.ac.id/jmpf

# A Comparative Study of Sound Resonance Using Arduino-Based Ultrasonic Sensors and Visualization Analysis with Python

**Feri Iskandar[1], Yudhiakto Pramudya[2]**
[1]*Institut Teknologi Batam, Gajah Mada Street, Sekupang, Batam, Kepulauan Riau 29424*
[2]*Physics Education Department, Faculty of Teacher Training and Education, Universitas Ahmad Dahlan, Pramuka 42 Street, Sidikan, Umbulharjo, Yogyakarta 55161*
*Corresponding Author Email: yudhiakto.pramudya@pfis.uad.ac.id

**Article's Info**
Received: 17th, September, 2024
Accepted: 23th, September, 2024
Published: 26th, November, 2024

**DOI**:
https://doi.org/10.20961/jmpf.v14i2.93454

***Abstract***. In the modern era, the study of sound resonance in physics laboratories has increasingly incorporated technological tools to improve the experimental process. While conventional approaches to resonance experiments remain common, they often face challenges related to equipment setup and limited real-time data analysis. This research compares conventional methods with Arduino-based techniques, combined with Python for data visualization and analysis, in sound resonance experiments. The integration of Arduino microcontrollers and ultrasonic sensors offers a more accessible and streamlined alternative to conventional resonance measurement techniques, facilitating improved data collection and interpretation. Data is gathered using PLX DAQ software connected to the Arduino system, with the results visualized and analyzed using Python tools. The experiments show that the average air column length when the water in the reservoir was lowered is 16.10 cm, with an error of 3.04%, and when the water was raised, the average length is 15.60 cm, with an error of 5.98%. A 512 Hz sound source was used to determine the fundamental frequency, revealing slight variations due to changes in the measurement distance. Specifically, the fundamental frequency was recorded as (528 ± 5) Hz when the water level was lowered and (545 ± 8) Hz when it was raised. This study highlights the positive role of technology in enhancing physics education and research, particularly in sound resonance studies.

**Keywords:** Arduino; frequency; Python; Sound resonance,  Ultrasonic sensor,

**How to Cite :** Iskandar, F., , Pramudya, Y., (2024). A Comparative Study of Sound Resonance Using Arduino-Based Ultrasonic Sensors and Visualization Analysis with Python. Jurnal Materi dan Pembelajaran Fisika, volume 14 number 2, 72-80



## INTRODUCTION

In education, laboratory experiments are one of the essential methods for understanding theoretical concepts through practical applications. In the 21st century, technological advancements and the growing demand for efficiency have transformed many aspects of human labor, with technology now playing a vital role in areas previously reliant on manual skills. This shift is evident in the increasing use of sophisticated applications that simplify everyday tasks and improve productivity (Pratiwi, 2019). One such experiment in physics education is the study of sound resonance. Sound resonance is a phenomenon where the amplitude significantly increases at certain frequencies that correspond to the natural frequency of an object (Halliday, 2018). A closed organ pipe, which is a cylindrical air column with one end open and the other end closed, also exhibits this phenomenon. When the air column inside the pipe vibrates, the air outside the pipe, in contact with the column, vibrates at the same frequency. Since the medium inside and outside the organ pipe is air, the speed of wave propagation is the same, resulting in identical wavelengths. The resonance observed in the closed organ pipe demonstrates how the concept of sound resonance can be applied to closed systems (Abdullah, 2016). Standing waves in a closed organ pipe are created when two waves of the same frequency travel in opposite directions and interfere with each other. This interference results in constructive and destructive patterns. During constructive interference, the waves amplify, producing regions of maximum displacement known as antinodes. In contrast, destructive interference causes the waves to cancel out, leading to regions with zero displacement, called nodes. These patterns of alternating nodes and antinodes characterize the standing wave phenomenon within the pipe (Serway & Jewett, 2004). Conventionally, experiments are conducted using manual tools that are not integrated with technological applications. However, this approach often faces several challenges, such as complex equipment setup, difficulties in achieving accurate measurements, and limitations in performing real-time data analysis. In addition, human error, such as uncertainty in reading results, inconsistent setups, and subjective data interpretation, is a common issue.

Recent studies have shown that the use of software, such as Audacity, can facilitate frequency measurements with greater ease and accuracy. For instance, demonstrated that Audacity is capable of measuring the frequencies of Gamelan instruments with consistent results (Pramudya et al., 2018). This is relevant in physics experiments, where technology can replace manual methods to improve accuracy. Moreover, software-based simulations, such as those employed using Scilab, illustrate how frequency vibration visualization can be enhanced through technology (Handayani et al., 2018). Moreover, software-based simulations, such as those employed using Scilab, illustrate how frequency vibration visualization can be enhanced through technology.

Building on these technological innovations, the use of Arduino as a microcontroller platform, combined with ultrasonic sensors, provides an efficient and economical method for conducting resonance experiments (Budiarso, 2023). Arduino enables faster and more accurate data collection, while ultrasonic sensors can determine the speed of sound in air by utilizing the propagation of emitted waves to detect subtle changes in sound waves that might not be detected through manual methods (Boimau et al., 2019). The Arduino microcontroller is divided into two parts: hardware and software. The hardware, known as the Arduino development board, interacts with sensors to collect data, while the software, known as the Arduino IDE (Integrated Development Environment), simplifies the development and execution of code on the hardware (Jamil et al., 2022). The Arduino IDE is software used to create, write, modify, and upload Arduino program code. The Arduino IDE software makes it easier to develop microcontroller applications such as source programs. The source programs created for microcontroller applications use the C/C++ and JavaScript programming languages (Syahwil, 2017).

In this research, the data collected by Arduino will be processed using the Python programming language. Python, a powerful programming language with extensive data analysis capabilities, allows for deeper data processing. Additionally, Python supports adequate data visualization, making it easier to understand and present experimental results more effectively and efficiently (Ismailov & Jo'rayev, 2022). Python is a well-designed programming language that can be used for real-world programming. It is renowned for its easy-to-understand syntax and a vast collection of libraries that support various computational needs. In previous studies, Python has been successfully employed to analyze free-fall motion, with results showing its accuracy in calculating air resistance by processing data efficiently and providing in-depth insights into object dynamics (Nurfitni & Pramudya, 2023). Python is highly flexible due to its ability to integrate modular components written in other programming languages. Some of the modules commonly used include NumPy and Matplotlib (Srinath, 2017). NumPy (Numerical Python) is a fundamental library for scientific computing in Python. It provides support for large multidimensional arrays and various mathematical functions. Meanwhile, Matplotlib is a plotting library for Python that offers an interface for creating various types of graphs. Both of these libraries are used to create and visualize sinusoidal waves propagating along the y-axis (Bu'ulolo et al., 2023).

Therefore, this study aims to conduct a comparative analysis between conventional methods and Arduino- and Python-based methods in the context of sound resonance. This research is expected to demonstrate improvements in accuracy, efficiency, and ease in studying sound resonance, while also providing new insights into the use of technology in physics education and research.

## METHOD

This research was conducted at the Basic Physics Laboratory, Batam Institute of Technology using computational and experimental method from April 2024 to July 2024. The equipment used in the study included a Windows 10 Pro 64-bit laptop with 16 GB RAM, which was essential for collecting and analyzing the data. To measure distances, the HC-SR04 sensor was employed, utilizing ultrasonic waves to calculate the time it took for the waves to reflect back. Additionally, the KY-037 sensor was used to capture sound produced by the resonance tube. Both sensors were controlled through the Arduino IDE software, which played a critical role in their operation, allowing them to interface with the Arduino Uno microcontroller. This microcontroller served as the bridge between the sensors and the laptop, connected via various cables. The resonance tube setup, comprising a water-filled tube connected to a reservoir and mounted on a stand, was an integral part of the experiment. The setup of the equipment is illustrated in Figure 1. Data collection was streamlined through the use of PLX DAQ software, which enabled real-time data transfer from the Arduino to Microsoft Excel. Finally, a frequency generator application on Android was used to produce specific sound frequencies necessary for the experiment.

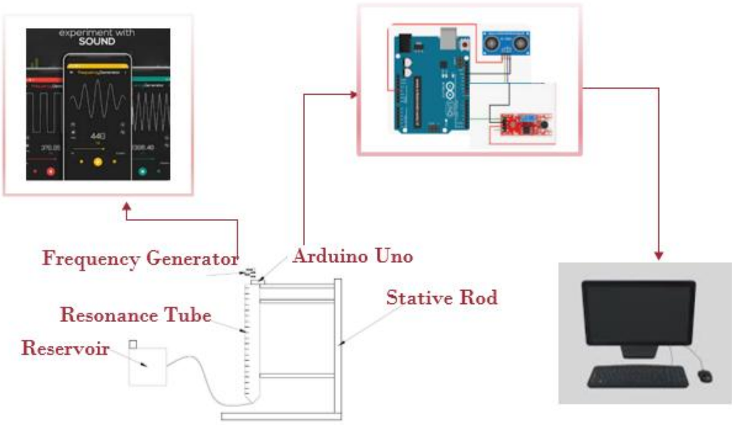
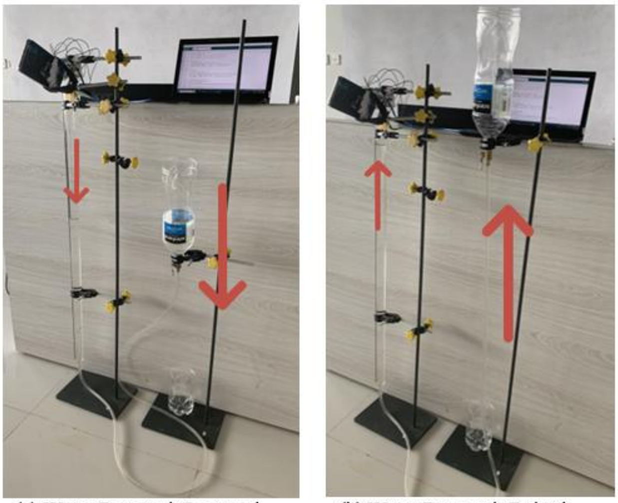



**Figure 1.** Sound Resonance Experiment Setup Diagram.

The research procedure began by assembling the HC-SR04 and KY-037 sensors on a circuit board, which was connected to the Arduino Uno using jumper cables. The circuit board was then clamped onto a stand and positioned above the resonance tube, with the HC-SR04 sensor placed precisely 1.55 cm above the tube's mouth, while the KY-037 sensor was attached to the side of the tube's opening. The Arduino Uno was connected to a laptop via a connecting cable, and the Arduino IDE software was launched to control the sensors. A smartphone running the Frequency Generator app, set to 512 Hz, was clamped onto the same stand and positioned in front of the resonance tube. The experimental setup, including the resonance tube and water reservoir, was carefully arranged as shown in Figure 2.



(a) Water Reservoir Lowered (b) Water Reservoir Raised

**Figure 2.** Illustrates the process of adjusting the water level to influence the resonance in the tube.

During the experiment, the water in the reservoir was gradually lowered from a depth of 5 cm to 30 cm and then slowly raised again. This process was repeated five times to ensure data consistency with theoretical predictions. As the experiment proceeded, the program in the Arduino IDE was executed, and it interfaced with the PLX DAQ application in Microsoft Excel, allowing for real-time data collection. The HC-SR04 sensor measured the distance as the water level fluctuated, while the KY-037 sensor recorded the amplitude of the sound resonance. The experiment continued until the largest amplitude values, indicating resonance, were identified. Based on the organ pipe theory, the resonance frequencies can be calculated using the formula:

$$f_n = \frac{nv}{4L} \quad [1]$$

Where $f_n$ is the resonant frequency, $n$ is the mode number, $v$ is the speed of sound, $L$ is the length of the air column, which in this case corresponds to the distance measured by the sensor. Any data that was inconsistent or significantly deviated due to external disturbances was disregarded, ensuring the accuracy of the results. This methodical process was crucial in obtaining reliable data for the study

For the data analysis, first, collect five sets of data when the water is lowered and five sets when it is raised. Then, plot the water depth on the x-axis and the amplitude on the y-axis. Next, identify the resonance pattern by looking for specific depths that correspond to the highest amplitude values. From these resonance points, subtract 1.55 cm (the distance from the mouth of the tube to the sensor) and calculate the average value, standard deviation, and error. Then, calculate the fundamental frequency and its associated error using repeated measurement analysis. Once the data has been collected, the analysis will be visualized using a Python program, where the flowchart of the Python code is illustrated in Figure 3 below.

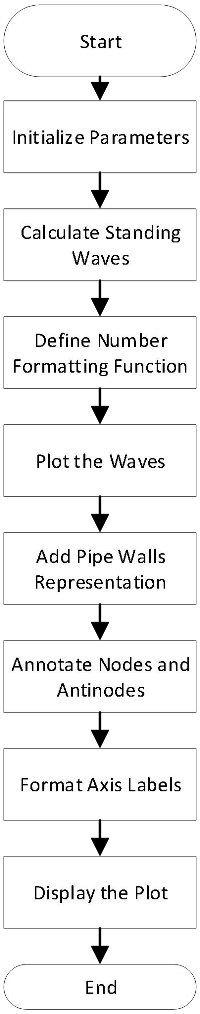



**Figure 3.** Flowchart of the Python Code for Data Visualization and Analysis.

## RESULT AND DISCUSSION

### RESULT

This research was conducted by collecting data on the length of the air column during resonance. One of the plotted data results showing the relationship between amplitude and the distance at which sound resonance occurs is presented in Figure 4.

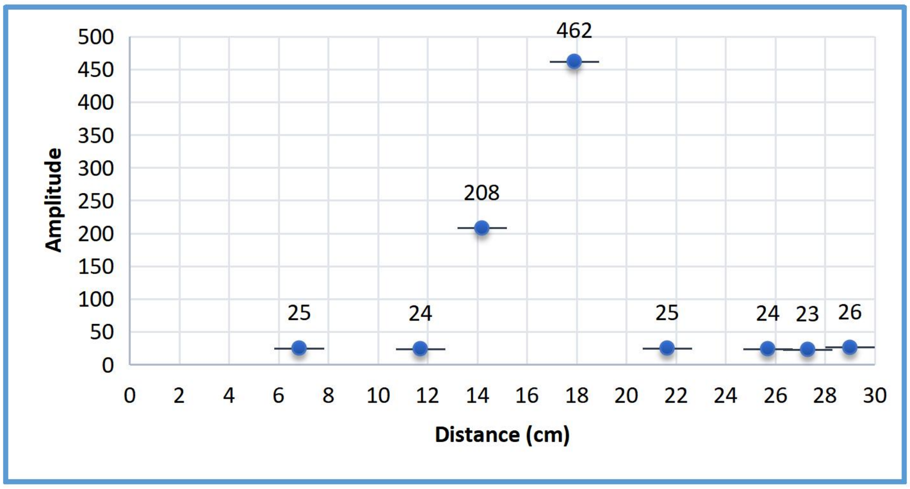



**Figure 4.** Graph of the Relationship Between Distance and Amplitude: Identification of Resonance Points

As shown in Figure 4, the relationship between distance and amplitude reveals a significant increase in amplitude at a specific distance. This sharp rise indicates the occurrence of resonance at that particular point, suggesting that the system is oscillating at its natural frequency. Resonance occurs when the frequency of an external force matches the natural frequency of the system, leading to maximum energy transfer and a substantial amplification of the oscillation's amplitude. In this case, the highest amplitude observed at a distance of 18 cm marks the system's resonant point. The selection of the highest amplitude as an indicator of resonance is based on the fundamental principle where maximum amplitude occurs when the driving frequency aligns with the system's natural frequency. At this point, energy from the external source is transferred efficiently into the system, causing a significant rise in vibration amplitude, evidenced by the peak value of 462 at the resonant distance, while other points show relatively low amplitudes, indicating non-resonant behavior. The horizontal error bars in the figure represent the uncertainty in distance measurements, which stem from potential inaccuracies in the measurement process. These error bars illustrate the range of possible variations in distance due to limitations of the measuring instrument or environmental factors, helping to convey the precision and reliability of the data. Therefore, identifying these peaks, along with acknowledging the measurement uncertainties, is crucial for understanding the system's dynamic behavior under oscillatory conditions.

The data was collected through five experiments, with two treatments: gradually lowering the water in the reservoir and slowly raising the water in the reservoir, as shown in Table 1.

**Table 1.** Measurement of Air Column Length in a Closed Organ Pipe Using HC-SR04 Sensor

| Reservoir Lowered (*cm*) | Reservoir Raised (*cm*) |
|---|---|
| 16.03 | 16.35 |
| 15.72 | 16.35 |
| 16.35 | 15.08 |
| 16.35 | 15.08 |
| 16.03 | 15.18 |

The data in Table 1 represents the length of the air column during fundamental resonance. The average air column length when the water in the reservoir was lowered is 16.10 centimeters. Using Equation 1, the air column length at the first resonance is calculated to be 16.60 centimeters, resulting in an error of 3.04%. The average air column length when the water in the reservoir was gradually raised is 015.60 centimeters, with an error of 5.98%. These results were then processed using repeated measurement techniques, yielding the fundamental frequency and its error, as shown in Table 2.

**Table 2.** Measurement of Air Column Length in a Closed Organ Pipe Using HC-SR04 Sensor

| Water Condition | $l_0$ (*cm*) | $\lambda_0$ (*cm*) | $f_0$ (*Hz*) |
|---|---|---|---|
| Lowering | 16.10 | 64.38 | 528 ± 5 |
| Raising | 15.60 | 62.43 | 545 ± 8 |

Table 2 presents the comparison of air column length ($l_0$), wavelength ($\lambda_0$), and fundamental resonance frequency ($f_0$), under two water conditions in the reservoir: lowering and raising. From this data, it can be observed that the air column length is slightly longer when the reservoir is lowered, which results in a larger wavelength and a slightly lower resonance frequency compared to when the reservoir is raised. The small difference in wavelength and frequency highlights the changes in resonance characteristics due to the movement of water within the resonance tube. The measurement uncertainty for the frequency is also shown in the table, with an error of ±5 Hz for the lowering condition and ±8 Hz for the raising condition, indicating minor variability in the data collected during the experiment. Then the data displayed in Table 2 is visualized using Python programming, resulting in the waveform at the fundamental frequency as shown below:

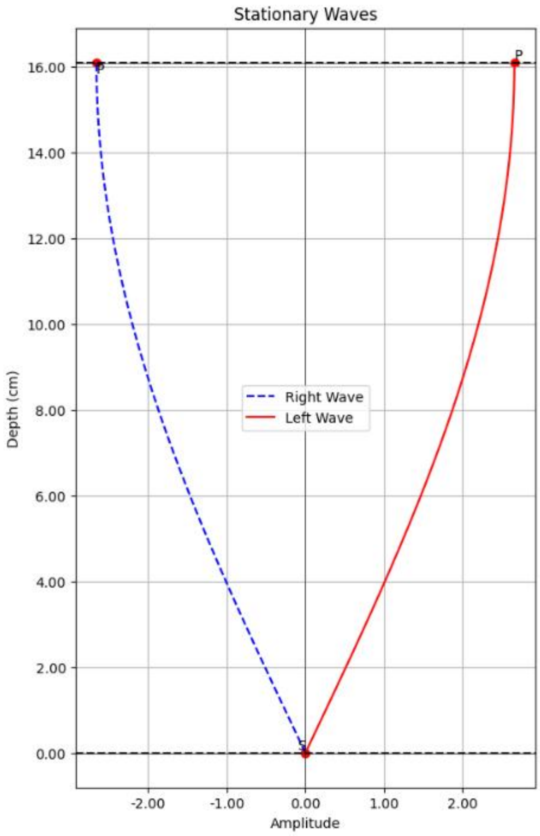



**Figure 5.** Wave at the First Resonance of a Closed Organ Pipe

In Figure 5, the standing wave pattern produced corresponds to the theory. The node, where the wave amplitude is zero, occurs at the closed end of the pipe (x = 0) due to destructive interference between the incoming and reflected waves. Meanwhile, the antinode, where the amplitude is maximum, forms at the open end of the pipe (x = 16.10 cm) because of constructive interference. This pattern creates the first resonance, where a quarter of the wavelength is formed inside the pipe, producing the fundamental tone. The incoming wave travels from the open to the closed end, while the reflected wave moves in the opposite direction, both having the same amplitude but opposite phases, resulting in the characteristic stationary wave of a closed organ pipe.

## DISCUSSION

In this study, measurements of the air column length during resonance were conducted using the HC-SR04 sensor. The collected data show a significant increase in amplitude at a certain distance, indicating the occurrence of resonance at that point. According to the principle of resonance, a system will oscillate with maximum amplitude when the frequency of the vibration source is close to or matches the system's natural frequency. From the experiment results, the average length of the air column when the water level was lowered was 16.10 centimeters, while the average length when the water level was raised was 15.60 centimeters. The difference in the air column length between the two conditions produced an error of 3.04% and 5.98%, respectively. This indicates minor variations in the measurements but remains within acceptable limits for laboratory experiments. In Table 2, the data show that the fundamental resonance frequency was (528 ± 5) Hz when the water level was lowered and (545 ± 8) Hz when it was raised. This difference could be due to variations in water flow or other environmental factors affecting the measurements.

Furthermore, the visualization of the standing wave pattern during the first resonance corresponds with the resonance theory of a closed organ pipe. In this pattern, it is clearly seen that a node, where the wave amplitude is zero, forms at the closed end of the pipe. This is caused by destructive interference between the incoming and reflected waves. Conversely, at the open end of the pipe, an antinode forms, where the amplitude reaches its maximum, due to constructive interference between the waves. This phenomenon aligns with the principle that during the first resonance or fundamental frequency, a quarter of the wavelength is trapped within the pipe, resulting in a larger amplitude at the open end.

This wave pattern also demonstrates how the incoming and reflected waves interact harmoniously to form a standing wave. The incoming wave travels from the open end to the closed end, while the reflected wave moves in the opposite direction. Both waves have the same amplitude but different phases, leading to the creation of a stationary wave, which is characteristic of resonance in a closed organ pipe. These results further confirm that the resonance frequency plays a crucial role in determining energy distribution and the formation of standing waves in the pipe. The consistency between the visualization and theory highlights the reliability of the measurements and the validity of the resonance concept applied in this experiment.

## CONCLUSION

This research successfully demonstrates that the Arduino-based method with Python visualization is superior to conventional methods in the study of sound resonance. By utilizing HC-SR04 and KY-037 sensors connected to Arduino, along with Python for visualization analysis, sound resonance experiments can be conducted more easily. The resonance frequency measurements obtained show higher accuracy with smaller errors, where the average air column length when the water in the reservoir was lowered is 16.10 cm with an error of 3.04%, and when the water was raised, it is 15.60 cm with an error of 5.98%. The first resonance value obtained from a 512 Hz sound source and varying measurement distances produced different fundamental frequency values, highlighting the system's sensitivity to changing conditions. Thus, the use of Arduino and Python-based technology in physics experiments not only improves the reliability and accuracy of the results but also simplifies the data collection and analysis process, offering new insights into the application of technology in physics education and research.

## REFERENCES

Boimau, I., Irmawanto, R., & Taneo, M. F. (2019). Rancang Bangun Alat Ukur Laju Bunyi Di Udara Menggunakan Sensor Ultrasonik Berbasis Arduino. *Cyclotron*, *2*(2). https://doi.org/10.30651/cl.v2i2.3253

Bu'ulolo, E., Mesran, Hasibuan, N. A., Aripin, S., Utomo, D. P., & Syahputra, R. (2023). *Big Data Analysis dengan Python untuk Perguruan Tinggi*. Alfabeta.

Budiarso, Z., Nurraharjo, E., Listiyono, H., Studi, P., Informatika, T., Informasi, F. T., Stikubank, U., Studi, P., Informatika, M., Informasi, F. T., & Stikubank, U. (2023). Rekayasa Alat Ukur Panjang Gelombang Suara Menggunakan Tabung Resonansi Berbasis Arduino Untuk Pengembangan Praktikum Fisika Dasar. *JUPITER*, *15*(1), 237–246.

Halliday, D., Resnick, R., & Walker, J. (2018). *Fundamentals of Physics* (10th Editi). John Wiley & Sons.

Handayani, D. N. S., Pramudya, Y., Suparwoto, S., & Muchlas, M. (2018). The Application of Scilab Software in Frequency Mode Simulation on the Circular Membrane. *Journal of Physics: Theories and Applications*, *2*(2), 83. https://doi.org/10.20961/jphystheor-appl.v2i2.31274

Ismailov, A. S., & Jo'rayev, Z. B. (2022). Study of arduino microcontroller board. *"Science and Education" Scientific Journal*, *3*(3), 172–179. www.openscience.uz

Jamil, M., Wahab, I. H. A., Kiswanto, & Alting, H. (2022). *Pemograman Arduino dan Internet of Things*. Deepublish.

Nurfitni, D., & Pramudya, Y. (2023). Studi Gaya Hambat GJB Pada Variasi Luas Permukaan Kertas Cupcake dengan Analisis Video & Python. *Navigation Physics : Journal of Physics Education*, *5*(2).

Pratiwi, S. N., Cari, C., & Aminah, N. S. (2019). Pembelajaran IPA abad 21 dengan literasi sains siswa. *Jurnal Materi Dan Pembelajaran …*, *9*, 34–42. https://jurnal.uns.ac.id/jmpf/article/view/31612%0A

Serway, R. A., & Jewett, J. W. (2004). Physics for Scientists and Engineers , Vol . I. In *American Journal of Physics* (6th ed., Vol. 44, Issue 9). Thomson Brooks/Cole. https://doi.org/10.1119/1.10359