Landslide Monitoring using Inclinometer with Micro Electromechanical System (MEMS)

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Abstract. Being located on the Pacific Ring of Fire and a tectonically active country, Indonesia has to cope with the constant risk of volcanic eruptions, earthquakes, floods and landslides. Landslides and other mass movements are serious geo-environmental hazards in Indonesia. Following report from the Indonesia National Disaster Management Authority (BNPB), landslides are among high disaster death toll throughout the archipelago. It claimed 248 lives last year alone. The number of landslides in Indonesia increase steadily to 376 in 2014 from 291 in 2012. Hence, landslide monitoring system is required to determine style of landslide movement, for risk and even emergency risk management assessments and to assist with the design of mitigation works. A landslide instrumentation program including an inclinometer is designed for landslide monitoring. The inclinometer, or tilt sensor, is an instrument used for measuring slope, tilt, or inclination. In this paper we use Micro Electromechanical System (MEMS) as a sensor to measure changes in an angle. Then information is transferred to a central server soon after real-time accelerations are monitored. A data logger also used as a data recording. With low-cost MEMS accelerometers, the results show this instrument is able to provide reliable ground-motion data in network-scale deployments.

1. Introduction
Indonesia is located at the joining point of four major tectonic plates. Most areas in Indonesia are highly prone to various hazards. According to Meteorology, Climatology and Geophysics Agency (BMKG) chairwoman Dwikorita Karnawati said that the nation lacked programs to raise disaster awareness, despite the country sitting on the Pacific Ring of Fire [1]. Indonesia is prone to earthquakes and volcanic eruptions. Landslides and other mass movements are serious geo-environmental hazards in Indonesia. Landslides are among the highest disaster death toll throughout the archipelago, according to the BNPB.

Landslide monitoring is required to determine style of landslide movement, for risk and even emergency risk management assessments. This is used to assist design of mitigation works. The monitoring of surface displacement is crucial for the prevention and forecast of landslides. There are several systems and techniques for landslide monitoring, one of them is ground-based techniques using inclinometer to measure slope, tilt or inclination.

2. MEMS
In order to obtain high quality of micro earthquake data, micro earthquake sensors deployed in the field have several main characteristics, such as high sampling rate response, sensitivity, wide frequency bandwidth with low frequency coverage, high temperature resistant, and high pressure and humidity resistant. There are numerous applications of MEMS. The usage of MEMS in electronics such as disk
drive heads and inkjet printer heads. MEMS sensor also used in different domains which include medical, automotive, communications and defense. The following parts are used to build MEMS sensor. Each part has its own role and specific characteristics.

2.1. The Core
Conventional seismometers use coil as the main sensor. Coil is relatively cheap, but in order to cover low frequency range, it becomes frail and has inappropriate sampling rate. Moreover, coil has harmonic frequencies which add some noise to the recorded data. There is often a second resonance at much higher frequency, which is produced by the combination of the inductance of the sensor coil combined with capacitance [2]. This millennium breakthrough technology has the answer for overcome the limitation of conventional seismometers, namely a MEMS sensor. The MEMS is made from glass and silicon substrate which has no harmonic frequency characterization. It enables covering wide bandwidth with low frequency cover and high sampling rate response with high sensitivity. It has been used three MEMSes Colibrys 1500SN.A for developing a 3-C borehole seismometer. Each MEMS represents one axis direction. The specification of this type of MEMS can be seen in Table 1.

Table 1. Specification of MEMS 1500SN.A

| Parameter                        | Value   | Unit       |
|----------------------------------|---------|------------|
| Linear Output Range              | ± 3     | g peak     |
| Sensitivity                      | 1.2     | V/g        |
| Frequency Response               | DC to 1500 | Hz      |
| Dynamic Range                    | 120     | dB         |
| Noise (10 to 1000 Hz)            | 300 to 500 | ngrms/√Hz |
| Cross-axis rejection             | > 40    | dB         |
| Shock Limit (0.5 ms l/2 sine)    | 500     | g peak     |
| Vibration (20 Hz - 2000 Hz)      | 60      | g pk-pk    |
| Operating Temperature            | -40 to +125 | °C      |
| Sensitivity Temperature Coef.    | 75      | ppm/°C     |
| Offset Thermal Coefficient       | ± 100   | μg/°C      |
| Linearity Error                  | ± 0.1 % | Full Scale |
| Input Voltage                    | ± 6 to ±15 | Volts DC |
| Quiescent Current                | < 11.6  | mA         |

Instrumentation system of MEMS based seismometer borehole consists of 3 units 1500SN.A MEMS, amplifier, low pass filter, analog to digital circuit, and microcontroller. MEMS based seismometer borehole block diagram is shown in Figure 1.
Micro earthquakes are sensed by MEMS as input signals. Then the MEMS converts the land vibration into electronic signals, having low level of voltages. Thus, the signals need to be amplified. The captured signal by MEMS is not only micro earthquake signal but they consist also many land vibration sources such as man activities, sea waves, vehicles vibrations, etc. The various input signals are separated by filter. Afterward, the filtered signals are converted into digital signal by ADC. The results are sent to memory unit by microcontroller.

Colibrys 1500SN.A is an MEMS accelerometer having several requirements compared to a low frequency geophone, e.g. it needs a DC power supply. As can be seen in Figure 2, MEMS accelerometer has a good stability character compared to low frequency geophone. Monitoring micro earthquake events for geothermal engineering takes months even years for real time monitoring, so a proper seismometer should have a good stability response [3].

2.2. Amplifier
Since microearthquake events have low amplitudes producing very low output voltage, thus an amplifier is needed. The MEMS 1500SN.A’s sensitivity is 1,2mV/gm. It means that the output voltage for weak motion is in the order of 10-3 volt. This very low output voltage needs to be amplified in order to be read by the ADC. Figure 3 shows the circuits of amplifier.
Differential amplifier is an op-amp based active amplifier. It has low precision because there are two resistors which has to be adjusted precisely. Thus, this amplifier must be modified becoming a better one. Basic circuit (known as instrumentation amplifier) can be seen in Figure 4. It has been used an AD620AN device as main amplifier component. AD620AN has low offset voltage drift, low noise performance, high common mode rejection ratio, high input impedance, and low power consumption. Thus, there is one adjustable resistor (R1 or Rg) as amplification factor, in which its circuit can be seen in Figure 5.

2.3. Filter
The MEMS 1500SN.A detect any motion within its range of measurement. It sends all signals in every frequencies to ADC and CPU. Desired signal is only signal with frequency below 500 Hz. Therefore, a filter is needed for separating signals based on frequency. Active LPF with 500 Hz as a cut-off frequency is used to reject signal above 500 Hz. MEMS does not have harmonic frequency, thus band pass filter is not needed. Only a low pass filter (LPF) is needed to separate desired frequencies from the others. Figure 6 shows basic schematic of one order LPF.

2.4. ADC and Microcontroller
Analog signal that come out from LPF is already in voltage level that possible to be processed by ADC. A 12-bit ADC is used to convert analog signal into digital signal. The conversion result is sent to PC/memory unit from ADC through microcontroller. Microcontroller has a special task to control all the data acquisition system. It plays also an important role as a connector between the main controller units (PC) and the MEMS.

2.5. Casing
The casing For the MEMS is designed to protect the core from high temperature, high pressure, high humidity and shock. Current prototype MEMS casing is made of ordinary stainless steel to support laboratory test and small scale field test in geotechnical, which will be conducted in a near future. The next stage of MEMS development includes the research of the best type of casing materials and its structures.
2.6. Clamping

Current prototype MEMS- has not attached to any clamping system. The function of the clamping system will be temporary replaced by special acquisition installation technique. This technique is aimed to achieve similar environment as if it is attached to a clamp in a borehole, in most of rock formation types.

3. Laboratory Test

Physical simulation as laboratory scale test is performed to obtain result seismometer core part performance. The test is done by putting the seismometer core (already inside a cylindrycal casing) on a spring. The idea is to test whether the seismometer can detect the small disturbance (represented with shaking spring in three axis) as illustrated in Figure 7. The response is recorded by a laptop computer. The MEMS-based seismometer borehole shows the performance of its recorded small signal.

![Figure 7. LPF Spring test (a) stable position. (b) disturbance in z axe. (c) disturbance in 3-axis.](image)

Figure 8 describes laboratory test equipment for testing core’s signal to noise ratio performance. The signal generator is used to calibrate the signal indicator, amplifier, low pass filter and analog to digital circuits both independently and dependently. Afterward, the prototype of 3-C MEMS borehole seismometer is connected and the signal-to-noise ratio performance test is started and recorded. While the test is conducted, the oscilloscope shows the output signals and it can be compared to the displayed signal on laptop.

The prototype of MEMS-based seismometer borehole is able to record desired signal and stable to measure and record continuous data. The noises, recorded and displayed, are caused by the fan of power supply. This means that the seismometer’s signal to noise (S/N) ratio is high.
Figure 8. Laboratory scale test – core part

Figure 9. Result of signal to noise ratio test

4. Conclusions
Micro earthquake signals are low level in term of frequency and amplitude. However the signal amplitudes can still be amplified by using instrumentation amplifier. In the other hand, active LPF is the solution for separating signals based on frequency. From physical simulation as laboratory test, the MEMS works properly as their functions. The next project is to finalize the casing, to attach the core to be inside the casing, and to conduct small scale the field test.

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