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Research Article

Simple Experiment of Doppler Effect Using Smartphone Microfon Sensor

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Abstract

Doppler effect is the physical phenomena in which the emitted frequency is a source of change at a time when accepted by the detector due to relative movement of the detector towards the source of the wave or vice versa. This research aims to identify the Doppler effect symptoms by utilizing sensors found in smartphones. This research uses experimental method that combine the mechanical instruments and microphone smartphone sensor as measurement tool. The mechanical instruments used are a smartphone with the help of frequency sound generator software, Physics Toolbox, the camera as an instrument of data collectors, and Tracker as a motion analyzer software. Based on the results of the experiments, the author retrieved the value of the error and the standard deviation of each of the observed symptoms. The symptoms of Doppler effect upon source moving closer and moving away when the silent observer shows the error value of 0.04 % and 0.1185 % respectively with a standard deviation of 0.018 and 1.005. In addition, the experiment on Doppler effect as the source is staying still and as the observer approaching the source provides error value of 8.60 % and standard deviation of 13.501. As for the experiment on Doppler effect as the source and the observers are approaching each other displays the error value of 4.31 % and the standard deviation of 0.087. Overall, this experiment generates error value of 3.267 % and standard deviation of 3.665, inferring that the experiments conducted are accurate and precise in representing the Doppler effect phenomenon. Based on the results of this experiments, the researcher recommends to carry out practicum on Doppler effects with the help of smartphone sensors.

Keywords: *Doppler effect; smartphone; microphone sensor*

Eksperimen Efek Doppler Sederhana menggunakan Sensor Smartphone

Abstrak

Efek Doppler merupakan suatu kejadian dimana frekuensi gelombang dari suatu sumber yang diterima oleh detektor mengalami perubahan akibat adanya pergerakan relatif detektor terhadap sumber gelombang atau sebaliknya. Penelitian ini bertujuan untuk mengidentifikasi gejala efek Doppler dengan memanfaatkan sensor yang terdapat dalam ponsel pintar. Penelitian ini menggunakan metode eksperimen dengan memadukan perangkat mekanik dan sensor mikrofon pada ponsel pintar sebagai alat ukur. Instrumen mekanik yang digunakan adalah ponsel pintar dengan bantuan perangkat lunak *pembangkit frekuensi suara, Physics Toolbox, dan kamera sebagai instrumen pengumpul data serta perangkat lunak Tracker sebagai analisator gerak. Berdasarkan hasil percobaan diperoleh nilai eror dan standar deviasi dari masing-masing gejala yang diamati. Gejala efek Doppler pada saat sumber bergerak mendekat dan menjauh ketika pengamat diam memberikan nilai eror sebesar 0,04 % dan 0,1185 % dengan standar deviasi 0,018 dan 1,005. Percobaan efek Doppler pada saat sumber diam dan pengamat mendekat memberikan nilai eror sebesar 8,60 % dan standar deviasi 13,501 serta untuk percobaan efek Doppler pada saat sumber dan pengamat bergerak saling mendekat memiliki nilai eror sebesar 4,31 % dan standar deviasi 0,087. Secara keseluruhan percobaan ini menghasilkan nilai eror 3,267 % dan standar deviasi 3,665. Sehingga dapat disimpulkan bahwa percobaan yang dilakukan tergolong akurat dan presisi dalam merepresentasikan fenomena efek Doppler. Berdasarkan hasil percobaan ini peneliti merekomendasikan untuk melaksanakan kegiatan praktikum efek Doppler dengan bantuan sensor ponsel pintar.*

Kata Kunci: *efek Doppler; ponsel pintar; sensor mikrofon*

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I. INTRODUCTION

The times towards the digital world looks very promising. This can be seen on the effectiveness and efficiency of work in the industrialized world. In the world of physics, the scientific accuracy of the data as well as the data display became one of the real benefits of advances in digital technology [1,2].

Smartphone is currently circulating in community without giving restrictions on specific social status. Age groups, gender, and types of work no longer give the typical characteristics associated with smartphone users. Even in school, smartphone is very beneficial to students as a learning tool. This is due to a large number of providers of online learning consulting services or applications that assist students in solving their current learning [3,4].

Nevertheless, it is still a bit of a learning process that uses smartphone as a learning medium actively, the majority still use smartphone as a complementary learning resources for student [5–7]. This is unfortunate because on smartphones, in addition to software development, the physical form of sensor devices can also be optimized in learning. This refers to various studies that attempted to free the physical capabilities of smartphones to be optimized in the learning process. Among them are the experiment of uniform linear motion and acceleration linear motion using magnetic sensor [8,2], the Doppler effect experiment [9,10], parabolic motion experiments [11,12], a mechanical pendulum experiment [13], spectroscopy experiment [14,15], rotational dynamics [16,17], and the experiment of friction [18,19].

The majority of research on the Doppler effect are based on the analysis of Doppler effect by using various instruments and application of the Doppler effect in technology. This could be observed on the research conducted by McBeath on the phenomenon of Doppler effect and its influence on the change of sound intensity level [20], Parolin's research about the use of smartphones in identifying sound speed on some gas [21], and Ahmad et.al who showed symptoms of the Doppler effect in the underwater wireless network [22]. Based on such matters, the attempts to develop a form of learning-based experiment associated with Doppler effect has yet been made.

Based on the results of the previous research, there is excessive use of smartphones in learning, including the learning feels more interesting because there is innovation in the form of the use of user-friendly technology. In addition, the implementation of the experiment using the smartphone also gives an overview to the learners about learning that can be sourced from anywhere [23,24].

Passive monitoring of the Doppler effect through analysis of super harmonic microbubble emissions allows users to track microbubble velocities using standard passive cavitation detection systems. Thus, our method provides an inexpensive, easily accessible, and readily available tool for the estimation of microbubble movement near surfaces or vessel walls [25].

Recently, Dybala and Radkowski proposed a Doppler effect reduction method based on the Instantaneous Frequency Estimation (IFE) via Hilbert transformation. However, frequency-domain methods have some drawbacks. For example, the characteristic frequencies of the defective bearing must be known in advance, which are difficult to be estimated because of the complex structure of the shaft system. In addition, the embedded Doppler effect brings in blending of the characteristic frequency band as the defective roller bearing's characteristic frequencies which are usually very close to each other (like a comb), which will highly reduce the effectiveness of the band-pass filter. Moreover, the curve of the estimated instantaneous frequency is usually fluctuant because of the influence of background noise and the drawbacks of the band-pass filter, which cause errors in the result [26].

Based on the earlier experimental tool development conducted by Gomez-Tajero using air as a media to track the movement of objects, it shows the result that the precision and the accuracy are great for straight motion experiment [27]. Therefore, in this research, the effort to create an experimental tool of Doppler effect uses a combination of software and physical devices present on a smartphone so that the already advanced technology can contribute positively in the learning.

II. METHOD

Experiments were done by utilizing smartphone as a physical instrument, the application of sound frequency generator, physics toolbox, and PC with software Tracker as an analyzer. The Research Flow can be seen in Figure 1.

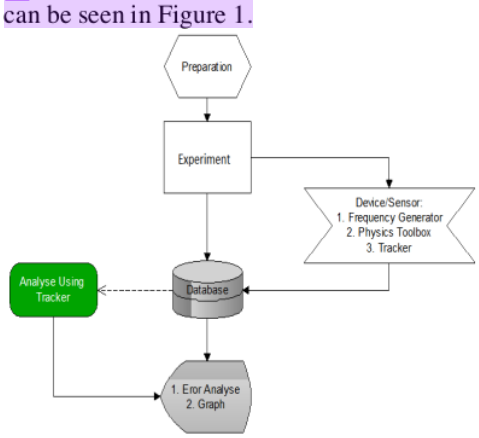

Figure 1. Research Flow

The research is began with the preparation stage as the set up. During the data collection, an object was recorded using the camera's resolution 30 frames per second, which then was analyzed using the Tracker software. Data analysis of the Tracker containing the speed of motion of the object either moving closer or moving away (see Figure 2).

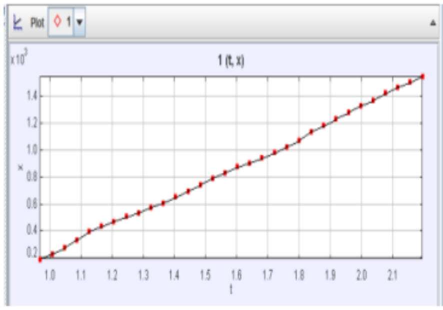

Figure 2. The Results of Fitting Position-Time Data with Linear Equations by Tracker

Frequency sound generator used as a source of varied-frequency is set to 500 Hz, 1000 Hz, and 1500 Hz (see Figure 3).

Figure 3. Frequency Sound Generator

Then, the value of the frequency is changed due to the movement of the object using the application of Physics Toolbox (see Figure 4).

Figure 4. Interface Physics Toolbox (Soundmeter)

Data measurement results have been collected and then analyzed by using the Doppler effect equations. Mathematically, the equation can be seen in equations 1 [28]:

$$f_p = \frac{v \pm v_p}{v \pm v_s} f_s \qquad (1)$$

The Doppler effect predominantly involves electromagnetic waves, the principle demonstrated using acoustic waves is the same. In astrophysics, the relativistic effects often come into play which is not applicable to acoustic Doppler, and so the experiment in this paper elucidates the principle of electromagnetic Doppler effect when the velocity is much large than the speed of light [29].

III. RESULTS AND DISCUSSION

Silent Observer and the Approaching Source

The first case of the Doppler effect observed is when the source approaching stationary source situation. In simple logic, this will cause an increase in the intensity of the sound in the hearing. Along with that, the frequency also experienced an increase in the frequency of the source movement in v. The change of the value of the velocity can be seen in Figure 5.

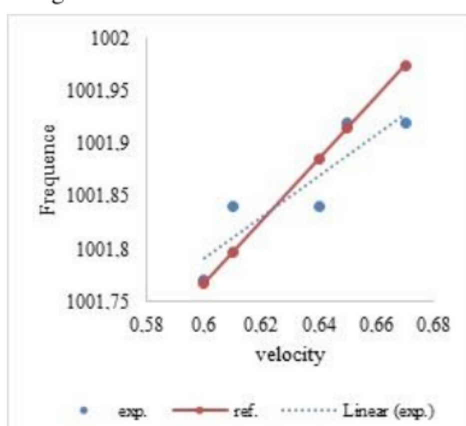

Figure 5. Graph Against Time to Position the Source Approaching Stationary Observer

On Figure 5, it is seen that the data obtained in the range of lines and trendlines have the same tendency with the results plot in theoretic. At the data, it is observed that the error is in a very small measurement with a mean error of 0.04 % with a deviation measurement of 0.018.

In the rotational and radial moves, Doppler effects should take place simultaneously in the scattered light. The radial Doppler effect can be detected from the time-periodic interference pattern via power detector [30].

Table 1. Observation of Doppler Effect at the Moment the Source Approaching the Stationary Observer

F.S (Hz)	K.S (m/s)	K.P (m/s)	F.P (Hz)	F.H (Hz)	Error (%)
500	0.60	0	500.88	500.88	0.00
500	0.63	0	500.88	500.92	0.00
500	0.65	0	500.92	500.95	0.00
1000	0.60	0	1001.77	1001.76	0.00
1000	0.61	0	1001.84	1001.79	0.00
1000	0.64	0	1001.84	1001.88	0.00
1000	0.65	0	1001.92	1001.91	0.00

Description: Frequency Source (F.S), Velocity of source (K.S), Velocity of the Observer (K.P), Frequency of the Observer (F.P), and Count Frequency (F.H)

Table 1 shows how conformity experiment data is similar to the calculation result data. Simply put, it does give an indication that the form of the method of the related measurement has high accuracy. Furthermore, the observed value of a relatively small standard deviation indicates that the instruments used are capable of producing a consistent quantity [31].

The Doppler effect can be well tested in the trans-relativistic probe within the framework of special relativity to the precision of the spectrograph. In addition to the testing of the Doppler effect under the framework of special relativity, one can also test special relativity itself and constrain the photon mass within more generalized theories[32].

Observer Approaching a Stationary Source

Different conditions occur when a source was approached by an originally silent observer. Mathematically, the influence exerted by the movement of the observer is linear positive for the approaching observers and negative for the observers moving away from the source. On the research of this graph plots, the frequency changes are obtained on a moving observer approaching the stationary source as there is in Figure 6.

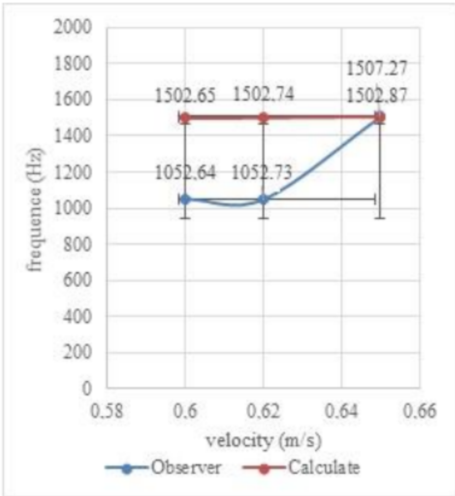

Figure 6. Graph Against Time to Position an Observer Approaching Stationary Source

Figure 6 gives information which is a little different from the expectations of the results of the experiment. It is observed that irregular graph is indicated by the picture. In this case, the explanation is probably that an influence from human error and level of sensitivity tool is very high, so the noise is very small – any pesky display data indicated.

Table 2. Observation Data Doppler Effect when an Observer Approaching the Stationary Source

F.S (Hz)	K.S (m/s)	K.P (m/s)	F.P (Hz)	F.H (Hz)	Error (%)
500	0	0.60	500.88	500.88	0.00
500	0	0.63	500.92	500.93	0.00
500	0	0.63	500.96	500.93	0.01
1000	0	0.60	1001.76	1001.76	0.00
1500	0	0.60	1052.64	1502.65	29.95
1500	0	0.62	1052.73	1502.74	29.95
1500	0	0.65	1507.27	1502.87	0.29

Overall, the second experiment (see Table 2) gives the mean value of the error is large enough, that is 8.60 %, with a standard deviation measurements of 13.501. A fairly large error value provides the basic conclusion that this practical set is less accurate. Nevertheless, it is still within the tolerance data reception error, where the value allowed is below 20 % mainly for mechanical equipment as basic as this teaching sets [33].

The Observer and the Source are Approaching Each Other

Upon the experiment, it is interesting that at the moment the source and the observer are moving closer to each other, we note that there is a difference of graphs that are caused by the movement of source and observer as they are moving closer to each other.

Table 3. Doppler Effect Observation Data at the Time the Source and Observer Approaching Each Other

F.S (Hz)	K.S (m/s)	K.P (m/s)	F.P (Hz)	F.H (Hz)	Eror (%)
500	0.54	1.29	501.43	502.70	0.00
1000	0.55	0.43	1002.86	1002.87	0.00
1500	0.55	0.41	1278.28	1504.21	0.15

The data in Table 3 show that the error analyzed is in small average number of 0.05 %. If the observed velocity and frequency data are made in the form of a plot, then the graph is formed as shown in Figure 7.

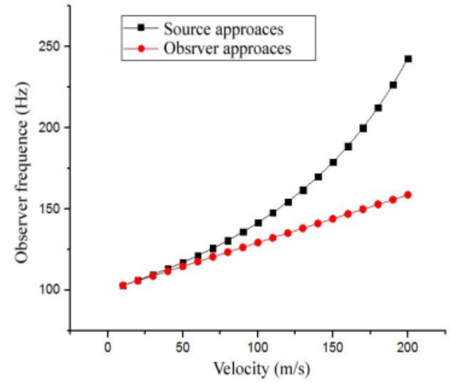

Figure 7. The Graph Changes the Frequency of the Observer at the Time of the Source and the Listener is Moving Closer

Figure 7 indicates that there is a difference in the slope of the graph that was caused by the movement of the source. This is because of the position of the source in the mathematical relationship which is on the denominator. If the note carefully the graph has the same pattern with the graph formed by $y = 1/(1 - x)$. This is in accordance with the theoretical explanation contained in Equation 1 [34].

Table 3 as a representation of the results shows a pattern that is a combination of the graph in Figure 5, the inherent patterns as graphs generated by the approaching source but with a larger slope. Based on the data contained in table 3, it is observed that it has high accuracy measurement on the frequency of 500-1,000 Hz and starts giving a considerable bias in the measurement of the frequency of 1,000-1,500 Hz. This is caused by several factors including the following: smartphone sensor receiver capability has a certain limit and the noise caused by the surrounding objects. The quantitative error value generated on this measurement is 0.07 to source frequency of 500 Hz, 0.11 to source frequency of 1,000 Hz, and 0.08 for the frequency of 1,500 Hz with a value of overall error was 4.31 %.

The Source Moves Away from the Silent Observer

Doppler effect can also be observed at the time of the observer moves away. Simply put, when the movement of the observer or the source away, then the frequencies heard will experience a reduction of the emitted sources. For more details look at Figure 8.

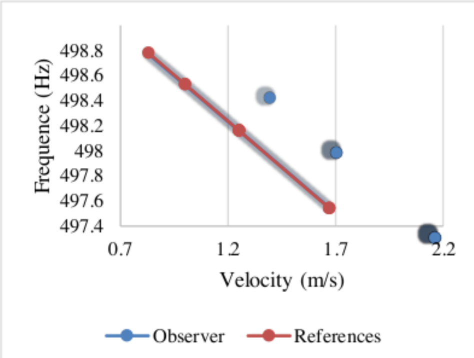

Figure 8. The Graph Changes the Frequency of the Observer at the Time of the Silent Observer and Source Away

Figure 8 shows the negative slope of a graph. A negative slope indicates that the greater the value of the speed of motion of the source away from the observer the more reduction in the value of the frequencies is heard [35]. Mathematically, a reduction in the value of the frequency of the vocal observers stated by equation 2.

$$y = -2.9067x + 999.7 \qquad (2)$$

Table 4. Data Observation when Source Away from Silent Observers

F.S (Hz)	K.S (m/s)	K.P (m/s)	F.P (Hz)	F.H (Hz)	Error (%)
500	0.43		498.80	499.36	11.31
1000	1.20	0	996.49	99.48	0.04
1500	0.41		1494.93	1498.16	22.95

Overall, this fourth trial (see Table 4) gives the average value of a fairly small error of 0.1185 % with a standard deviation of measurements of 1.055.

There are some limitations of this research, namely the reliance on the ability possessed by smartphones, as the sensor of a less good smartphone and the already damaged one can provide less accurate measurement results. A similar thing is true on Smartphones as the transmitter frequency. In addition, disturbances in the form of sound in a certain scale can also affect the results of the measurements, as the digital instrumentation sensors work.

The results of the study show that experiment using smartphones as a measuring instrument give results in accordance with the theory. It also shows good consistency in some other experiments using smartphones such as Nuryantini et.al in their experiment to measure the magnetic field [8], Klein e.al in motion experiment [9], Beath in Doopler experiment [20], and Fatimah et.al in the analysis of educational aspect [3].

Based on the results of this study, it is expected to be a solution for the limitation on laboratory equipment. The study also provided an opportunity to develop the utilization of smartphone as an experimental device.

IV. CONCLUSION

The use of sensors embedded in the smartphone gives the possibility to optimize the practical activities. Based on the results of a test done to see that the results of the measurements obtained are more accurate and have a good level of precision in almost all forms of the symptom of the Doppler effect. Good results for the measurement gives the possibility to the teachers or other researchers to develop and carry out a practical work-based smartphone. With the reading instrument are available and easy to use, researchers provide recommendations to carry out a practical work-based smartphone on a larger scale. Some of the records that must be considered on the basis of the findings in this research are the level of sensitivity of the sensors that might just give influence to measurement results. Overall, teaching the Doppler effect by using the help of sensors on a smartphone gives small number of error and standard deviation.

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