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Innovation of Arduino Uno-Based Physics Practicum Tool with MAX4466 Sound Sensor

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ABSTRACT

The purpose of this study was to make an Arduino Uno-based doppler effect practicum tool with a Max4466 sensor, to find out the results of testing an Arduino Uno-based doppler effect practicum tool with a Max446 sound sensor. The research methodology used is linear regression of the instrument calibration experiment. The data of this research is data from the experimental results of practicum tools made with the calibration tool. This study states that the Max4466 Sound Sensor reads the frequency of sound then the data is processed and sent by Arduino Uno via commands on the Arduino IDE and the Data Streamer menu to Microsoft Excel. After that, the tool calibration process is carried out by comparing the frequency value between what is read on the sensor and the calibrator (digital multi-meter). This practicum tool innovation could directs teachers and students. The benefit of this research is to provide learning media that supports the teaching and learning process and improves students' skills. This research suggestion is for future researchers to look for other calibrators that can record data automatically to facilitate instrument calibration and conduct further research on the effect of air (environment) on a sound.

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Introduction

Everyday phenomena that occur are caused by humans or natural events, natural events regarding sound are often experienced by human hearing, including someone standing on the road listening to the sound of an ambulance siren from a distance moving towards him, the sound of an ambulance. The siren

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gets louder and slower as the ambulance moves away from the person (Aprilia et al, 2022). The phenomenon that occurs in an ambulance is an example of the phenomenon of the Doppler effect on waves. Waves will continue to occur if the source of this vibration vibrates continuously and the waves carry energy from one place to another (Sirait, 2020). This phenomenon is abstract in nature which is difficult to understand in theory, therefore it is necessary to have an intermediary tool/media in explaining it.

An abstract physical phenomenon is the phenomenon of sound, where sound can only be heard with the ear without being clearly visible to the eye (Haisy. M. C. et al, 2015). In the concept of sound, there is the phenomenon of the Doppler effect where the difference between the source frequency and the listener's frequency is due to interference. From this, the important role of interesting learning media is needed so that it can increase understanding and skills. The importance of media / practicum tools in the physics learning process, teachers are able to use the media to show in real / direct how the Doppler Effect phenomenon can occur, so that students (students) are able to understand the concept.

The understanding of students in learning at school must be considered by all parties, one of which is the school. The provision of learning facilities and infrastructure in schools must be considered in order to realize students' skills and understanding. Infrastructure that needs to be considered such as learning media and learning tools. Supporting learning media must be balanced with the methods used such as practicum methods. The practicum method is able to provide an understanding of theoretical concepts and skills in using tools by students (Nisa, 2017).

The development of technology and information as well as the curriculum used requires schools to create and develop media and learning tools that are effective and efficient and support the current era. In reality there are schools that still do not provide these props. Not only at school, the lecture level still does not accommodate practicum tools / teaching aids on the Doppler Effect material. This is evidenced by a survey of researchers of the Physics Education study program laboratory and the central laboratory of the Sebelas Maret University campus who have not found these teaching aids / practicum tools.

The development of this practicum tool was based on previous research regarding the Doopler effect teaching aids, among others: According to Karimah et al, 2019 Physics Education Students at FMIPA Semarang State University regarding "Development of Doppler Effect Teaching Devices". The research conducted was a type of R&D research with a large percentage of the feasibility test of the tool 87.5% and a large percentage of the feasibility test of the use module of 92.86% which was tested and assessed by expert lecturers. The results of the calibration of the development of this tool obtained a relative error of 0.004%.

Figure 1. Design for the Development of Doppler Effect Practicum Tool
Source: Karimah et al (2019)

Fathul Arifin et al, 2019 Physics Education Students at the Faculty of Mathematics and Natural Sciences, Jakarta State University regarding "Development of Practicum Tools for Serving Sound and Doppler Effects Based on Condenser and Microcontroller Microphone Modules". The research conducted

is a type of R&D research. The results of the calibration of the development of this tool obtained a relative error of 12.36%.

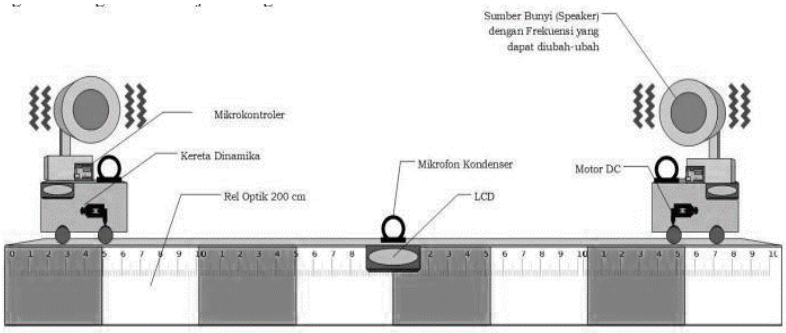

Figure 2. Design for the Development of Doppler Effect Practicum Tool
Source: Arifin et al, 2019

The development of the Doppler effect practicum tool developed this time is based on Arduino Uno with the Max4466 sound sensor as a sound frequency value reader. The development of this tool is made with a proportional size and looks like real phenomena that occur in everyday life. The development of this Doppler effect practicum tool in its use is able to provide students with skills in using the tool and analyzing data in Microsoft Excel. Practicum tools can be set according to the wishes of students between sound sources and listeners. The development of this practicum tool consists of a car as a source, a black box as an detector and a track. The sound source emitted will be captured by the Max4466 sound sensor which is then sent to Microsoft Excel, so that the practicum data is automatically read in Microsoft Excel. This Doppler effect practicum tool aims to provide an understanding of theoretical concepts and minimize students' misconceptions and improve scientific skills. The benefits of developing this practicum tool are as a learning medium that supports the teaching and learning process, increases interest in creating creative media for teachers, provides learning facilities in schools that can be utilized by both teachers and students and improves school quality.

Literature Review

Digital Multi-meters

A digital multi-meter or often also referred to as a digital multi-tester is the same type of multi-meter that uses a digital display as a display of measurement results. The measurement results displayed on the digital multi-meter are the results that are appropriate, so there is no need to do calculations between the measurement results and the measuring limit. The Digital Multi-meter uses digital number displays and measuring quantities based on the voltage converted to digital signals.

Arduino

Arduino has features that can be used to design a practicum tool (props), including: analog and digital output inputs, counters, timers, ADC, PWM. Arduino is a platform based on a simple input output circuit that can be developed into software on a computer (Anantama A, et al, 2020). Arduino UNO is a circuit board based on the Atmega328 microcontroller. This board has 14 digital input/output pins, 6 analog pins, a USB connection, a power jack and a reset button (Yalandra H & Jaya P, 2019)

Arduino IDE (Integrated Development Environment) is software used to program Arduino, or as a medium for programming the Arduino board. Through programming written in the Arduino IDE application, NodeMCU V3 ESP8266 or Arduino will perform programming functions. This Arduino IDE

uses a programming language that resembles C language. The language used in this programming is different from other programming applications, where the language is easy to understand and understand for early users (beginners).

Max4466 Sound Sensor

The MAX4466 sound sensor is a sound sensor that has a power supply ranging from 3.3 to 5 VDC which is used to receive sound and has a microphone with a sensitivity of -56 dB (Lapono, et al, 2018). This sensor is capable of converting sound quantities into electrical quantities such as sound frequency (sound) into electrical frequencies. This sensor has a better and more precise test quality than the KY-037 Sound Sensor.

Microsoft Excel

Microsoft Excel is a worksheet program that is able to process numerical data easily for users (Patmawati, H., & Santika, S. 2017). This software is able to simplify the processing of complex numeric data into simple ones, so that the use of Microsoft Excel is very important in managing numerical data obtained from the use of practicum tools. Microsoft excel has many features that can be used, such as graphs, tables, formulas, diagrams, and others. With the many features available in Microsoft Excel, users can easily work on assignments in the desired form, for example: task diagrams of a decrease / increase in the number of deaths in a place, graphs of student graduation, practicum data tables and others.

Practicum

Practicum is an activity that aims to improve students' (students) theoretical understanding and skills (Nisa, 2017). Hamid (2011), defines that the practicum method is an activity directed at students (students) in carrying out scientific processes both individually and in groups. According to Hurrahman (2011), practicum learning is able to prove/find theoretical concepts that occur in a phenomenon so that students get impressive learning outcomes, or it can be interpreted that Physics practicum is an activity of Physics learning methods that is impressive in increasing understanding abilities and skills to determine concepts. Based on the implementation, practicum is divided into 2, namely online and offline

Practicum Tool

Practicum tools are learning media that can visualize a material in order to explain a concept, symptom, phenomenon, law that cannot be observed by the five senses (Maemunah et al, 2020). According to Nana (2010), a practicum tool is a tool that can be used to assist in a more effective and efficient educational process through eye and ear observations. Practicums or experiments in the laboratory play an important role in the development of processes and products in order to achieve learning objectives and indicators (Purwaningsih, et al, 2020). The use of practicum tools (props) has low precision accuracy if measurements are done manually resulting in large error values (Boimau, et al, 2020). Based on the description above, it can be concluded that the importance of practicum tools in facilitating the explanation of material both a concept, symptom, phenomenon in order to achieve learning indicators and the need for microcontroller-based practicum tools to reduce error values. The use of practicum tools has 5 objectives explained by Dewi (2015), including: increase scientific knowledge, improve skills in experiments, improve scientific attitudes, improve judgment skills, provide motivation.

Methodology

The research methodology used is the linear regression method, analyzing the calibration line equation to determine the value of the sensor reading accuracy. This research was conducted with the aim of producing an IoT (Internet of Things) based experimental tool using Microsoft Excel to determine frequency values at certain positions and circumstances. Making this practicum tool begins with designing a tool design consisting of hardware and software.

1. Hardware design consists of a frequency detector design and a practicum tool design

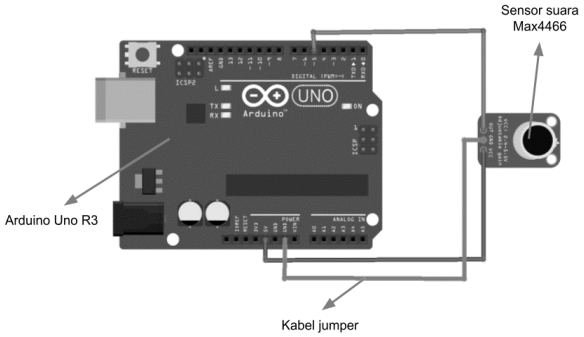

Figure 3. Frequency Detector Design

Source: Private Document, 2023

In designing this component using the Max4466 Sound Sensor and Arduino Uno. In designing the components above, observe the following table (1):

Table 1. Preparation of the Design of the Doppler Effect Practicum Components

Max4466 Sound Sensor	Arduino Uno
Pin VCC	Pin 5V
Pin GND	Pin GND
Pin OUT	Pin D5

Source: Private Document, 2023

After designing the components, the researcher proceeded to the finishing stage of the tool, namely the design of the practicum tool. The following is the design of the Doppler effect practicum tool.

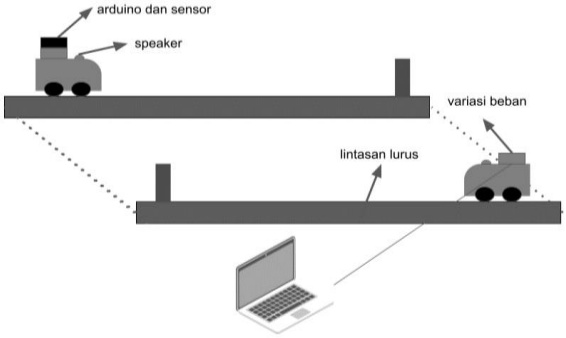

Figure 4. Doppler Effect Practicum Tool Design

Source: Private Document, 2023

2. Software design consists of installing the Arduino IDE, installing the FreqCounter library, creating the Arduino IDE program and activating the Data streamer feature. In designing software for this practicum tool, researchers used several software including: Arduino IDE and Microsoft Excel. The following is a picture of the Doppler effect practicum software schematic.

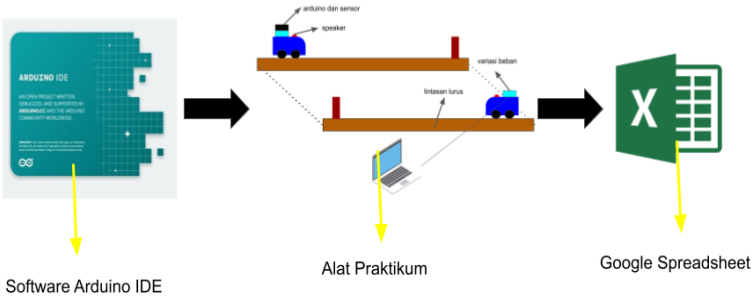

Figure 5. Practicum Tool Work Scheme
Source: Private Document, 2023

The practicum tools that have been made are then carried out repeated and gradual data collection. Data is obtained through the following Steps:

1. Open the Arduino IDE and Microsoft Excel software
2. Connect Arduino IDE to Microsoft Excel
3. Connecting the doppler effect practicum with a laptop
4. Varying the position of the sound source to the max4466 sound sensor between 0 cm, 10 cm, 20 cm, 30 cm and 40 cm
5. Turn on the sound source (siren)
6. Analyze data recorded by Microsoft Excel

The data that has been obtained is then analyzed by comparing data from practicum tools that are made with a Digital Multi-meter measuring instrument. The following are the steps in tool calibration:

1. Connect Max4466 sound sensor with digital multi-meter

Table 2. Compilation of a Sound Frequency Calibration Circuit With Digital Multi-meter

Max4466 Sound Sensor	Digital Multi-meter
Pin VCC	-
Pin GND	Pole (-) / black color
Pin OUT	Pole (+) / red color

Source: Research Result (2023)

2. Conduct tests with a sound source (siren) in several positions 0 cm, 10 cm, 20 cm, 30 cm and 40 cm between the sound and the sensor
3. Record video on a digital multi-meter and record data on the Arduino IDE (Microsoft Excel)
4. Retrieve calibration data for each position 3 repetitions

After collecting calibration data, perform calculations between the max4466 sound sensor data and digital multi-meter data, accuracy can be calculated by the equation (Suciyati et al., 2021):

$$A = 1 - \left| \frac{\bar{Y}_n - \bar{X}_n}{\bar{X}_n} \right| \times 100\%$$

Information:
A = Accuracy (%)
X = sound frequency on a Digital Multi-meter (Hz)
Y = sound frequency on the max4466 sound sensor (Hz)

Results and Discussion

Tool Making Results

Arduino Uno Based Doppler Effect Practical Tool with Max4466 Sound Sensor. This practicum tool consists of sound frequency detectors, tracks and cars. The sound frequency detection tool is designed from Arduino UNO, Max4466 Sound Sensor, Arduino UNO USB Cable and jumper cables. This detector is in the form of a block measuring 8 cm x 6 cm x 2 cm made of acrylic (plastic). The track on this practicum tool is made of plywood measuring 120 cm x 10 cm. The toy car used in this lab tool is black with a size of 19 cm x 7 cm. The display of the tool that has been made can be seen in Figure 6, Figure 7 as follows:

Figure 6. Sound frequency detector

Source: Private Document, 2023)

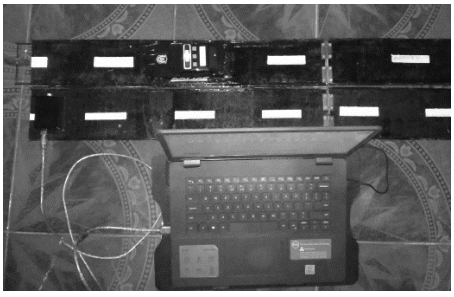

Figure 7. The design of the practicum tool looks above

Source: Private Document, 2023

Tool Calibration Results

The accuracy and uncertainty of the max4466 sound sensor is calculated using the accuracy equation. The following is the measurement result of the max4466 sound sensor.

Table 3. Sound Frequency Measurement Data by Max4466 Sound Sensor and Digital Multi-meter before Calibration

Distance (cm)	Digital Multi-meters (Hz)	Max4466 Sound Sensor (Hz)	Digital Multi-meter Average (Hz)	Sound Sensor Average Max4466 (Hz)	Accuracy	Uncertainty
0	781 761 749 748	696 675 669 662	741	637	0,859	0,140

	744	643				
	722	598				
	721	598				
	708	562				
	615	479				
	608	477				
	594	426				
10	581	418	567	428	0,754	0,245
	577	403				
	562	417				
	533	405				
	472	404				
	464	358				
	428	345				
	420	335				
20	414	330	402	303	0,755	0,244
	405	275				
	381	252				
	375	248				
	331	288				
	171	102				
	154	97				
30	125	62	137	76,6	0,556	0,443
	104	58				
	134	64				
	71	53				
	88	76				
	69	60				
	75	83				
40	72	53	78,6	66,8	0,850	0,149
	82	68				
	96	89				
	76	53				

Source: Research Result (2023)

The sound frequency accuracy value read on the max4466 sound sensor against a digital multi-meter at a distance of 0 cm is 0.859 and an uncertainty is 0.140. At a distance of 10 cm, the accuracy value is 0.754 and the uncertainty is 0.245. At a distance of 20 cm, the accuracy value is 0.755 and the uncertainty is 0.244. At a distance of 30 cm, the accuracy value is 0.556 and the uncertainty is 0.443. And at a distance of 40 cm, the accuracy value is 0.850 and the uncertainty is 0.149. The graph of the relationship between the readings on the max4466 sound sensor and the multi-meter before calibration is shown in Figure 8.

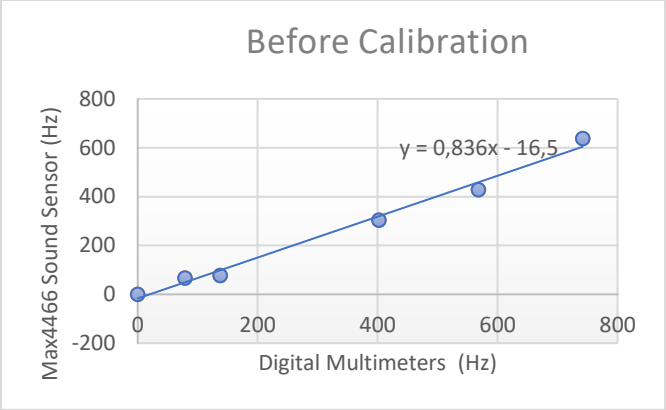

Figure 8. Graph of Sound Frequency Reading Relationship on Max4466 Sound Sensor with Digital Multi-meter Before Calibration

Source: Research Result (2023)

The linear regression equation between the results of frequency readings with the max4466 sound sensor and digital multi-meter is shown in the following equation

$$y = 0{,}836x - 16{,}5$$

Based on this equation, the x value is the max4466 sound sensor value and the y value is the value of the digital multi-meter measuring instrument. This equation is used in the Arduino IDE script to find the sound frequency value with the max4466 sound sensor after calibration. The sound frequency reading data from the calibrated max4466 sound sensor is compared to the sound frequency measured by a digital multi-meter. Shown in Table (4) as follows:

Tabel 4. Sound Frequency Measurement Data by Max4466 Sound Sensor and Digital Multi-meter after Calibration

Distance (cm)	Digital Multi-meters (Hz)	Max4466 Sound Sensor (Hz)	Digital Multi-meter Average (Hz)	Sound Sensor Average Max4466 (Hz)	Accuracy	Uncertainty
0	484	494	503	493	0,978	0,021
	479	456				
	582	568				
	509	522				
	535	483				
	510	481				
	448	451				
	484	489				
	479	386				
	477	528				
10	426	389	441	467	0,941	0,058
	418	487				
	507	508				
	417	473				
	405	496				
	404	471				

20	261 348 330 370 306 322 408 374 311 284	285 356 352 387 326 317 359 383 312 310	339	345	0,983	0,016
30	294 257 289 289 262 181 136 140 143 145	292 264 274 318 262 184 170 194 184 178	287	290	0,988	0,011
40	174 153 159 168	184 169 179 184	152	180	0,816	0,183

Source: Research Result (2023)

The sound frequency accuracy value read on the max4466 sound sensor against a digital multi-meter at a distance of 0 cm is 0.978 and an uncertainty is 0.021. At a distance of 10 cm, the accuracy value is 0.941 and the uncertainty is 0.058. At a distance of 20 cm, the accuracy value is 0.983 and the uncertainty is 0.016. At a distance of 30 cm, the accuracy value is 0.988 and the uncertainty is 0.011. And at a distance of 40 cm, the accuracy value is 0.816 and the uncertainty is 0.183. The graph of the relationship between the readings on the max4466 sound sensor and the multi-meter before calibration is shown in Figure 9.

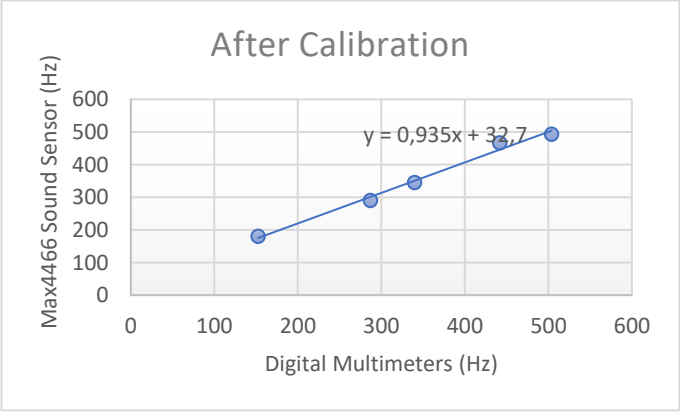

Figure 9. Graph of Sound Frequency Reading Relationship on Max4466 Sound Sensor with Digital Multi-meter After calibration

Source: Private Document (2023)

The linear regression equation between the results of frequency readings with the max4466 sound sensor and digital multi-meter is shown in the following equation:

$$y = 0{,}935x - 32{,}7$$

Based on the equation above, the sensor reading accuracy value is 0.935 so that the development of the Doppler effect practicum tool is feasible to be applied in learning Physics in the classroom.

Discussion

The research and development that has been carried out has resulted in a Doppler effect practical tool based on Arduino UNO with a Max4466 sound sensor. This practical tool consists of tracks, cars as sound sources, detection devices as listeners. The development of this tool is carried out by testing the frequency value calibration, this calibration uses a Digital Multimeter. The calibration process is carried out repeatedly at 5 positions, namely 0 cm, 10 cm, 20 cm, 30 cm and 40 cm with the same sound source (siren). The Max4466 sound sensor is connected to the calibrator (Digital Multimeter) which then records the video on the digital multimeter reading. The video recording data is then compared with data in Microsoft Excel via a straight-line equation graph and produces an equation of y = 0.836x – 16.5. The equation is changed to x = (y + 16.5) / 0.836 to be substituted for the Arduino IDE coding. Experiments and data comparisons were carried out again after changing the equations in the Arduino IDE coding. The resulting equation is y = 0.935x – 32.7 with an accuracy value of 0.935. The resulting accuracy value can be said to be very good (almost close to 1) so that this practicum tool is suitable for use in aspects of accuracy and precision.

The development of this practicum tool is also linked to previous studies. The following is a comparative explanation of the development of practicum tools with previous researchers presented in Table 5 as follows

Table 5. Comparison of the development of practicum tools with previous research

Previous Researcher	Lack	Advantages of development
"Perancangan alat ukur kecepatan menggunakan sensor ultrasionik dan prinsip efek doppler" Imam Sucahyo dan Najibuddin Habibi (2015)	In this study, reading data must be done manually by looking at the readings on the LCD	What has been developed from this deficiency is teaching aids/practicum tools that are able to read data/display data automatically in Microsoft Excel
"Pengembangan Alat Praktikum Pelayangan Bunyi dan Efek Doppler Berbasis Modul Mikrofon Kondenser Dan Mikrokontroler" Arifin, F., Indrasari, W., & Rustana, C. E. (2019)	In this study, the visual aid has a relative error value of 12.36% and the track size is too small	The thing that was developed from this deficiency is to produce tools with relative errors in the range of 2% - 10% for a distance of 0 cm - 40 cm and enough (not too small) traverse
"Pengembangan Alat Peraga Efek Doppler" Karimah, dkk. (2019)	In this study, the teaching aid has a large size in the form of a walking speaker	Resulting in props that are ideal and easy to use and carry such as toy cars, tracks that can be folded

Source: Research Result (2023)

Table 5 describes the novelty of the development of practical tools / teaching aids, in addition to updating the sensors used and the use of software in displaying data. The development of a Doppler effect practicum tool based on Arduino Uno with a max4466 sound sensor also has the following advantages:

1. The design of the tool is attractive and looks like the original
2. Automatic data reading by sensor
3. Able to be displayed with a variety of state variations of sound sources and listeners.
4. Support students in skilled use of tools and graphing
5. More practical in its presentation

Based on the eligibility criteria for the practicum tool Afriyanto (2015) that the development of the Doppler effect practicum tool is in accordance with the concept of Physics (characteristics of the Doppler effect equation), the Doppler effect practicum tool can be applied to all applicable curricula, The practicum tool is easy to understand, attractive and easy to use. According to Arsyad (2018), learning media can be used in the teaching and learning process and can stimulate students' attention and interest in learning, it is hoped that the feasibility of this practical tool can increase students' attention and interest

Conclusion

The Doppler Effect Practicum Tool based on Arduino UNO has been successfully built and tested. The Max4466 Sound Sensor acts as a detector and inputs sound into the Arduino UNO microcontroller which is then processed by the Arduino IDE program. The results of the programming are sent to Microsoft Excel via the Data Streamer menu. The results of testing the doppler effect practicum tool based on Arduino UNO with the Max4466 sound sensor in determining the frequency of sound get an accuracy value of 83.6% which is then carried out by a calibration process and tested again to get an accuracy value of 93.5%. Things that need to be considered by future researchers regarding this topic include: conducting experiments with 2 max4466 sound sensors attached to the sound source and the listener, conducting further research on the effect of air (environment) on a sound, making repeated measurements in each condition and experiments to produce standard values of error and uncertainty, looking for a new calibrator that can record data automatically to facilitate instrument calibration.

Author's Contribution

All authors have contributed to the final manuscript. The contributions of each author are as follows, Muhammad Khairul Annam Najahy; collecting data, drafting manuscripts and drafting drawings, drafting key conceptual ideas and Lita Rahmasari and Supurwoko provided excellent guidance and provided critical revisions of articles. All authors discussed the results and contributed to the final manuscript.

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Declaration of Competing Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Reference

Afriyanto, E. (2015). Pengembangan Media Pembelajaran Alat Peraga pada Materi Hukum Biot Savart di SMAN 1 Prambanan Klaten. JRKPF UAD, 2(1), 20–24.

Anantama, A., Apriyantina, A., Samsugi, S., & Rossi, F. (2020). Alat Pantau Jumlah Pemakaian Daya Listrik Pada Alat Elektronik Berbasis Arduino UNO. *Jurnal Teknologi Dan Sistem Tertanam*, *1*(1), 29-34. https://doi.org/10.33365/jtst.v1i1.712.

Aprilia, R. D., Harijanto, A., & Subiki, S. (2022). Rancang Bangun Alat Peraga Fisika Efek Doppler Menggunakan Modul Sensor Suara dan Arduino. *Jurnal Fisika Unand*, *11*(2), 139-145. http://jfu.fmipa.unand.ac.id/index.php/jfu/article/view/796

Arifin, F., Indrasari, W., & Rustana, C. E. (2019, December). PENGEMBANGAN ALAT PRAKTIKUM PELAYANGAN BUNYI DAN EFEK DOPPLER BERBASIS MODUL MIKROFON KONDENSER DAN MIKROKONTROLER. In PROSIDING SEMINAR NASIONAL FISIKA (E-JOURNAL) (Vol. 8, pp. SNF2019-PE). https://doi.org/10.21009/03.SNF2019.01.PE.56.

Arsyad, Azhar. (2018). Media Pembelajaran, Jakarta: PT.Rajagrafindo Persada. http://repository.unj.ac.id/3419/

Boimau, I., Mellu, R. N., & Manuain, M. R. (2020). Rancang Bangun Alat Praktikum Viskometer Berbasis Arduino. *Wahana Fisika*, *5*(1), 28-40.

Dewi, M. L. (2015). Pengembangan Modul Praktikum Fisika Berbasis Data Logger untuk SMA. Prosiding Seminar Nasional Fisika (E-Journal) SNF 2015.

Habibi, N. (2015). Perancangan Alat Ukur Kecepatan Menggunakan Sensor Ultrasonik dan Prinsip Efek Doppler. Inovasi Fisika Indonesia, 4(3).

Haisy, M. C., Astra, I. M., & Handoko, E. (2015, October). Pengembangan alat peraga resonansi dan efek doppler berbasis soundcard pc/laptop untuk meningkatkan motivasi belajar fisika siswa sma. In *PROSIDING SEMINAR NASIONAL FISIKA (E-JOURNAL)* (Vol. 4, pp. SNF2015-II).

Hamid, Darmadi. (2011). Metode Penelitian Pendidikan. Bandung: Alfabeta

Karimah, H. N., Subali, B., Ellianawati, E., Handayani, L., & Natalia, E. S. (2019, October). Pengembangan Alat Peraga Efek Doppler. In Seminar Nasional Lontar Physics Forum (pp. 47-53). http://conference.upgris.ac.id/index.php/lpf/article/view/555.

Lapono, L. A. S., & Pingak, R. K. (2018). Rancang Bangun Sound Level Meter Menggunakan Sensor Suara Berbasis Arduino Uno. *Jurnal ILMU DASAR*, *19*(2), 111-116. http://isjd.pdii.lipi.go.id/file_download/19_2_2018_111-116_1411-5735.pdf.

Maemunah, A. N., Siswoyo, S., & Wibowo, F. C. (2020). Pengembangan Alat Praktikum Pembiasan Cahaya Menggunakan Sensor Photodioda Sebagai Media Pembelajaran Fisika, Prosiding Seminar Nasional Fisika E-Journal (Vol. 9, pp. SNF2020PF-163).

Nana, S. (2010). Dasar-dasar Proses Pembelajaran. Bandung: Sinar Baru

Nisa, U. M. (2017). Metode praktikum untuk meningkatkan pemahaman dan hasil belajar siswa kelas V MI YPPI 1945 Babat pada materi zat tunggal dan campuran. In *Proceeding Biology Education Conference: Biology, Science, Enviromental, and Learning* (Vol. 15, No. 1, pp. 62-68). https://jurnal.uns.ac.id/prosbi/article/view/27684/19106.

Patmawati, H., & Santika, S. (2017, February). Penggunaan Software Microsoft Excel sebagai Alternatif Pengolahan Data Statistika Penelitian Mahasiswa Tingkat Akhir. In PRISMA, Prosiding Seminar Nasional Matematika (pp. 124-129). https://journal.unnes.ac.id/sju/index.php/prisma/article/view/21630/10226.

Purwaningsih, S., Nehru, N., Jufrida, J., Pathoni, H., & Muliawati, L. (2020). Pengenalan Alat-Alat Praktikum Fisika Pada Materi Optik Bagi Siswa SMA Negeri 8 Muaro Jambi. *Selaparang Jurnal pengabdian kepada Masyarakat berkemajuan*, *4*(1), 692-695. https://repository.unja.ac.id/id/eprint/17168

Sirait, R. (2020). Fisika Gelombang. Medan: UIN Sumatera Utara

Suciyati, S. W., Hidayatullah, M. S., & Pauzi, G. A. (2021). Analisis Sistem Perolehan Data Suhu, Oksigen, dan Karbon Dioksida Pada Kulkas Dengan Arduino Mega 2560. Jurnal Ilmiah Pendidikan Fisika Al-BiRuNi, 10(1), 119– 127.

Yalandra, H., & Jaya, P. (2019). Rancang bangun pengaman pintu personal room menggunakan sensor sidik jari berbasis arduino. *Voteteknika (Vocational Teknik Elektronika dan Informatika)*, *7*(2), 118-125. http://ejournal.unp.ac.id/index.php/voteknika/article/view/104347.