MEMS and IoT Applications in ISLE-based STEM Physics Learning Media for Mechanics Topic with LabVIEW Integration

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Abstract. The development of technology in the 21st century is so rapid both in the field of sensor and data communication. In fact, almost all smartphones have used the technology. In addition to using cutting edge sensor technology, smartphones are also equipped with internet communication features so they can be categorized as IoT (Internet of Things) devices. However, both of these technologies have not been optimally used as a media for learning physics. This paper discusses the use of MEMs (Micro-electromechanical system) sensor (ADXL-345) to detect the oscillation of the spring-mass system. Data obtained by MEMs is read by IoT based Microcontrollers (NodeMCU EPS8266) and directly transferred to the intranet WIFI network via the UDP (User Datagram Protocol). The data transmitted in the UDP packet is received by a computer that is integrated with LabVIEW, a user-friendly software that is based on a Graphical Programming. Students were encouraged to conduct several experiments to investigate the dependence of the period of the spring-mass system on the mass, the spring constant, and the amplitude. The oscillation of the spring-mass system received by the computer recorded the amplitude and the period of oscillation. Then students will compare the data from various observational experiments to predict the relation among the variables. Finally, they tested their prediction by conducting a testing experiment. This learning model is using ISLE (Investigation Sciences Learning Environment) syntax where students constructed their knowledge about mechanics, especially about spring-mass system, and enjoyed their discoveries as scientists did. Since the learning media has used technology and also carried out engineering process stages and involved the calculation of mathematics to understand the measurement results, it can be said to have used the STEM (Sciences, Technology, Engineering, and Mathematics) approach. We observed that an atmosphere of “learning is fun” existed during the lesson.

1. Introduction
We can find numerous vibrations or oscillations in nature, so understanding this phenomenon is very important for students. By understanding the concepts of oscillation, we can explain other phenomena such as waves and energy. One simple vibration phenomenon is the harmonic oscillation in springs or pendulums. This concept can be learned by conducting experiments on pendulum or springs by analyzing the relationship between force and vibration in pendulums and springs. Several previous studies have shown that students have difficulty understanding the topic. Students are less able to
understand related scientific terms, where students are less skilled in identifying parameters needed in calculations and students lack confidence in solving problems of Simple Harmonious Motion (GHS) [1]. Another difficulty occurs when students do not understand the meaning of an oscillator graph [2]. The Ministry of National Education of the Republic of Indonesia issued the Ministerial Regulation No. 22 of 2006 (Permendiknas No. 22 of 2006), which states that one of the objectives of physics is that students can understand the concepts and principles of physics and have the skills to develop their knowledge as provisions to continue their education at a higher level [3]. The cause of students not understanding the GHS topic can occur if students feel bored or inactive when taught in class [4]. Understanding a learning topic is important because it is the basis for students to solve various physics problems [5].

The teacher's role greatly influences students in achieving competency achievement or learning goals. The teacher needs to optimize learning through experimentation and the use of instructional media that are interesting, easy and efficient. An interesting learning media can reduce the static atmosphere and can create an effective, interesting, interactive and fun learning process. One indication that experiments are considered beneficial for students is when students can find conclusions in the form of formulas, hypotheses, and models after conducting experiments. Based on these models students can predict other phenomena that will occur. Predicted phenomena can be tested by conducting experimental testing and this becomes an interesting challenge for students [6].

When the predicted phenomenon is confirmed through experimentation, it will be a pleasant learning achievement for students. To increase understanding, the teacher can use several examples using videos or images that show the application of the model in everyday life. If the experiment does not match the prediction, the teacher can encourage students by stating that the experiment will be more interesting and challenging if students revise the model, re-analyze the prediction or check the quality of the experiment. All of these processes can occur in several cycles for the Investigative Science Learning Environment (ISLE) model, a constructive learning model for Physics introduced by Eugenia Etkina from Rutgers University's Graduate School of Education, New Jersey [7] [8] [9].

Observations from experimental activities are important in the ISLE model. Experiments were carried out using MEMs and IoT sensors to study mass springs and visualization integrated with LabVIEW. An approach using advanced technology in learning is believed to give students the skills they need in 21st-century education [10].

In this paper we discuss student activities related to mass spring vibrations taught in class X presented in Chapter 11 (Simple Harmonious Motion (GHS)) in textbooks written by Marthen Kanginan [11]. This lesson is expected to help students achieve core competencies and basic Competencies (3.11, 4.11) in accordance with Ministerial Regulation No. 24 of 2006 issued by the Ministry of Education and Culture of the Republic of Indonesia (Permendikbud No. 24, 2016) ([12] [13]) for students in class X which can be seen in Table 1. Regulations were issued as an integrated part of the revision of the Indonesian national curriculum namely the 2013 Curriculum or K-13 (see [14]).

**Table 1. Permendikbud No. 24 2016 for the core competencies and basic competencies of class X in Physics [12]**

| Original version                                                                 | Translation Version                                      |
|---------------------------------------------------------------------------------|----------------------------------------------------------|
| 3.11 Menganalisis hubungan antara gaya dan getaran dalam kehidupan sehari-hari  | 3.11 Analyzing relationship between force and oscillation in real life |
| 4.11 Melakukan percobaan getaran harmonis pada ayunan sederhana dan/atau getaran pegas berikut presentasi hasil percobaan serta makna fisisnya | 4.11 Performing the harmonic oscillation experiments for simple pendulum and/or spring vibration followed by presenting the experiment results and physical meaning |
The basic competencies shown in Table 1 are indicators of achievement that must be achieved by class X students, which contain processes, reasoning, presentation and creation in the realm of concrete and abstracts related to the development of what students learn in school independently, effectively, and creatively using scientific methods. Basic competence 4.11 is a skill that supports core competence 3.11, which is the knowledge students must have in analyzing the relationship between force and vibration in everyday life.

2. Methods

In this section we will explain the lesson plan with syntactic following the ISLE model that is centered in experiment activities. We use the cutting edge technology for acceleration sensor known as MEMs and the IoT ready microelectronic NodeMCU 8266 with UDP protocol for each node for data communication. Finally, for visualization and analysis we cooperated the LabVIEW software from National Instrument [15] [16] [17]. Mathematics involved in the experiment by applying them in modeling the real world situation, meanwhile the pedagogical aspects also addressed in the lesson.

2.1. Lesson Plan

Learning is designed using the ISLE-Based STEM approach model to study the harmonic spring vibrations. Previous studies using the ISLE-based STEM approach model have been carried out for harmonic pendulum oscillation (see [18]). The activity begins with students observing. Students were given a spring to be observed. Then students were also given a meter and dynamometer (can be replaced with a mass or a hanging digital scale). From the results of observations, students were expected to be able to observe the pattern of changes in force on strain or increase in rope length. From the pattern, they can find an equation which is the Hooke’s law.

Furthermore, students are given a spring with a mass of MEMs sensor devices that have been equipped with IoT based microcontrollers. Students are asked to observe and measure the change in the spring and draw a graph of the function of the change in the position of the spring concerning time on paper. What parameters can they get from the graph and how practical is the measurement? The final result expected is students can describe a sinusoidal harmonic function that has a period and frequency parameters. The results obtained by each group were communicated among groups.

After that, students are introduced to MEMs sensor technology and how to connect the probes to LabVIEW via the IoT based microcontroller. To measure the oscillations, we started from a simple UDP data communication scheme and advanced the scheme until a complete scheme example was given. With this technology, students can immediately see how the function of spring harmonic vibrations in the form of acceleration can be determined directly by its period and frequency.

The verification experiment of physical parameter measurement was done by manual method, wave observation, and signal processing by LabVIEW for determining the period and frequency. The success of verification with the acquisition of the predicted value was something fun to be experienced for students. The observation made manually was a change in the position of the spring deviation, while what is observed by the MEMs sensor is a change in the acceleration value. Students can determine the phase difference between the spring deviation function and the acceleration function by analyzing the extreme position and middle values of the two functions. However, it can also be done by observing the acceleration value at the initial position of the spring when it was released. It is expected that students will get a 180-degree difference because, according to the equation $ma = -kx$, there is a minus sign that represented the direction of the force exerted. But the experiment could have a phase difference of 0 degrees because it depends on the sensor’s mounting orientation.

2.2. MEMS as Cutting Edge Technology for Educational Props Sensor

The first thing to be considered in making computer-based physics props is the availability of sensors for observation of physical parameters. In this experiment, the latest acceleration measurement technology is used by using MEMs (Micro-electromechanical system) technology which is small in size, economical, and easy to use. Various electronic equipment and almost all smartphones use the technology. However, it is still very poorly used for educational props so we are interested in developing it.
MEMs are defined as a miniature device or arrangement of devices that combines electrical and mechanical components using the Integrated Circuit (IC) batch processing technique [19]. MEMs are a mechanical system in the form of a miniature that is very small and can convert electrical energy into mechanical energy and vice versa. MEMs look like ordinary circuit chips, but there are mechanical systems with a very small mass, moving rods, and springs inside them. In this paper, we discuss the use of MEMS in detecting and measuring the amount of acceleration, or commonly called the MEMS accelerometer (MEMS accelerometer) as shown in figure 1.

The working principle of the MEMS accelerometer is very simple. Imagine a mass-spring system, if we move the system, there will be a change in spring length. According to Hooke's law and Newton's law, the change in the spring length in the system is directly proportional to the amount of acceleration imposed on the same system. Therefore, when we detect changes in spring length, we get the amount of acceleration acting on the system. In MEMS, a mass-spring system is also called a resonator because this system can move back and forth around an equilibrium point [20].

**Figure 1.** (a) The functional diagram of ADXL345 [21] (b) The accelerometer MEMS on board [20]

### 2.3 IoT as Cutting Edge Technology for Educational Props Communication

Internet of Things (IoT) is a concept that uses the internet as the main infrastructure network that connects certain objects [17]. In this case, IoT can also be interpreted as an internet link between things, where things here mean information such as metadata [18] [22]. NodeMCU ESP8266 is a module derived from the development of the IoT (Internet of Things) platform ESP8266 type ESP-12 family. The function of this module is almost similar to the Arduino module platform, but the difference is that it is devoted to "Connected to the Internet" or better known as IoT ready devices.

**Figure 2.** (a) The functional diagram of ESP8266EX (b) NodeMCU ESP2866 board [23].
NodeMCU ESP8266 as shown in figure 2 has fully supported internet communication from the seven-layer OSI (Open Systems Interconnection) model. The physical layer uses WIFI media for signal and binary data transmission. The Transport layer uses the User Datagram Protocol (UDP). UDP is a simple transmission protocol provides unreliable service and no mechanisms to monitor congestion control or packet loss. UDP has no checking features and does not require establishing hand sacks between nodes. A simple condition of UDP will avoid overhead processing at the network interface. From the side of the node, this will facilitate communication without many errors appearing because one could have sent me without anyone receiving or conversely there was a waiting to receive without anyone sending data. In terms of UDP speed is faster than TCP (Transfer Control Protocol) because there is no need for error checking, error correction, or acknowledgment.

2.4 Integrating LabVIEW with IoT-based MEMS

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a system-design platform and development environment for a visual programming language from National Instruments. The visual programming will user-friendly for beginners user especially students who focus on their experiment and rapid software design for data accusation, processing, and visualization [24] [16] [17]. This advantage will assist students effectively in the engineering design process, however, because of limited space, it will not discuss in this paper.

Figure 3. The experiment design and associate connectivity

Figure 3 shows the acceleration parameters recoded by MEMS sensor sends it to NodeMCU Arduino with I2C protocol. The NodeMCU converts the data to a text string and sends it to the Computer via WIFI with UDP protocol. The text data consist of information number data, the value of acceleration data, and millisecond timestamp.

Figure 4 shows the LabVIEW received the string in a package and split into the individual string and convert it to the numerical value. Waveform chart facilities can visualize the series of data in a graphical waveform. LabVIEW has Tone Measurements facility for signal processing and get the frequency of the signal.
Figure 4. LabVIEW complete block diagram for measuring spring vibration with timing facilities, determination of frequency and period.

2.5. Sciences of Harmonic Spring Vibration and Mathematics Application

Most students are not interested in learning post-basic-calculus mathematics like differential equations because they look abstract and are not real in everyday life. ISLE-based STEM activities will create learning activities with the use of mathematics is naturally needed when understanding the processes occurred in an experiment [6]. When students are given a physics problem, they will try to find out what the problem is and how to get a solution. In Figure 5 there is a spring that is loaded with an object with mass $m$. We invited students to investigate several questions. First, does the system depend on time or not? If it is time-dependent, what physical parameters change over time? When discussing change, the solution arises from a differential resolution.

Figure 5. Simple harmonic motion of the body $m$ at the end of the vertical spring [14]
Look at figure 5, initially the spring is not given a mass, so there will be a balanced condition, $F = 0$. Furthermore, springs are given a mass so there will be a strain on the springs with length of $\Delta x$, so that the system goes to the new equilibrium point $F = 0$.

$$F = m \frac{d^2 x}{dt^2} = mg - k\Delta x = 0$$  \hspace{1cm} (1)

When it reaches a new equilibrium point and new coordinates can be used with the relationship $x_s = x_s = x_o + \Delta x$, so equation (1) can be changed to

$$F = m \frac{d^2 x_o}{dt^2} = mg - k(x_o + \Delta x) = -kx_o + (mg - k\Delta x) = -kx_o$$

$$F = m \frac{d^2 x_o}{dt^2} = -kx_o$$  \hspace{1cm} (2)

The mass parameter $m$ and the spring constant can be combined into one formula $\omega^2 = \frac{k}{m}$ that equation (1) can be written as

$$\frac{d^2 x_o}{dt^2} = -\omega^2 x_o$$  \hspace{1cm} (3)

If there is no external force then the balanced position $x_o = 0$ and the term in equation (3) is zero. However, if given an external force there will be a deviation which means providing additional energy to the system that has been balanced. Then the position will be dynamic by becoming the solution of equation (3). The function $x(t)$ in equation (3) is derived twice over time and produced the function itself multiplied by $-\omega^2$. It is expected that students can obtain one form of the following function

$$x(t) = Ae^{i\omega t} + Be^{-i\omega t} = Ce^{i((\omega t + \phi)} = C' \sin(\omega t + \phi) = D \sin(\omega t) + E \cos(\omega t)$$  \hspace{1cm} (4)

From the solution of equation (4), it is clear that $\omega$ is in a sinusoidal function multiplied by time which is a parameter of angular velocity. These parameters have a relationship with frequency and period that can be expressed by the equation

$$f = \frac{1}{T} = \frac{\omega}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$  \hspace{1cm} (5)

In this experiment, it is clear how from the first-order differential linear equation we can obtain the physical frequency and period parameters that can be observed both in experiments and daily life.

Figure 6. (a) Prototype of the IoT based MEMs Sensor props (b) students measure the spring length due to the mass of the sensor props (c) students do a spring vibration experiment.
3. Results and discussion
The harmonics spring vibration experiment activities have been carried out from making IoT based MEMs sensors, connecting to computers, displaying in LabVIEW, to being tested on students. Figure 6a shows a prototype sensor that is made and installed on the project board. In the picture, the overall weight of the sensor device is 203.15g which is the mass that will charge the spring. The load is related to the gravity of \( W = mg = 0.203\text{kg} \times 9.8\text{m/s}^2 = 1.96\text{N} \). The acceleration due to the gravity of 9.8 m/s^2 is a commonly used value.

The spring used has an initial length \( x = 16\text{cm} \), when the sensor load is hung, the length becomes \( x + \Delta x = 68\text{cm} \) (see figure 6b), so the addition of length experienced by the spring is \( \Delta x = 50 \). Based on this information the spring that we use has a spring constant \( k = \frac{W}{\Delta x} = \frac{1.96\text{N}}{0.5\text{m}} = 3.92\text{N/m} \). Based on equation (5) the frequency is obtained

\[
f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} = \frac{1}{2\pi} \sqrt{\frac{3.92\text{N/m}}{0.203\text{kg}}} = 0.699\text{Hz} \quad T = 1/f = 1.429\text{s}
\]

![Figure 7. Spring vibration waveform results and frequency and period values obtained](image)
Based on the results of manual calculations using a stopwatch that were repeated three times, 10 times oscillation requires a time of 15.22s, 15.53s, 15.33s. So the average is 15.36s and the average period obtained is \( T = \frac{15.36s}{10} = 1.536s \) which is close to the results obtained in the calculation (6). The results of calculations using the manual method are very useful to give students an understanding on how to determine the period and frequency directly from several waves distributed by the number of waves. But the manual method is rather difficult to see directly that the waveform is a function of \( x(t) \). With the help of the IoT based MEMs sensor and LabVIEW software and the block diagram of Figure 4, the waveforms in Figure 7 were obtained.

Figure 7 shows the wave measurements for 10s. In the picture, there were 6.5 waves formed. Based on the results of the graph the wave period \( T = \frac{10s}{6.5} = 1.5385s \) is obtained. This result is also relatively close to the one obtained in equation 6. The determination of the number of waves is not too detailed but can explain the concept of the period, number of waves, and length of measurement. LabVIEW has many features provided by National Instrument, one of which is the signal processing feature, which in this case, is the automatic determination of the dominant frequency of a wave. Figure 7 shows the frequency generated by the LabVIEW signal processing is 0.6613 Hz associated with the 1.512s period. These results are also comparable with the results obtained from equation (6). When a table is made of each value obtained from each method:

| Table 2. Period values obtained from various measurement methods |
|---------------------------------------------------------------|
| Methods | Equation (6) | Manual | LabVIEW Graph | Signal processing |
|---------|--------------|--------|----------------|------------------|
| Period Value (s) | 1.429 | 15.36 | 1.5385 | 1.512 |

These are just some of the basic parameters measured from a spring vibration experiment. This research can still be developed further and the relationship between the amplitude of the deviation and the amplitude of the acceleration can also be studied.

4. Conclusion
Harmonic vibration experiments on simple swings and/or spring vibrations and the results of experiments and their physical significance have been established. MEMs and IoT integrated LabVIEW help students understanding the concept of mechanics through a spring vibration experiment according to learning goals mandated by Permendikbud No. 24 of 2016 for class X part 4.11. MEMs, IoT, and LabVIEW technology were reliable combinations for physics learning media in facing the 21st-century skill-need. Investigations carried out in the ISLE model are more about building knowledge, while LabVIEW helps students in designing knowledge, but for the use of technology, more technical manuals are needed. The mathematical exercises conducted during the experiment are very interesting especially when the results of the mathematical model are verified by the results of the experiments with various methods making the atmosphere of "Learning is fun" presented.

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