Optimized Vibration Chamber for Landslide Sensory and Alarm System

1Eliza Sabira Binti Ismail, 1Mohamed Hadi Habaebi, 2Jamal I. Daoud and 1Md Rafiqul Islam

1Electrical and Computer Engineering Department, 2Science in Engineering Department, International Islamic University Malaysia

elizasismail@gmail.com; habaebi@iium.edu.my; jamal58@iium.edu.my; rafiq@iium.edu.my

Abstract. Landslide is one of natural hazard that is not unfamiliar disaster in Malaysia. Malaysia has experienced this disaster many times since 1969. This natural hazard has become a major research concern for Malaysian government when many people were injured badly and even had been killed. Many previous research works published in the open literature aimed at designing a system that could detect landslide in early stage before the landslide becomes catastrophic. This paper presents the early works on a major work-in-progress landslide early warning system for Malaysian environment. The aim of this system is to develop the most efficiently reliable cost-effective system in which slight earth movements are monitored continuously. The challenge this work aims at is to work with a low budget system that produces efficient performance. Hence, the material used is off-the-shelf. Early design optimization results of the vibration sensor used is quite promising detecting the slightest faint tremors, which are amplified using the best vibration chamber available. It is shown that the choice of proper pipe length and diameter dimensions in combination to a gravel to exaggerate the produced higher sensitivity level noise of 5 dB.

1. Introduction
Landslide also known as slope failure, landslips or slums can be defined as movement of rock or debris down a slope. In other words, landslide is the changes of the condition of the slope from stable to unstable. Landslide can happen due to natural phenomenon and human activities. The factors that causes landslides naturally are earthquakes, groundwater, erosion and volcanic eruptions. Whereas, acts by human that result in landslides are deforestation, construction, blasting, earthwork and vibrations from machinery. In Malaysia, 1969 was the earliest landslide occurred and it was in Pahang. There were seventeen landslides were recorded in total now and the latest was the last year in Selangor. People were injured and killed in this natural hazard and had caused tremendous damages to the environment infrastructure. These would have cause a lot of money for the recovery. The purpose of invention of landslide early warning system is to reduce all the risks mentioned above. In fact, many lives could be saved from becoming the victim of this natural hazard. Many research papers were published regarding this landslide early warning system from time to time to develop the most reliable and efficient system in order to alert people in the prone area about this hazard while it is still
This paper aims to design a vibration sensor and to investigate its different parameters to improve its capability in detecting landslides using commercial off-the-shelf materials. The optimum sensing structure dimensions were investigated for sensor casing for maximum acoustic density. The type of sensor that can detect ground movement is identified and it was decided to use vibration sensor SW-420. Next, as an effort to increase the accuracy and intensity of the vibration, gravels were placed inside a pipe before buried in the ground. In fact, several experiments were carried out to investigate this matter and the results obtained is positive. Lastly, in finding the optimum dimension of pipe, numerous experiments were conducted for three different lengths of pipes with four different diameters for each length. The paper is organized as follows. Section 2 briefly surveys the different projects used recently for landslide monitoring. Section 3 introduces the methodology. Section 4 presents the results and discussion. Section 6 concludes the paper.

2. Literature review
The development of landslide sensor has been evolving every day in order to produce the most reliable and effective system in detecting landslide hence alert the people in the prone area at the same time. A lot of studies regarding landslide sensor can be found today and generally, they are all different in two important aspects which are first, the type of sensor or sensors utilized in their projects and second is the data transmission from sensor node to base unit. Given these points, in this chapter, those two important aspects will be reviewed thoroughly coupled with the outcomes from their studies. Landslide can be described as a movement of soil, debris or rock down a slope caused by earthquake, rainfall or rapid snow melt [1,2]. Since 50 years ago, the speed of the movement in the ground have been changing from slowest to very slow [3]. To put it another way, the speed of the landslide is getting higher from time to time. Every year, landslides has affected many countries over the world in fact has endanger even killed many human life and destroyed the environment. Therefore, data transmission in real-time regarding the status of stability of slope in the prone areas has become a major concerned in research area in the hope that an efficient landslide early warning system could be developed. Landslide monitoring system is basically requiring experimental studies to test the sensors together with the data transmission from the sensor node to the base unit before deploy those sensors in the prone area. However, for more precise work, landslide mapping can be done before conducting any experiments. Landslide mapping helps to identify the exact area of susceptible landslide hence determine the right place to deploy sensor. A thorough investigation regarding landslide and its complex interaction on control factors such as lithology, elevation and slope are very beneficial in predict landslide both in space and in time [4]. Data transmission is actually a communication from sensor node to base unit. It lets the base unit to know when there is changes in the ground. Nowadays, wireless sensor node (WSN) has been widely used because of its capability to transmit data in real-time. Once a data is received at the base unit that indicates there is potential landslide, early warning system (EWS) plays a major role to alert the people to save their lives. EWS can be defined as to instantly spread meaningful warning information so that people nearby that are exposed to a hazard can prepare and act accordingly to reduce the possibility of danger or loss [5]. EWS is not just merely flashing red light on computer whenever a threshold value is exceeded. The people could be warned by SMS or a siren and when that happens, these people should know and understand what kind of hazard they are threaten to and how to act appropriately [5]. This alarm system is very important because this is the only way to alert the people in the prone area to that a natural hazard is about to happen and their lives are in danger. By the time the alarm is generated, the hazard is still in early phase and before it become catastrophic, the people could have enough time to save their lives and valuable belongings such as identification card, bank card, mobile phone also important documents. Since the focus of this paper is on the sensor itself, we will limit our discussion to it.

Type of sensors: Different types of sensors have been introduced for landslide detection in every research paper. The first type of sensor is called vibration sensor and it is used to sense any movement in the ground. Biansoongnern, Plungkang, & Susuk, (2016) propose to place SHOCK-801S which is a
vibration sensor in a stainless steel pipe [6]. The pipe then is buried in the ground together with the sensor. The utilization of this pipe can be the solution to prevent the sensor from broken during the landslide phenomenon. On the other hand, Woo [2] claims that landslide can be detected by ADXL 202 biaxial accelerometer which measures both inclination angle and acceleration of ground movement. Besides that, Woo (2016) has conducted several experiments in order to confirm the ability of this sensor to detect any motion in the ground [2]. Figure 1 shows different types of sensors.

![Image of sensors](image)

**Figure 1.** From left to right: Vibration Sensor (SHOCK-801S) [6], Accelerometer sensor (ADXL 202 biaxial accelerometer) [2], Extensometer and Tilt Sensor.

However, extensometer can be used to measure the slope surface displacement while inclinometer can be used to measure the movement of the slope. Above all, for slow and sudden ground movement, tiltmeter is the best choice [7,1]. Apart from gravity, rainfall also could trigger any ground movement or landslide [6]. Landslide rainfall-induced is caused by either high intensity rainfall or prolong rainfall with medium intensity [1]. For this reason, other parameters that are influenced by ground movement such as pore water pressure, rainfall intensity, soil pressure and surface displacement are considered in landslide monitoring system [7]. As suggested by [1,7], sensors like osmometer, dielectric moisture sensor, pore pressure piezometer, strain gauge and rain gauge are very useful to measure the parameters that is to say pore pressure and moisture content of the soil.

**Table 1.** Sensors and their functions.

| Sensor                        | Function                                                                 |
|-------------------------------|--------------------------------------------------------------------------|
| Vibration                     | To detect debris vibration in the ground.                                |
| Accelerometer                 | To obtain the acceleration of the ground movement.                       |
| Extensometer                  | To measure the displacement of the slope.                                |
| Inclinometer                  | To measure vertically and horizontally the movement of the slope.        |
| Tiltmeter                     | To measure slow and sudden movement of soil layer                       |
| Osmometer                     | To measure pore water pressure.                                          |
| Dielectric moisture sensor    | To measure the permittivity or dielectric constant of the soil.          |
| Pore pressure piezometer,     | To measure pore water pressure.                                          |
| Strain gauge                  | To measure the deflection of soil layer when the ground has a movement.  |
| Rain gauge                    | To measure the accumulative of rainfall.                                 |
| Geophone                      | To measure vibration.                                                   |

**3. Experiments and Methodology**
The type of sensor used to detect ground movement is vibration sensor, SW-420 known as highly sensitive sensor. When there is no vibration, the output signal is low and the LED will not turn on. Whereas, when there is vibration the output signal is high and the LED will turn on. As shown in figure 2, the vibration module consists of the sensor itself, an LM 393 chip and a potentiometer. LM 393 chip is a comparator and it is used to detect vibration if it is exceeded the threshold. This threshold can be adjusted by the potentiometer. Turning the potentiometer in clockwise direction will decrease the sensitivity while anticlockwise direction will increase the sensitivity. A PVC pipe is used to place the sensor and several experiments were conducted to determine the optimum dimensions in terms of length and diameter in producing the highest vibration intensity. As for the real-time data transmission, it is very important to transmit data from the sensor to the base unit before this natural hazard become catastrophic. Therefore, wireless sensor network (WSN) is the best choice to transmit data from the sensor to the base unit instantly. Wi-Fi module, ESP 8266 is used to read the value from the sensor and to transmit the data to the Base Unit. An efficient alarm system is needed in order to alert the people nearby when there is potential landslide. Many lives and valuable properties could be saved if these people receive this alarm.

![Image of vibration sensor module SW-420](image)

**Figure 2.** Vibration sensor module SW-420.

Off-the-shelf PVC pipes of 1 meter, 2 meters and 3 meters length and diameter (mm) of 15, 32, 50 and 80 for each length are used and tested which one is the optimum dimension for placing the sensor with some gravels before buried in the ground. When there is a movement in the ground, the gravels inside the pipe is moving as well and hit the inner wall of the pipe hence produce vibration thus sensed by the vibration sensor. Other than that, other advantage of using this pipe is, it can protect the sensor during the landslide so that it can continuously function during the landslide phenomenon. There are three different experiments were conducted. The first experiment was conducted to test the functionality of the sensor. The objective of this experiment is to test the functionality of the sensor. Suppose the sensor obtain a measurement when there is motion applied to the pipe and not record any measurement when there is no motion applied to the pipe. The second experiment was conducted to identify which position of pipe produce higher vibration measurement also to test if the gravel inside the pipe can increase the vibration measurement. The third experiment was conducted to find the optimum dimension of the pipe in terms of length and diameter. Components used in the experiments are: Vibration module sensor (SW-420), LED, Arduino UNO board, Jumper wire, PVC pipes, gravel and laptop.

| Table 2. Dimensions of pipe. |
|-----------------------------|
| Length (m) | Diameter (mm) |
| 1 | 15 | 32 | 50 | 80 |
| 2 | 15 | 32 | 50 | 80 |
| 3 | 15 | 32 | 50 | 80 |
In order to test the functionality of the sensor, the assembly is connected to the laptop and the sensor is placed inside the 2m pipe with diameter 15mm. The code is compiled and uploaded by using Arduino software. A serial monitor on Arduino software is clicked to obtain the measurement of the sensor and the measurement is recorded for ten seconds. Secondly, the vibration intensity was tested from the pipe with gravel and without gravel inside the pipe when the pipe is laid horizontally and vertically and for different pipe lengths and diameters.

The vibration was induced vertically and horizontally by shaking the pipe in back/forth and up/down motions for ten seconds. To find the optimum dimension of pipe in terms of length and diameter, 10 pieces of gravels are put inside the different pipe to be tested to induce stronger acoustic vibration.
4. Results and Discussion
All the measurement recorded were presented in graph form for better visualization and comparison.

Experiment 1: To test the functionality of the sensor.

Graph 1. (a)Vibration measurement when no motion applied to the pipe and (b) vibration measurement when motion applied to the pipe.

Based on graph 1(a) there was no measurement recorded in Experiment 1 since there was no motion applied to the pipe. When there is motion applied to the pipe, there was measurements recorded as shown in graph 1(b). Therefore, it can be confirmed that this sensor is working perfectly hence it can be used for the next experiments.
Experiment 2: To test the vibration intensity with gravel and without gravel inside the pipe when the pipe is in horizontal and vertical position.

**Table 3.** Comparison of data for horizontal and vertical position of pipe.

|                | HORIZONTAL | VERTICAL |
|----------------|-------------|----------|
| With gravel    |             |          |
| Average        | 15096.709   | 4208.340741 |
| Variance       | 759911221   | 135802130.4 |
| Standard deviation | 27566.487   | 11653.41711 |
| Without gravel |             |          |
| Average        | 8039.777    | 1748.291667 |
| Variance       | 305353399   | 20824466.71 |
| Standard deviation | 17474.364   | 4563.383252 |
| With gravel    |             |          |
| Average        | 35.197631   | 28.94987849 |
| Variance       | 71.56194    | 67.12980137 |
| Standard deviation | 8.4594291   | 8.193277816 |
| Without gravel |             |          |
| Average        | 31.997333   | 24.80375801 |
| Variance       | 89.095055   | 63.220448 |
| Standard deviation | 9.4390177   | 7.951128725 |

While for Experiment 2, the value of mean, variance is obtained from those measurements as shown in table 3. From these values, it can be seen that the pipe with the gravels inside has higher value compared to pipe without gravels inside for both horizontal and vertical position of the pipe. This means, the gravels produced vibration as well when the pipe was moved hence increased the vibration intensity. For this reason, it can be confirmed that the gravels could increase the accuracy in detecting landslide movement. These measurements are important in setting the threshold value in which will determine the occurrence of ground motion.

The comparison between the horizontal vibration measurement and the vertical vibration measurement can be seen in table 3. It clearly shows that when the pipe is laid horizontally with the gravels inside the pipe produce the most vibration intensity. This is because, when the pipe is moved back and forth horizontally, the were reflection occurred between the gravels and the inner wall of the pipe. Less reflection occurred when the pipe is held vertically and is moved up and down as the gravels are moved up and down as well and not hit the wall much. Therefore, it can be concluded that this sensor can function perfectly when the pipe is laid horizontally and can be utilized in this project together with the gravels.

Experiment 3: To find the optimum dimension of pipe in terms of length and diameter.

Comparison of pipes in terms of length (m) and diameter (mm) based on average value from the output signal level.
Length = 1m

- HORIZONTAL-Up and down
- VERTICAL-Back and forth
- HORIZONTAL-Back and forth
- VERTICAL-Up and down

Length = 2m

- HORIZONTAL-Up and down
- VERTICAL-Back and forth
- HORIZONTAL-Back and forth
- VERTICAL-Up and down
Graph 2. Vibration intensity for diameter 15mm, 32mm, 50mm and 80mm when pipe is (a) 1m length, (b) 2m length and (c) 3m length. Square indicates the pipe is laid horizontally and is moved up and down continuously. Triangle indicates the pipe is held vertically and is moved back and forth. Cross indicates the pipe is laid horizontally and is moved back and forth. Circle indicates the pipe is held vertically and is moved up and down.

Moreover, from Experiment 3, we can see in those graphs clearly that, when the pipe is laid horizontally, the vibration intensity is much higher compared to when the pipe is held vertically. In graph 2, it can be confirmed that the optimum dimension of the pipe is 2m length and 50mm diameter.

Table 4. Average values from dominant output signal level for (a) pipe length is 1m, (b) pipe length is 2m and (c) pipe length is 3m.

| Diameter (mm) | HORIZONTAL-Up and down | VERTICAL-Back and forth |
|--------------|------------------------|-------------------------|
| (a)          |                        |                         |
| 15           | 11477.15929            | 3447.957746             |
| 32           | 18674.85106            | 8761.093023             |
| 50           | 19415.27586            | 7725.948529             |
| 80           | 13349.20952            | 11968.59091             |
| (b)          |                        |                         |
| 15           | 7213.244275            | 10701.80992             |
| 32           | 15707.84259            | 9907.015625             |
| 50           | 22741.28889            | 15162.71304             |
| 80           | 5122.768595            | 9528.75                 |
| (c)          |                        |                         |
| Diameter (mm) | HORIZONTAL-Up and down | VERTICAL-Back and forth |
| 15           |                        |                         |
| 32           |                        |                         |
| 50           |                        |                         |
| 80           |                        |                         |
5. Conclusion

As can be seen, the first objective for this project has achieved successfully that is to investigate different types of sensors in detecting landslide. Through the reading of research papers had help a lot in understanding the concept of this project. Every research papers have introduced different approaches with different types of sensor. However, their goals are the same that is to detect any ground movement at early phase before the natural hazard become catastrophic and of course this is very important so that people can save their lives and valuable belongings. After conducted several experiments, the vibration measurements produced from vibration sensor SW-420 has clarify that, PVC pipe of length 2m and diameter 50mm with gravel inside the pipe (laid horizontally) is the most favourable. Hence, our future test-bed will use this information into the design consideration.

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