Relative gravimeter prototype based on micro electro mechanical system

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Abstract. This research to make gravity measurement system by utilizing micro electro mechanical system based sensor in Gal order. System design consists of three parts, design of hardware, software, and interface. The design of the hardware include of designing the sensor design to measure the value of a stable gravity acceleration. The ADXL345 and ADXL335 sensors are tuned to obtain stable measurements. The design of the instrumentation system the next stage by creating a design to integrate between the sensor, microcontroller, and GPS. The design of programming algorithm is done with Arduino IDE software. The interface design uses a 20x4 LCD display to display the gravity acceleration value and store data on the storage media. The system uses a box made of iron and plate leveling to minimize measurement errors. The sensor test shows the ADXL345 sensor has a more stable value. The system is examined by comparing with gravity measurement of gravimeter A-10 results in Bandung observation post. The result of system test resulted the average of system correction value equal to 0.19 Gal. The system is expected to use for mineral exploration, water supply analyze, and earthquake precursor.

1. Introduction
Gravitational acceleration instruments are growing in their measurement methods in the 21st century. Researchers of the world produce measurement methods using laser interferometers, quartz, superconductors, and Micro-Electro-Mechanical Systems (MEMS) to measure the acceleration value of gravity with the smallest resolution possible.

Problems that occur in the field are expensive instruments that measure the rate of earth gravity acceleration provided by leading manufacturers such as L-coste and Scintrex. Another problem is the dimensions provided by the manufacturer are too large. Previous research produced several gravimeters by applying various sensors. The Massachusetts design gravimeter produces a quartz gravimeter with a resolution of 3-10 mGal[1]. The Gravimeter using MEMS designed by Mutoh yields a resolution of 0.5 mGal[2]. In this case, the design using MEMS is influenced by temperature[3]. The study was conducted with the aim of obtaining a measurement method that can produce instruments with dimensions as small as possible and low cost. Amirullah's research from Jember University entitled Design of Earth Gravity Acceleration Measuring Instrument (Gravimeter) Using Parallel Capacitors succeeded in making gravimeter by utilizing piezoelectric effect[4]. Research rocks have a resolution of up to 0.01 m/s² which has an accurate error value of 2.63% and a precision error of 0.045%.

This research uses ADXL sensor to measure gravity acceleration, RTC as system time sign, GPS as sign of system location, 20x4 LCD as system interface, and micro SD card as system storage media. This study aims to produce a measurement instrument of gravity acceleration value with a more efficient
dimension and an affordable price. The designed system is expected to assist geophysical analysis such as mineral exploration, water supply survey, and earthquake precursor.

2. Implementation of System
This system consists of acceleration sensor ADXL 345, RTC DS1307, and GPS U-Blox Neo 6M as a component that provides input signal for microcontroller. The microcontroller processes the input signals of each component with algorithm. Microcontroller sends output signal in the form of digital data processing of input signal to LCD 20x4. The microcontroller and RTC communicate with each other at a certain baud rate to get the timing value. Microcontroller inserts the measurement data into the micro SD card. Figure 1 shows the block diagram of the system.

![Diagram block of system](image)

**Figure 1.** Diagram block of system (a) and flowchart of system (b).

This system performs measurements by initializing the entire component so that the system is ready to perform data acquisition. The system performs reading of microcontroller input signals and processes algorithms to produce inclination values, gravitational acceleration, location, and time. The gravity data averaged every 40 readings for smoothing. All of data is displayed on LCD and saved on SD card. Figure 1 shows the system flowchart.

The system uses a waterproof box to protect the component so it can be carried to survey. System and has three adjustable legs for leveling. System interface using LCD located at the top of the box. The system has a small dimension to facilitate transportation to a measurement location. The system dimension is 20 cm x 15 cm x 30 cm (length x width x height). The iron box is equipped with a lock so it can be opened and closed to perform component replacements or troubleshooting the system.

3. Data Validation
The ADXL sensor test uses an inclinometer as a reference to get the value of $g_0$. The inclinometer shows the degree of inclination of a field with the resolution on the inclinometer is $2^\circ$. Test results produce correction values which are then used in the measurement calculation. The comparison of the sensor compares the sensor output in the form of a slope angle to the Y axis (pitch) and the slope of the X axis.
(roll) with the plane and the inclinometer. The pitch and roll value of 0 has a straight line or perpendicular to the Z axis. Figure 2 shows the result of comparison of ADXL in degree.

The comparative results show the distribution of ADXL335 data wider, that is, has a maximum distribution value approaching 0.02° and -0.04° for the minimum distribution. ADXL345 has a relatively smaller data distribution than ADXL335 which is still around 0° (zero degree). Researchers used ADXL345 as a sensor in the measurement of gravity acceleration based on the stability of the sensor in the measurement of the test results to obtain a stable gravity acceleration value.

![Distribution of ADXL335 Correction Results](image1)

![Distribution of ADXL345 Correction Result](image2)

**Figure 2.** Comparison between ADXL345 and ADXL335.

Testing the system using the gravity observation post in Bandung as the location of testing that include Geophysical Station Bandung as a binding point measurement, post Lembang, and Post Tangkuban Perahu. Testing was conducted on August 23, 2017 from 09.00 am until 13:35 pm.
Figure 3. Comparison between ADXL345 and ADXL335.

Figure 6 shows the graph of data processing testing. The gravity value of the system shown by blue has the same trend as the A-10 measurement data, where the system follows the A-10 data pattern when there is an increase and decrease in A-10 data although there is still a correction on the system. The data pattern corresponds to the altitude of the measurement location, whereas the elevation of the location increases the acceleration value of gravity will decrease and vice versa when the location altitude decreases the acceleration value of gravity will increase.

Figure 4. Comparison between ADXL345 and ADXL335.

Table 1 shows the results of calibration calculations with U95 is a 95% confidence interval and EN is the value of data received with. The calibration results show the average uncertainty value of the system of 2.8 Gal with the En value still in the range of -1 to 1. The uncertainty value indicates the range where there is a true value of a measurement as in Figure 4.12 where the first value is the standard reading value and the after value is the measurement value using the system.
Table 1. Comparison between ADXL345 and ADXL335.

| Lokasi | Standard (Gal) | U95 | Drift (°) | g new (Gal) | koreksi | gobs (Gal) | gobs avg (Gal) | def | U95 | EN  |
|--------|----------------|-----|-----------|-------------|----------|------------|----------------|-----|-----|-----|
| Geof   | 977.965        | 0.000000823 | 837.187 | 0.0000 | 837.187 | 0.0000 | 977.965 | 977.967 | -0.00145 | 2.82847 | -0.00051 |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
| Lembang | 977.855        | 0.00001059 | 836.688 | -0.1258 | 836.814 | -0.3730 | 977.592 | 977.594 | 0.26027 | 2.82848 | 0.09202 |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
| Tangkuban Perahu | 977.816 | 0.00001071 | 836.606 | -0.2029 | 836.809 | -0.3779 | 977.588 | 977.589 | 0.22667 | 2.82848 | 0.08014 |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
| Lembang | 977.855        | 0.00001059 | 836.685 | -0.2814 | 836.966 | -0.2201 | 977.745 | 977.747 | 0.1073 | 2.82848 | 0.03794 |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
| Geof   | 977.965        | 0.00000823 | 836.814 | -0.3693 | 837.183 | -0.0035 | 977.962 | 977.964 | 0.00178 | 2.82848 | 0.00063 |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |
|        |                |     |           |     |         |        |        |       |    |      |     |

Figure 5. Comparison between ADXL345 and ADXL335.

The measurement results of gravity acceleration shows the presence of external factors and in the system that influence the measurement. The authors analyzed changes in the tool level, temperature, and position of the system in influencing the measurement of gravitational acceleration in the designed system. The value of temperature correlation to the measurement of gravity acceleration is 0.7 indicating a strong correlation. The value of the slope correlation of the system to the measurement of gravity acceleration is 0.3 indicating a low correlation. The correlation value of both factors shows the value of
0.78 which indicates that two factors interplay the measurement simultaneously. Both components of the temperature and tilt factor have a strong correlation to the drift correction value of the system.

4. Conclusion
This research shows that the ADXL345 sensor has data with a smaller deviation than ADXL335. The system which use ADXL 345 has average correction value of 0.19 Gal and 2.8 Gal of uncertainty value. The measurement result of this system has followed the pattern of the gravimeter A-10. Environmental noise i.e. the temperature and leveling system still influence in system causing noise.

Subsequent research can be developed using sensors that have better resolution and sensitivity to obtain measurements of gravity acceleration to miliGal or microGal orders. Another box material can used to minimize the environmental noise.

References
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