Development of seismic acquisition instrumentation system based MEMS accelerometer using SPI communication with Raspberry Pi

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Abstract. The background of this research concerned to the operational cost and human resources to conduct seismic data surveys. In seismic surveys, the tools and cables are very heavy and need very long cables, so they spend a lot of cost and resources. Based on those reasons, an improvement of Geophone technology for data acquisition was needed in this study to reduce cost and resources. Accelerometer based on MEMS technology was proposed to replace a conventional geophone to reduce costs and human resources. In previous research, a study of seismic signal acquisition instrumentation based on MEMS accelerometer sensor could acquire only two geophones. In this study has renewed seismic signal accelerometer by communication aspect to acquire more geophones or seismic signal acquisition instrumentation. So, it would be more efficient and reduce cost and need fewer resources. The hypothesis is Output data of this system is almost the same with output from conventional geophone. This system uses SPI Extender module to make one Raspberry Pi to acquire more MEMS geophone and with further cable reach. Respond result or output of geophone is saved into Raspberry Pi first so that it can be taken wirelessly by the host computer. Trial test is done at Universitas Indonesia. Based on the test results, the response of the MEMS Geophone, when given a wave explosion, is almost the same as a conventional Geophone.

Keywords: Accelerometer, geophone, Raspberry Pi, seismic survey, SPI extender

1. Introduction
In various fields of research, measurement is the basis for finding correlation between interpretation and theoretical predictions [1]. Without measurement activities, the bridge will be broken [2]. One of the research field is to interpret seismic waves in the geological structure known as seismic methods using geophones at certain configuration. When an actuator produces seismic signal, reflects, and captured by the geophone due to layers of the geological structures. Michael S. Hons had developed and tested an analog MEMS (Micro Electronics Mechanical System) accelerometer-based seismic sensor. He obtained the transfer function between accelerometer and geophone so that the data output can be compared directly [3]. The principle mechanism of a MEMS accelerometer is that change acceleration is proportional to the different capacitance as the seismic mass of the accelerometer moves between two plates.

In previous research, Awaludin [4] developed a digital geophone based on MEMS accelerometer to replace conventional geophone. (A MEMS accelerometer acquire the accelerations of motion of earth
surfaces and converted into velocities so that seismic waves can be detected in order to replace conventional geophones [5].

The MEMS accelerometer could operate under its resonance frequency (> 1 kHz) so that MEMS accelerometers can detect seismic waves below 10 Hz without any difficulties. Many MEMS accelerometers can measure three propagation components using a single MEMS chip. The idea of this research was motivated from the conventional geophones that usually used for seismic explorations still required a lot of human resources, high costs and use very long cable. The previous digital geophones used I2C communication protocol and could controlled only two MEMS accelerometers. In this study, the system was able to control 10 geophones using only one Raspberry Pi.

2. Method

2.1. System design method

The seismic signal acquisition system in this study consists of several components/devices such as Raspberry Pi, Wi-Fi modem as router, geophone with SPI Extender module. In this study 10 (ten) geophones were assembled in series and controlled using a Raspberry Pi single board computer (SBC) as shown in figure 1. The ten geophone and a Raspberry Pi were interconnected using an ethernet cable based on RJ45 ports on each geophone. The communications topology used in this system was the BUS Topology where the nodes (in these case geophones) were connected serially. This system would be easy for any developer to assemble each geophone to a Raspberry Pi. The communication between host computer to Raspberry Pi was wireless communication technology that is by using Wi-Fi, where in this research used Wi-Fi modem as router that connect Raspberry Pi with host computer.

2.2. SPI communication testing method

SPI Communication Testing required to test the maximum cable length that can be used on each geophone to acquire data and send to the receiver. In this test, SPI Communication testing was intended to find the maximum Cable length to minimize the loss of data acquired. The cable length

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Figure 1. Geophone MES data acquisition system
refers to the length of the cable from Raspberry Pi to Geophone, and the geophones configurations shown in figure 2. In order to extend the cable length and the number of geophones an additional SPI Extender module was added to the previous work [4]. In this study, the number of geophones were ten pieces.

2.3. Method of testing sampling speed
In the sampling speed test, the same program is used by acquiring data, but this time the start time and stop time of acquisition is recorded to be used to calculate the frequency and sampling period. Calculating the sampling frequency is by dividing the data obtained with the required data, then we can calculate the sampling period with,

\[ f_s = \frac{1}{T_s} \]  

whereas \( f_s \) is the sampling frequency and \( T_s \) is the sampling period.

2.4. MEMS geophone response test method
The data acquisition process for MEMS Geophone Response test shown as figure 3. The data acquisition process was started by configuration the Raspberry Pi, and ended to the saving the acquired data to SD-Card.

Acceleration that can be measured by an accelerometer is an important parameter for various types of measurements such as measuring motion, vibration and measuring shocks [6]. The MEMS accelerometer used in this study is a product of Freescale Semiconductor with a module type MMA7455LL as shown in figure 4.

The MMA7455LL Accelerometer Module is an accelerometer with digital data output with face-to-face communication using I2C or SPI with signal conditioning features: low pass filter and self-test. The measurement sensitivity is available in 2 g, 4 g, or 8 g using the 8-bit measurement mode that can be selected by configuring the registers of this chip. The required voltage ranged between 2.4–3.6 V. All devices, both Raspberry and Geophone get a voltage source from the motor battery with a maximum voltage of 12.5 V.

The testing of the developed geophone were done in the first step was done in the laboratory for various conditions. The next step was done that the geophones were planted in the ground to mimic the real-life condition for a seismic data surveying.

The testing was done by giving an explosion to one geophone and detected the acceleration as a response to this explosion. The same method was done to several geophones in order to get the maximum cable length between geophones. Once the data were obtained, then these acceleration data were converted into speed using Cumulative Trapezoidal Numerical Integration method.

![Figure 2. Illustration of cable length required](image-url)
The data were obtained from these Geophones based on MEMS accelerometer were compared using the Geophone GS-11D which has been standardized on an industrial scale. This Geophone is a product from the Geospace Technologies from Houston, Texas, USA.

3. Results and discussion

3.1. SPI communication testing
In this experiment for SPI communication tested the quality of the acquired seismic data using an additional SPI Extender module. The results showed that to acquire 10 (ten) MEMS geophone, the maximum cable length for each geophone was 4 m. However, for 5 m of cable length for each geophone could acquire only 6 geophones as shown in table 1.

3.2. Test sampling rate
Sampling rate in seismic data acquisition systems is one of the important parameters in acquiring signals, which must match with the Nyquist theorem. Testing was done by retrieving data at
a specified time. A stopwatch was used to determine the specific time, then data acquisition was
started and stopped manually at the certain time. The tests were conducted 10 (ten) times with time
interval of 0–50 s and time difference of 5 s for each data acquisition. The data output was stored into
SD-Card that was connected to Raspberry Pi and then sent to the host computer.

In this sampling speed test, it is found that the amount of data obtained is proportional to the
time required, so the sampling speed is always constant and near linear as shown in figure 5 with the
correlation coefficient, $R^2 = 0.9997$.

After the average of sampling rate according to data, we got the sampling rate of 6.05 ms.
The amount of data obtained were less in the view of waves or signals that appear. However,
the MEMS geophone could respond to the vibration or small waves. This sampling speed of 6.05 ms
did not met the standard for sampling speed in acquiring seismic waves. In accordance with the basic
theory, the minimum sampling rate for acquiring a seismic signal is 2 ms. This discrepancy was due to
the additional SPI Extender module equipment to the MEMS-based seismic acquisition system.

3.3. Comparation geophone MEMS with conventional geophone
The purpose of this test was to compare the developed MEMS Geophone and the conventional
geophone. Both geophones were subject to the same source of vibration with the same power.
The purpose of this test was to see whether the MEMS accelerometer can respond to vibrations.

3.3.1. Response of 1 (One) MEMS geophone one explosion at outdoor testing. On testing outside the
room was done behind Building B, FMIPA UI on the plains in the form of soil. Data retrieval was
carried out for 10 seconds by giving an explosion as much as 1 (one) time when the time has been
running 5 s. The distance between the geophone and the vibration source is 3 m. The source of the
vibration is a stone weighing about 5 kg dropped by hand manually when the 5th minute.

| Table 1. Cable length testing data with SPI communications. |
|-----------------------------------------------------------|
| **Cable length of each geophone** | **# of geophones** |
| 100 cm | 10 geophone |
| 200 cm | 10 geophone |
| 300 cm | 10 geophone |
| 400 cm | 10 geophone |
| 500 cm | 6 geophone |

**Figure 5.** Graph of speed sampling testing
All Raspberry good devices, and Geophone get a voltage source from a motor battery with a maximal voltage of 12.5 V. The results obtained in the graphs of figure 6, figure 7 and figure 8 are the responses of the three axes of the MEMS accelerometer, the \( x \)-axis, the \( y \)-axis, and the \( z \)-axis.

As shown in those graphs that the rise and fall of the wave occur in the same position. In this case, the geophone with the accelerometer can receive or respond to the vibration that is given through a medium, i.e. the soil. From the graph shows that a considerable noise, but the main signal responses due to Explosion were clearly visible. A very small vibration that propagates in the ground might generate noises, these vibrations were not from the vibration sources.

3.3.2. Response of 1 (One) MEMS Geophone and 1 (One) Conventional Geophone with Five Explosions at Indoor Testing. In this method, the developed system was tested in indoor room by putting the two types of geophone on Styrofoam. The geophone can stand with the nail down towards the earth. Testing is done by acquiring data with a certain time. In this test the time required is 30 s by giving 5 beats for every 5 s.

![Figure 6](#) x-axis graph output of geophone MEMS response at outdoor testing.

![Figure 7](#) y-axis graph output of geophone MEMS response at outdoor testing.

![Figure 8](#) z-axis graph output of geophone MEMS response at outdoor testing.
Figure 9. Conventional geophone output response with 5 explosions at indoor testing.

Figure 10. MEMS geophone output response with 5 explosions at indoor testing.

An explosion was given to the area around the geophone but still within the scope of the Styrofoam. The results obtained in the graphs of figure 9 and figure 10 are MEMS accelerometer responses. In addition, the output signal on MEMS geophone also almost follows the output signal on conventional geophones. On the graph we can see that the rise and fall of waves occur at the same position.

In this case it can be seen that the geophone with an accelerometer can receive or respond to vibrations given through a styrofoam which is thinner and easily transmits waves. However, noise on conventional geophones is less than noise on MEMS geophones. In addition, there is also a difference in the amount of data due to the sampling rate between the two different geophones, but from these data, the MEMS geophone response position almost same with the conventional geophone response signal.

4. Conclusion
Based on the design and implementation of tilting effect correction system and a series of spatial dimension measurement system testing on the object, we can conclude that communication system / face to face in this research successfully updated with SPI communication (Serial Peripheral Interface) with the addition of SPI Extender module. Maximum cable length that can be used each geophone MEMS which is 10 (ten) geophone that is 400 cm or 4 m. If you want to use a cable length of 500 cm or 5 m then the maximum geophone used is 6 (six) pieces of geophone. The output waveform of this system is quite similar to the waveform of conventional geophone. The acquisition process has been carried out wirelessly with the captured data stored first on Raspberry Pi for later taken by the host computer.

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