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Statistical analysis in engineering practices

Juan Andrés Serrano Granja
https://orcid.org/0009-0007-6582-1896
juan.serrano.granja@udla.eu.ec
Universidad de las Américas
Carrera de Ingeniería Electrónica y Automatización
Quito, Ecuador

Andrea Camila Manangón Palacios
https://orcid.org/0009-0001-1142-5800
andrea.manangon@udla.edu.ec
Universidad de las Américas
Carrera de Ingeniería Electrónica y Automatización
Quito, Ecuador

Thommy Elián Calderón Mera
https://orcid.org/0009-0009-9209-4932
thommy.calderon@udla.edu.ec
Universidad de las Américas
Carrera de Ingeniería Electrónica y Automatización
Quito, Ecuador

Daniel Adrian Sánchez Proaño
https://orcid.org/0009-0006-9849-2235
daniel.sanchez.proano@udla.edu.ec
Universidad de las Américas
Carrera de Ingeniería Electrónica y Automatización
Quito, Ecuador.

Alexander Javier Sánchez Vinueza
https://orcid.org/0009-0002-4917-0548
alexander.sanchez.vinueza@udla.edu.ec
Universidad de las Américas
Carrera de Ingeniería Industrial
Quito, Ecuador.

Roberto Andrés Zurita Molina
https://orcid.org/0009-0003-4428-7787
roberto.zurita.molina@udla.edu.ec
Universidad de las Américas
Carrera de Ingeniería Electrónica y Automatización
Quito, Ecuador.

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Abstract. - In this project, an engineering experiment was conducted utilizing measurements to estimate gravity analytically and graphically. This experimental approach aims to demonstrate the usefulness of engineering principles in verifying Earth's gravity values. Statistical methods were employed to enhance comprehension of the underlying concepts and ensure precise error estimation. The principal findings suggest that this engineering practice is an effective tool for evaluating gravity, with descriptive statistical analysis playing a pivotal role in presenting dependable and precise data.

Keywords: gravity estimation, statistical methods, error analysis, experimental engineering.

Análisis estadístico en prácticas de ingeniería

Resumen: En este proyecto se realizó un experimento de ingeniería utilizando mediciones para estimar la gravedad analítica y gráficamente. Este enfoque experimental pretende demostrar la utilidad de los principios de ingeniería para verificar los valores de la gravedad terrestre. Se emplearon métodos estadísticos para mejorar la comprensión de los conceptos subyacentes y garantizar una estimación precisa de los errores. Los principales resultados sugieren que esta práctica de ingeniería es una herramienta eficaz para evaluar la gravedad, en la que el análisis estadístico descriptivo desempeña un papel fundamental a la hora de presentar datos fiables y precisos.

Palabras clave: estimación de gravedad, métodos estadísticos, análisis de errores, ingeniería experimental.

I. INTRODUCTION

As a fundamental discipline for solving problems and creating innovative solutions, engineering encompasses widespread fields and applications [1]. From building infrastructure to designing technological devices, engineers employ a combination of scientific knowledge and practical skills to address different challenges in our modern society. Within the realm of engineering practice, measurement, and data analysis constitute fundamental pillars in the evaluation and enhancement of systems and processes [2]. Within this framework, statistics emerges as a critical instrument enabling engineers to extract meaningful insights from datasets, discern patterns, and formulate well-informed decisions.

Statistics have a critical role, particularly in estimating physical parameters, like Earth's gravity [4]. Precise determination of this value underpins numerous engineering applications [3], ranging from structural construction to satellite navigation. Accurate measurements are essential to guarantee the safety and functionality of the systems and devices that rely on them. Consequently, engineers prioritize experimental practices designed to measure and verify gravity values. These experiments not only aim to acquire accurate data but also to validate and refine the measurement methods themselves. Additionally, this approach fosters a deeper understanding of the factors influencing this fundamental physical phenomenon [5].

In this context, statistical techniques become essential for analyzing the data obtained during experimental practices. A proper application of statistical methods allows engineers to calculate not only average gravity values but also evaluate the precision of measurements, identify potential sources of error, and improve results obtained reliability. Therefore, this study focuses on spotlighting the importance of statistics in engineering practices, specifically in the measurement and evaluation of the gravity of Earth. Through the performance of controlled experiments and the statistical analysis of the data collected, the aim is to demonstrate the effectiveness of statistical methods in obtaining accurate and reliable results, which are fundamental for the development and successful applications of engineering solutions in various areas.

II. DEVELOPMENT

Engineering internships are essential for several reasons. Firstly, it provides students and professionals with the opportunity to apply the theoretical knowledge acquired in a practical and realistic environment. This allows them to understand better the concepts and theories learned in the classroom by seeing how they are applied in real-world situations [6]. In addition, engineering internships encourage the development of practical skills and technical skills. Students can work with tools, equipment, and technologies used in the industry, which helps them gain hands-on experience that cannot be gained simply through theoretical teaching. Another important aspect is that internships in engineering provide the opportunity to work in multidisciplinary teams and collaborate with professionals from different areas. This helps students develop communication, teamwork, and problem-solving skills, all of which are essential for success in the engineering field.

Additionally, internships are a great way to network and develop professional networks. Students have the opportunity to interact with industry professionals, meet potential employers, and learn about the latest trends and advancements in the engineering field. In this sense, it can be said that engineering internships are fundamental for the comprehensive training of students since they provide them with practical experience, help them develop technical and professional skills, and allow them to establish contacts in the industry.

A. Critical Thinking and Practical Activity in Engineering

Critical thinking is a fundamental skill in engineering and is actively exercised during the execution of practical activities. In engineering it is not enough to apply formulas or follow procedures; It is necessary to analyze, evaluate, and solve problems creatively and efficiently. Hands-on activities provide ideal environments to develop and put into practice critical thinking. During practical activities, engineers face real challenges that require careful evaluation of multiple variables and aspects associated with them. This involves questioning assumptions, identifying patterns, and generating innovative solutions to complex problems. Critical thinking manifests itself in the ability to analyze available information, discern between different options, and make informed decisions.

The hands-on activity also encourages collaborative problem-solving. Engineers often work in multidisciplinary teams where each member brings different perspectives and skills. This promotes the exchange of ideas, constructive debate, and the search for comprehensive solutions that contemplate multiple factors and considerations. Furthermore, practical activity in engineering offers the opportunity to experiment with different approaches and techniques. Engineers can test and validate their ideas through prototyping, testing, and simulation, allowing them to learn from their mistakes and continuously improve their skills and knowledge. This iterative process is critical to professional development in engineering and requires constant reflexive thinking to identify areas for improvement and optimization.

B. Statistics in Engineering Practice

Statistics plays a critical role in engineering practices at various levels. First, statistics provides tools for collecting, organizing, and analyzing data in the context of engineering projects. Engineers often face situations where it is required to collect data from experiments, tests, or field studies, and statistics provide them with methods to do so systematically and accurately. In addition, statistics are used to interpret the results of experiments and tests conducted during the development of engineering projects. It allows engineers to determine the reliability and accuracy of the data obtained, identify significant patterns or trends, and make informed decisions based on available information.

Statistics plays a crucial role when designing and analyzing experiments, helping engineers plan data collection efficiently, select representative samples, and determine the appropriate sample size to obtain meaningful and reliable results. In addition, descriptive and inferential statistics are used to model and predict the behavior of complex systems in engineering, allowing engineers a deep understanding of natural phenomena, optimize processes, and make informed decisions about the design and operation of systems and devices. The use of statistics in engineering practices is comprehensive and multifaceted. Also, it provides tools for data collection, analysis, and interpretation, thereby helping to find effective and efficient solutions in a wide range of engineering fields.

III. METHODOLOGY

The simple pendulum experiment was carried out considering different values of thread length, with the same mass, and three oscillations (Fig. 1) [7]. It shows a visual representation of the pendulum used in this engineering practice. This system was made by hand, so the thread used was cotton. The dough was made up of a rubber sphere with a radius of 3.2 cm.

Fig. 1. Visual representation of the simple pendulum.
Source: Generated by recraft AI

The data were analyzed using Excel software, licensed by the University of the Americas. The data were analyzed using Excel software licensed by the University of the Americas. Descriptive statistics were used to treat errors, and theoretical and experimental gravity values were estimated, as well as graphical analysis. In addition to the descriptive statistical analysis performed with Excel software, it is fundamental to highlight the crucial role of graphical visualization tools in engineering data interpretation [8][9]. Visual representation of results through graphs, diagrams, and tables makes it easier to identify trends, anomalies, and relationships between variables, helping engineers better understand the behavior of the systems studied and effectively communicate findings to colleagues, customers, and other stakeholders.

In addition, the use of statistics in engineering is not only limited to the analysis of experimental data but also extends to the design of experiments and process optimization. Engineers can apply advanced statistical techniques, such as factor experiment design or regression analysis, to investigate the influence of multiple variables on a system and identify optimal conditions that maximize performance or minimize costs in the production and operation of engineering systems. Through the strategic use of statistics in all these stages of the engineering process, informed decision-making and continuous improvement are promoted in the search for innovative and efficient solutions.

IV. RESULTS

Table 1 shows the data obtained in the experiment's first phase, showing that triple values have been taken for each length of the pendulum (length of the wire plus radius of the sphere). Additionally, the period values calculated from the number of oscillations are shown.

Table 1. Collected information in the experimental phase.

L(cm)	T1(s)	T2(s)	T3(s)	T^2
13.200	2.050	2.350	2.150	0.530
18.200	2.450	2.450	2.450	0.667
23.200	2.750	2.650	2.750	0.820
28.200	3.050	2.950	3.050	1.011
33.200	3.250	3.450	3.450	1.271
38.200	3.650	3.750	3.550	1.480
43.200	3.950	3.850	3.850	1.675
48.200	3.950	4.050	4.150	1.822
53.200	4.350	4.450	4.250	2.102
58.200	4.550	4.650	4.550	2.334
63.200	4.750	4.750	4.850	2.542
68.200	4.950	4.850	5.050	2.722
73.200	5.250	5.150	5.050	2.946

These data allowed us to estimate the analytical values of gravity, considering the general equation of the pendulum (1)

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

Where T is the period and l is the pendulum's length.

The data obtained in this experimental test are described in Table 2, where gravity values have been grouped and the frequencies have been estimated.

Table 2. Analytical Gravity Results.

$g(m/s^2)$	f_i
9.81-10.08	6
10.08-10.35	3
10.35-10.62	1
10.62-10.89	1
10.89-11.17	2

The values in the table represent ranges of measurements of acceleration due to gravity (g) in meters per second squared (m/s^2), along with the absolute frequency (f_i) of each range. We observed that most of the measurements (six of them) fall in the range of 9.81 to 10.08 m/s^2, suggesting that this is the most common range of measured values. This could indicate a consistency in measurements within this range, which is crucial for validating the accuracy and reliability of measurements. On the other hand, we noticed that ranges of higher g values have a lower absolute frequency, with only 1 or 2 measurements in each range. This may suggest that these higher values are less common in recorded measurements. These higher values may be associated with measurements made under specific conditions or with less accurate instrumentation, which could require greater attention in terms of calibration and quality control.

The analysis of this table suggests a distribution of g-values, which were centered around the range of 9.81 to 10.08 m/s^2, with some values scattered in higher ranges. This frequency distribution provides useful information about the variability of gravity measurements and can be useful in assessing the accuracy and consistency of the measurements made in the experiment.

Statistical analysis revealed that the mean value of T^2 is about 4.002, and the mean value of acceleration of gravity is about 10.342. On the other hand, the standard deviation for T^2 is around 0.832, and for gravity acceleration, it is about 0.656. The variance for T^2 is about 0.692, and gravity acceleration is about 0.430. We can note an inverse relationship between T^2 and acceleration of gravity, which is consistent with the expected physical relationship between the period of oscillation of a pendulum and the acceleration due to gravity. This is reflected in the negative correlation coefficient of -0.940, indicating a high inverse correlation between these two variables. The data showed that as the period of oscillation squared (T^2) increases, the acceleration due to gravity tends to decrease. This observation agrees with the known physical relationship between these two variables. Which also is observed in the negative correlation coefficient between them. The standard deviation provides a measure of the dispersion of the data around the mean, suggesting that the values of T^2 and gravity acceleration are relatively dispersed.

A. Statistical measures

The statistical data are presented in Table 3. It could be noted that the data do not show the mode. This is because all the values in this category are different.

Table 3. Statistical data.

Stocking	Standard deviation	Variance
2.183	0.153	0.023
2.450	0.000	0.000
2.716	0.058	0.003
3.016	0.058	0.003
3.382	0.115	0.013
3.649	0.100	0.010
3.883	0.058	0.003
4.049	0.100	0.010
4.349	0.100	0.010
4.583	0.058	0.003
4.783	0.058	0.003
4.949	0.100	0.010
5.149	0.100	0.010

Table 4 shows other statistical parameters. It can be noted that the dispersion given by the information is relatively small.

Table 4. Length, time, and gravity dispersion measurements.

	Variance	Standard deviation	Variation range
Lengths(cm)	0.03791666667	0.1947220241	0.6
Time(t)	0.9322089947	0.9655097072	3.2
Gravity (m/s^2)	0.19328	0.4396362132	1.12

The analysis of the simple pendulum is a cornerstone of engineering for several reasons. Due to its simplicity and accuracy, it serves as a fundamental model for understanding a vast array of physical phenomena and dynamical systems. This makes it an invaluable tool for studying concepts like oscillation, simple harmonic motion, and system dynamics. Furthermore, the principles derived from the simple pendulum analysis find application in numerous engineering disciplines. These include the design of structures, optimization of suspension and damping systems, and calibration of measuring instruments. Perhaps most importantly, the simple pendulum's principles are critical for designing control systems that regulate position, speed, and acceleration in mechanical and robotic devices, ensuring their precise and efficient operation.

Moreover, the simple pendulum transcends its role as a theoretical model by enabling the measurement of gravitational acceleration and its variation with both altitude and geographical location. These measurements are crucial in diverse engineering fields, ranging from navigation and geophysics to structural engineering and cartography. This versatility elevates the simple pendulum to a powerful tool in the engineer's toolbox, applicable to understanding core concepts, designing systems and structures, controlling processes, and even performing precise gravity measurements. Its reach extends across numerous engineering disciplines, where it significantly contributes to the development and refinement of innovative and efficient solutions.

CONCLUSIONS

Most acceleration measurements due to gravity (g) fall within the range of 9.81 to 10.08 m/s^2, suggesting consistency in measurements made in this range. This consistency is relevant for validating the accuracy and reliability of measurements, indicating fine quality control in the measurement process. On the other hand, higher acceleration values due to gravity have a lower absolute frequency, suggesting that these values are less common in the measurements made. This may be associated with measurements made under specific conditions or less accurate instrumentation. This finding highlights the importance of calibration and quality control in gravity measurements.

The distribution of gravitational acceleration measurements reveals a clustering around 9.81 to 10.08 m/s^2, with outliers scattered at higher values. This spread offers valuable insights into the measurement variability and can be used to assess the experiment's accuracy and consistency. Furthermore, statistical analysis unveils a robust inverse correlation: as the squared oscillation period (T^2) increases, the measured gravitational acceleration tends to decrease. This aligns perfectly with the expected physical relationship between these variables. This finding deepens our understanding of the link between a pendulum's oscillation period and gravity, potentially leading to new applications in various engineering fields.

These results underscore the critical role of meticulous accuracy and robust quality control in engineering gravity measurements. Consistent measurements within a defined range, contrasted with outliers beyond it, emphasize the necessity of precise instrument calibration and rigorous control of experimental conditions to guarantee reliable data. Furthermore, the robust inverse correlation between the squared oscillation period (T^2) and gravitational acceleration underlines the importance of grasping and accounting for variable interactions in engineering. This finding highlights the power of statistical analysis and mathematical modeling to unveil significant relationships between parameters, offering invaluable insights for design, optimization, and informed decision-making across a broad spectrum of engineering applications.

REFERENCES

[1] J. J. Solaz Portolés & V. Sanjosé López, «El papel del péndulo en la construcción del paradigma newtoniano», vol. 10, Barcelona, 1992, pp. 95-100. 2019.
[2] F. Díaz Céspedes, «El primer experimento de Galileo Galilei,» Letralia, 4 4 2016. [En línea]. Available: https://letralia.com/sala-de-ensayo/2016/04/04/el-primer-experimento-de-galileo-galilei/. [Último acceso: 5 1 2021].
[3] A. Hernández-Fereira. «Ampliación de las posibilidades del sistema hpci-1 para el estudio del movimiento de un péndulo simple real en oscilaciones pequeñas», *Revista Cubana de Física*. Vol. 38, Num. 112. Pp. 112-119. 2021.
[4] R. Espíndola-Heredia & G. del Valle, G. Hernández. «Numerical study of pendulums: From the simple pendulum approximation to the damped physical pendulum with variable mass». *Latin America of Journal Physics Education*. Vol, 2012, vol. 6, no 2, p. 202.
[5] F. M. Fernández. «Perturbation theory in classical mechanics». Europe. *Journal of Physics*. 18, 436. 1997. http://doi.org/10.1088/0143-0807/18/6/005.
[6] A. Zamalloa, G. Cruz, J. Camani, V. Almanza, B. Gonzales, D. Villa & B. Warthon. «Use of Tracker software for teaching distance physics laboratories: Demonstration of error reduction in the simple pendulum». arXiv:2306.06352 [*Physics Education*]. https://doi.org/10.48550/arXiv.2306.06352.
[7] A. Berazain & L.D. Prieto. «¿Cómo impulsar un péndulo? el ejemplo del botafumeiro». *Revista Cubana de Física*. 35, E48. 2018.
[8] G. A. Eguez, D.B. Campuzano, K. M. Katherin & M. T. Velasco. «The pendulum of the hand of statistics and engineering». *Athenea Engineering Sciences Journal*, 4(11), 15-22. 2023.
[9] C. Beainy, E. Caceres, L. Quintero, T. Molina & O. Amezquita. «Instrumento para el aprendizaje del movimiento armónico simple». *South Florida Journal of Development*. 2(1), 839-851. 2021.