Al-Hisab: Journal of Islamic Astronomy | e-ISSN: 3046-8515
Vol.1, No.4, December 2024, pp. 189 - 196

Gravitational Acceleration Measurement Using Simple Harmonious Motion at The Observatorium Ilmu Falak

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Article Info

Article History
Received 16-09-2024
Revision 10-10-2024
Accepted 15-11-2024

Keywords:
Gravitation
Harmonic Motion
Observatory

ABSTRACT

The gravity in various places varies, although not very significant. The measurement of gravitational acceleration in the city of Medan, especially in the Falak Science Observatory of the University Muhammadiyah of North Sumatra, was carried out to determine the magnitude value of gravitational acceleration as a reference for activity in the observatory area. The measurements were made using a simple instrument, Mathematical Swing, through simple harmonic motion. The research method used is experimental research. Data collection was carried out directly. In this study, the stages passed are single measurements and repeated measurements. The measurement was carried out by measuring the harmonious motion of a mathematical swing moved by the same angle θ for each experiment, and the duration of the movement was calculated when it reached ten swings. The experiment was conducted on the OIF UMSU outdoor area on the 7th floor/rooftop of the UMSU's Postgraduate Building. From the research, a single measurement result is (9.463777 ± 0.009) m/s^2, and the repeated measurement method obtained the result gravitation is (9.59825 ± 0.001) m/s^2.

I. Introduction

Gravitational acceleration is the acceleration experienced by an Object due to the mass of itself. In an Object, gravity then affects and causes the Object to have weight [1]. In addition, gravity is also different for each place on the Earth's surface. Newton's Universal Law of Gravity shows that a simple equation is a motion almost towards the Earth's center or perpendicular to the ground surface [2]Gravitational acceleration is the acceleration of a material experienced by an object moving under the influence of attraction on the Earth's surface towards the Earth's core. Objects of any magnitude and mass that, if dropped, will move towards the Earth's surface because there is a pull to the Earth's core. The NASA GRACE mission [3] measures the Earth's gravity map, which shows gravity deviations on the Earth's surface, as shown in Figure 1.

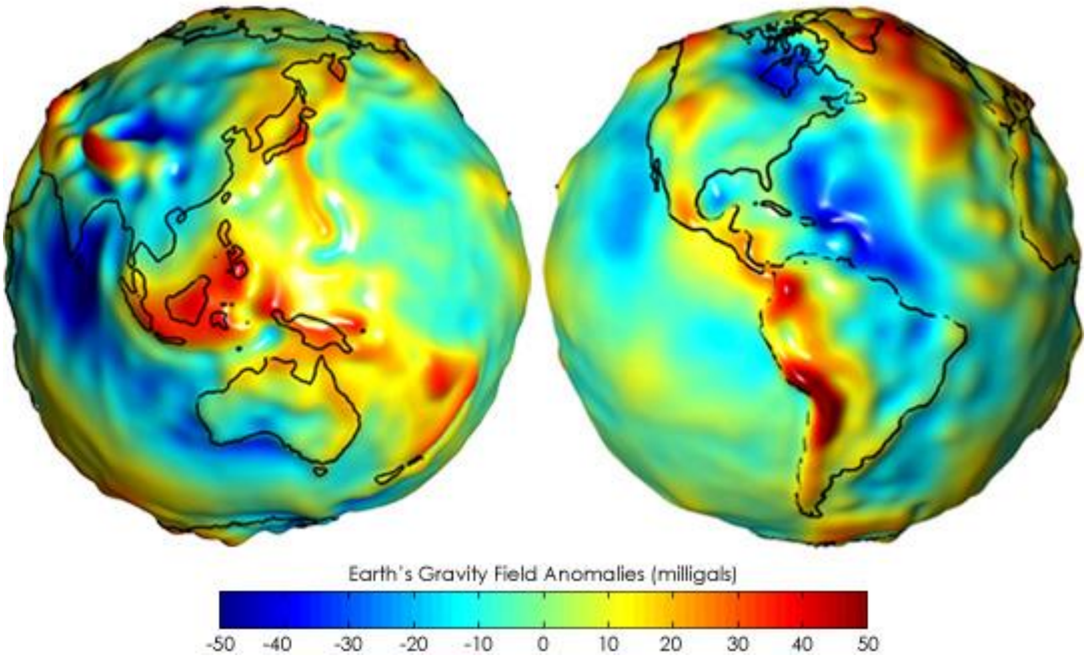

Figure 1. These "gravity anomaly" maps show where models of the Earth's gravity field are based on GRACE data. Red shows the areas where gravity is stronger than the smooth, standard value, and blue reveals areas where gravity is weaker.

Large measurements of gravity have been widely performed and applied in recent years. The magnitude of gravity is needed in several fields related to the position, height, and dimensions of objects on the Earth's surface. Its main application is to conduct investigations of structures/basins. Gravity measurements are also affected by many parameters such as topography, altitude from sea level, etc. Furthermore, it is reduced by applying appropriate corrections [4]. Gravity measurements have become a fundamental tool in various scientific and engineering disciplines, with significant advancements and widespread applications in recent years. Precisely measuring gravitational forces is essential in several fields, particularly those concerned with determining objects' position, height, and dimensions on the Earth's surface. These measurements are critical for a broad range of applications, including but not limited to geophysical surveys, infrastructure development, and environmental assessments. One of the primary uses of gravity data is to investigate subsurface structures and geological basins, as the variations in gravitational acceleration can reveal important information about the composition and physical properties of the Earth's crust. However, it is important to note that gravity measurements are subject to various influencing factors, such as local topography, altitude relative to sea level, and the Earth's dynamic surface conditions. These parameters can cause fluctuations in the observed gravitational values, making it essential to apply corrections to ensure accuracy and consistency in the data. For example, topographic and altitude corrections are commonly used to account for varying terrain and elevation effects. It allows for a more precise assessment of gravitational anomalies concerning Earth's surface.

Moreover, the magnitude of gravitational acceleration varies across different locations on the planet, with notable differences observed between the equatorial and polar regions. At the equator, the gravitational acceleration is approximately 9.78 m/s^2, whereas at the poles, it increases to around 9.83 m/s^2. This variation is primarily due to the Earth's slightly oblate shape and the centrifugal force generated by its rotation. As such, accurate gravity measurements are essential for understanding the Earth's physical characteristics and making informed decisions in the planning and design of engineering projects, where structural integrity and the ability to withstand gravitational forces are critical considerations.

Thus, the application of gravity measurements and the subsequent corrections for local environmental conditions play a crucial role in ensuring the reliability and relevance of the data in various scientific, industrial, and geophysical investigations. In everyday life, this gravitational phenomenon is very difficult to see because the interaction between objects and relatively small masses makes the gravitational force between the two very small, but we can see its effect on a broader view, such as the behaviour of celestial bodies and satellites that move on their trajectories due to the gravitational force [5]

On the Earth's surface, the magnitude of gravitational acceleration can be determined by several methods, including parabolic motion [2], a mass-spring system [6] and a pendulum system [7]. The magnitude of local earth gravity acceleration will be carried out in the research using a pendulum system or a mathematical swing [8]. The big difference in gravity in each area is due to the height of an area. Simple harmonic motion is the motion of an Object moving back and forth through a certain reference point (in this case, the equilibrium point) compared to the number of oscillations of the Object that occur in each constant unit of second. The motion exists because of the force that resists the change in the position of the Object to return to the equilibrium point, which is why simple harmonic motion occurs [9]

Simple harmonic motion is an Object that goes back and forth through a certain equilibrium point with the number of vibrations of objects in units of seconds [10], as shown in Figure 2. This motion oscillates at the equilibrium point due to the recovery force acting on the system. An example of simple harmonic motion can be found in one of the simple instruments, namely the mathematical pendulum. The pendulum swings continuously and back and forth [11]. A mathematical pendulum is a point that is hung on a light string that does not stretch and then swings so that it will undergo oscillation. The factors that affect it are the frequency, period, gravity and length of the string on the pendulum [12]. Experimentally, the magnitude of the Earth's gravitational acceleration can be determined by the mathematical oscillation method. An object is hung at a fixed point with a rope that is considered to be massless; then the rope is deflected at an angle θ to the vertical line [13].

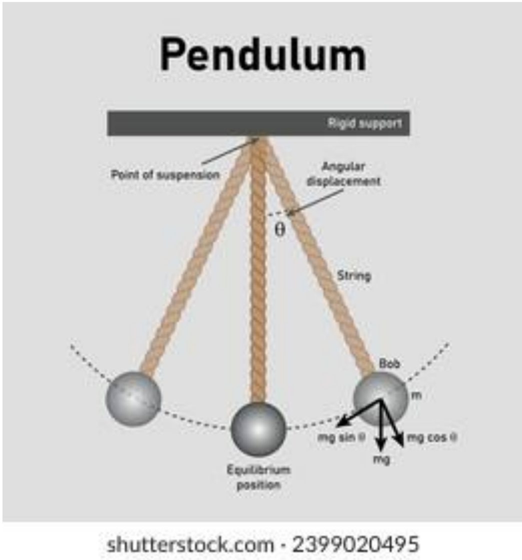

Figure 2. Simple Harmonic Motion of a Pendulum

The magnitude of the acceleration of gravity also needs to be known in some places, especially in big cities. Medan is one of the cities in the province of North Sumatra. It is located at 95° 43' East Longitude and 03° 34' N (North Latitude)[14]. However, the magnitude of the acceleration of gravity in the city of Medan, especially in the environment of the UMSU astronomy observatory, is not yet known. This research on the acceleration of gravity in the city of Medan is important to be used as a consideration in activities [15] and capacity in development when designing buildings and outdoor instruments, considering that there are limitations on the capacity of rooftop floors for public activities at the UMSU astronomy observatory [16]

II. Method

The research method used is experimental research. Data collection was carried out directly. In this study, the stages passed are (1) single measurement with a rope length of 30 cm and (2) repeated measurements with several rope lengths of the same and different. The measurement was carried out by measuring the harmonious motion of a mathematical swing moved by the same angle θ for each experiment, and the duration of the movement was calculated when it reached 10 swings.

To calculate the acceleration of gravity using equation (1) as follows [13]

$$g = 4\pi^2 \frac{l}{T^2} \qquad (1)$$

Next, to calculate the error using the equation (2):

$$S_g = \sqrt{\frac{\Sigma(g_i - g)^2}{N(N-1)}} \quad (2)$$

III. Results and Discussion

The data collection for this study was conducted in the UMSU OIF Planetarium room, where precise measurements were taken to investigate the relationship between rope length and swing period. Two primary analysis methods were employed: single measurement and repeated measurement. In the single measurement method, the rope length (l) and the swing period (T) were measured only once for each trial, providing initial data for analysis. For the repeated measurement method, the rope length was varied systematically, and each length was tested with a total of 10 swings to ensure the accuracy and reliability of the results. The full set of observations, including the measured values of rope length and swing period, are documented in Tables 1 and 2, respectively. These tables provide detailed information on the specific measurements and the corresponding periods recorded during each trial, offering a comprehensive overview of the experimental data for further analysis and interpretation.

Table 1. Single Measurement

Length (l)	Number of swings (n)	Time (t)	Gravity Acceleration (m/s^2)
30 cm	10	11.06 s	9,378403

Tabel 2. Pengukuran Berulang pada variasi panjang dengan n = 10

No	Length (l)	Time (t)	T Periode (s)	Frequency (Hz)	T2	Gravity Acceleration (m/s^2)
1	30 cm	11,01 s	1,101	1/1,101	1,212201	9,463777
2	30 cm	10,9 s	1,09	1/1,09	1,1881	9,655753
3	40 cm	12,64 s	1,264	1/1,264	1,597696	9,573786
4	40 cm	12,57 s	1,257	1/1,257	1,580049	9,680712
5	50 cm	14,1 s	1,41	1/1,41	1,9881	9,617222
Rata2						9,598250

The magnitude of the acceleration of the Earth's gravity g in the astronomy observatory measured by the mathematical pendulum swing is determined after the magnitude of the pendulum's swing period is known. The relationship between the periods is inversely proportional to the acceleration of Earth's gravity, as shown in equation (1). The result of the theoretical calculation of the Earth's gravity using Newton's Law of Gravity is g = 9.806 m/s2. In a study by [13] at the UAD Basic Physics Laboratory, Yogyakarta gave a large result of gravity in a single measurement method of (9,689 ± 0.009) m/s2, while repeated measurements obtained a gravitational magnitude at (9,832 ± 0.001) m/s2 [13] Meanwhile, according to [1] in Metro cities it is 9.86 ± 0.011 m/s^2.

The UMSU Astronomical Science Observatory experiments provided valuable data on the gravitational acceleration at the observatory's location. Using the single measurement method, the calculated value for gravitational acceleration was $g=(9.463777 \pm 0.009)\ m/s^2$. This result was obtained through a series of measurements of the rope length and swing period, using a simple pendulum setup to observe the period of oscillation under the influence of Earth's gravity. The small uncertainty of $\pm 0.009\ m/s^2$ indicates a relatively high degree of precision in the measurement, though it reflects the method's natural variability and experimental limitations. The repeated measurement method, which involved varying the rope length and performing multiple trials (10 swings for each variant), provided a slightly higher value for gravitational acceleration: $g=(9.59825 \pm 0.001)\ m/s^2$. This method allowed for greater accuracy by averaging the results of several repeated measurements, thus reducing random errors and providing a more reliable estimate of the gravitational acceleration at the location. The much smaller uncertainty of $\pm 0.001\ m/s^2$ reflects the increased precision achieved through multiple trials and careful results averaging.

When comparing these experimental values to those obtained by other researchers, [17] obtained an average gravitational acceleration of 9.796 m/s2 in gravity measurements using free-fall motion. By knowing the magnitude of this gravitational acceleration it can be used as a reference in several activities at OIF UMSU related to visiting game instruments such as water rockets, qibla pendulums, and information references to visitors in the environment of the Astronomical Observatory of the University of Muhammadiyah North Sumatra. In addition, the amount of gravity is a reference for the durability and maximum capacity of the number of visitors in the rooftop yard of OIF UMSU, such as in the canopy platform in the east and the capacity in the main courtyard, which is estimated to be a maximum of 150 people for mobile activities according to an interview with the civil engineering team of the UMSU graduate building.

IV. Conclusion

In the experiment of accelerating the Earth's gravity at the Astronomical Observatory of the University of Muhammadiyah North Sumatra, Medan gave results with various measurement methods; in a single measurement of g = (9.463777 ± 0.009) m/s2, the repeated measurement method gave the result g = (9.59825 ± 0.001) m/s2, the gravity obtained was lower than the theoretical gravity and received by other researchers in other locations. This value will be used as a reference and an excellent reference for the acceleration of gravity to visitors, variables in instruments related to acceleration and capacity in the environment of the Ilmu Falak Observatory, University of Muhammadiyah North Sumatra.

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