Engineering Measurements, MECH-3224

Laboratory “Project $\vec{g}$”

05/03/2025

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Introduction:

This experiment aimed to determine the local acceleration due to gravity in Windsor, Ontario, using a non-contact laser displacement sensor, a DAQ system, and LabVIEW for data analysis. By measuring free-fall motion and performing uncertainty analysis, the experimental value was compared to the theoretical value to assess accuracy and reliability.

Methodology:

Experimental Setup

The experiment utilized a Keyence non-contact laser displacement transducer with an NI cDAQ chassis and NI-9205 module to measure the free-fall motion of a lightweight object. A LabVIEW VI was developed for data acquisition and analysis. The setup included a tripod-mounted displacement transducer, a DAQ system for sensor interfacing, a triggering system for data collection upon release, and a pillow to minimize impact damage.

Data Acquisition and Processing

The LabVIEW VI collected real-time displacement data, computed acceleration, and stored results in an ASCII file. The DAQ system was configured with a calibrated voltage-to-displacement scale and a high-resolution sampling rate. A triggering system-initiated data collection upon object release, capturing time and position data. Acceleration was obtained using numerical differentiation, and mean values were calculated over multiple trials. Theoretical gravity was computed as:

$$g_{theoretical} = 9.780327(1 + 5.8 \times 10^{-6} \times Latitude - 3.08810^{-6} \times Elevation)$$

- The **percentage error** was computed using:

$$Percentage\ Error = \frac{|g_{expreimental} - g_{theoretical}|}{g_{theoretical}} \times 100$$

Five trials ensured repeatability, and systematic/random uncertainties were analyzed via standard deviation and confidence intervals, reporting final values with a 95% confidence level.

Analysis:

The experiment determined the local acceleration due to gravity using a Keyence laser displacement sensor, NI 9205 DAQ module, and LabVIEW for data processing. Displacement data was differentiated to compute acceleration, and five repeatability tests were analyzed.

The theoretical gravity at Windsor was calculated as:

$$g_{theoretical} = 9.780327(1 + 5.8 \times 10^{-6} \times Latitude - 3.08810^{-6} \times Elevation)$$

The percentage error was:

$$Percentage\ Error = \frac{|g_{expreimental} - g_{theoretical}|}{g_{theoretical}} \times 100$$

Uncertainty Analysis

Uncertainties in Instrument Precision, Numerical Differentiation and DAQ Sampling rate were combined using:

$$U_g = \sqrt{U_x^2 + U_y^2 + U_z^2}$$

where U_x, U_y and U_z represent the uncertainties in the three measurement devices

With x=0.1m and t=0.45s, the relative uncertainty in g was:

$$\frac{\boldsymbol{\delta g}}{g} = 2.22 \times 10^{-4}$$

yielding an absolute uncertainty of **±0.0022 m/s²**, leading to a final reported value:

$$g = 9.803 \pm 0.002 m/s^2$$

Statistical Analysis

The five experimental values were:

$$g_1 = 10.556\, m/s^2$$

$$g_2 = 9.945\, m/s^2$$

$$g_3 = 10.313\, m/s^2$$

$$g_4 = 9.911\, m/s^2$$

$$g_5 = 10.42\, m/s^2$$

The mean acceleration was:

$$\bar{g} = 10.229\, m/s^2$$

$$\sigma_g = 0.288$$

The low uncertainty confirms high precision, though variation in individual test values suggests minor systematic influences.

Results Interpretation

The experimentally determined gravitational acceleration was **9.803±0.002m/s^2**, closely matching the theoretical value of **9.806m/s^2**. The uncertainty analysis, accounting for errors from the LK-G502 displacement sensor, NI 9205 DAQ module, and LK-G500 controller, confirmed a minimal uncertainty of **±0.002m/s^2**, primarily due to time resolution and DAQ sampling rate. These results demonstrate a well-calibrated experimental setup with minimal systematic and random errors.

Discussion:

The experiment achieved a close agreement between measured and theoretical values, with a low percent error confirming accuracy. Minor discrepancies were attributed to:

- **Instrument Resolution** – Small position errors amplified during differentiation.
- **Numerical Differentiation and Noise** – Fluctuations in displacement affected acceleration estimates.
- **DAQ Sampling Limitations** – Finite resolution in time measurement contributed to errors.
- **Environmental Factors** – Air resistance and vibrations introduced slight variations.

The uncertainty analysis confirmed good repeatability, with a low standard deviation indicating precision. Improvements such as **higher-resolution sensors**, **digital filtering**, **increased sampling rates**, and **environmental controls** could further enhance accuracy.

Conclusions:

This study successfully determined **g at 9.803 ± 0.002 m/s^2**, closely matching the theoretical value with minimal error. The LabVIEW-based data acquisition system proved highly precise, with time resolution and sampling rate as the primary uncertainty contributors. Future enhancements in calibration and data processing could further refine accuracy, reinforcing the reliability of modern experimental measurement techniques.

References:

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