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Article

Development of a graphical interface for simulating dynamic systems using octave for the creation of digital educational materials

Desarrollo de interfaz gráfica para la simulación de sistemas dinámicos usando Octave para la creación de material didáctico digital

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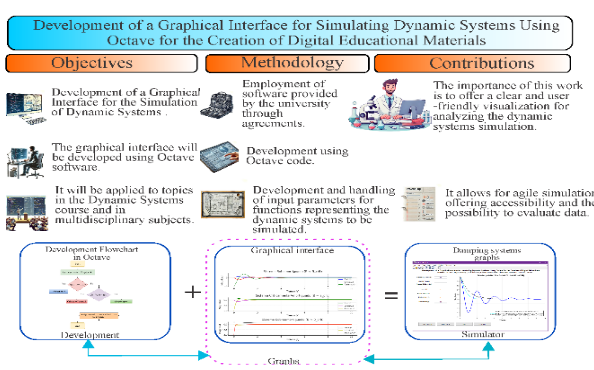
Abstract

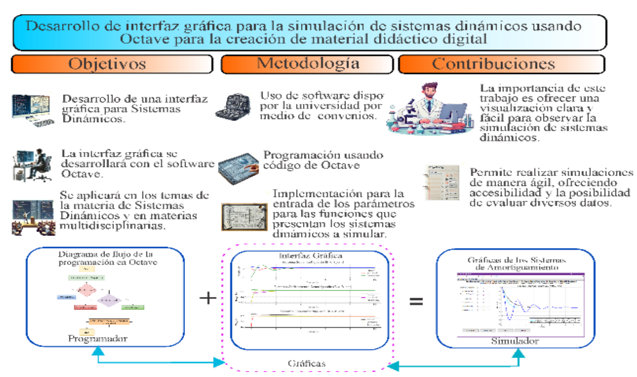
This work describes the development and implementation of a graphical interface for the simulation of dynamical systems, employing the free Octave platform. To achieve this, a user environment was designed to allow the input of initial conditions and specific parameters associated with elements such as the damper, the spring, and the force applied to the mass. In addition, functions were programmed to provide graphical representations for analyzing the behavior of the dynamical system, resulting in an interactive and intuitive environment. This resource facilitates the creation of digital educational materials by offering a clear, user-friendly tool for teaching and learning in various areas related to dynamical systems. Consequently, it fosters a deeper understanding of physical phenomena and contextualizes theoretical models, thereby enhancing the academic development of students in the Electrical-Electronic Engineering program at the Aragon School of Higher Studies, part of the National Autonomous University of Mexico.



Simulation, Octave, Interface

Resumen

El presente trabajo describe el desarrollo e implementación de una interfaz gráfica para la simulación de sistemas dinámicos, empleando la plataforma Octave siendo este un recurso gratuito. Para ello, se diseñó un entorno de usuario que permite ingresar condiciones iniciales y parámetros específicos relacionados con elementos como el amortiguador, el resorte y la fuerza aplicada sobre la masa. Asimismo, se programaron funciones enfocadas en la representación gráfica para el análisis del comportamiento del sistema dinámico, brindando un entorno interactivo e intuitivo. Este recurso promueve la generación de material didáctico digital, al ofrecer una herramienta clara y de fácil acceso para la enseñanza-aprendizaje en distintas áreas relacionadas con los sistemas dinámicos. Con ello, se favorece la comprensión profunda de fenómenos físicos y la contextualización de los modelos teóricos, contribuyendo a fortalecer la formación de los alumnos de la Carrera de Ingeniería Eléctrica Electrónica de la Facultad de Estudios Superiores Aragón UNAM.



Simulación, Octave, Interfaz

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

In recent years, the advancement of digital technologies has significantly transformed teaching and learning methods in various engineering disciplines, especially in the field of dynamic systems. The use of open-source software, such as Octave, has facilitated the integration of accessible computational tools, enabling students to visualize, analyze, and simulate complex phenomena interactively. The incorporation of graphical user interfaces (GUIs) not only improves the theoretical understanding of concepts but also optimizes the learning process by offering a practical and visual experience of physical and mathematical systems.

This interdisciplinary approach, combining applied mathematics, engineering, and digital tools, is revolutionizing the way fundamental principles of dynamics and control systems are taught, opening up new opportunities for the academic training of future engineers. The following explores the main advantages and applications of these digital tools in the context of teaching dynamic systems, highlighting their impact and potential in the training of Electrical and Electronic Engineering students.

The development of graphical interfaces for simulating dynamic systems, using open-source software platforms like Octave, has revolutionized the teaching of differential equations and the understanding of complex phenomena. By integrating interactive numerical simulations into computational tools, they facilitate the visualization and analysis of the temporal evolution of systems, resulting in optimal mathematical interpretation. These graphical interfaces enhance the accessibility and functionality of educational resources, optimizing intuitive interaction with underlying mathematical models and fostering the acquisition of analytical and programming skills [Avila et al., 2021].

Additionally, the design of digital platforms, based on semiotic principles, has transformed human-computer interaction, making learning more inclusive and efficient through dynamic and visual representations [González & Victoria, 2020]. Although, in other fields such as medical diagnosis, the integration of graphical interfaces with mathematical-computational algorithms has proven effective, technical challenges remain, which open up opportunities for future research [Osorio et al., 2019]. By integrating tools in the context of Electrical and Electronic Engineering, this particular work fosters more accessible and deeper teaching of dynamic systems, as it contributes to strengthening the training of students at FES Aragón UNAM.

The open-source software Octave has proven to be a versatile tool in solving complex mathematical problems, frequently used in areas such as matrix calculations, integral calculus, and solving differential equations.

According to Adra et al., [2003], Octave is capable of addressing engineering problems such as heat conduction, Laplace equations, and temperature distributions, standing out for its precision and ability to generate results comparable to those of other commercial software. In a similar vein, Banhakeia [2019], in her thesis, highlights Octave's potential in solving problems related to real functions, differentiation, integration, matrix operations, and linear systems, demonstrating its ability to replace proprietary software like Wolfram Mathematica. Additionally, Expósito [2021], in his presentation for the "Applied Computing" course, emphasizes how Octave can be used both as a basic calculator for simple operations and for more advanced calculations, with key examples such as complex number manipulation and vector and matrix management.

Furthermore, he highlights the importance of user interaction and program design from scratch, covering everything from the use of functions to the implementation of control structures such as loops and conditionals to facilitate data analysis and results. In this way, Octave is presented as a comprehensive educational tool for solving mathematical problems and their graphical representation, providing an efficient and cost-effective alternative in the context of Electrical and Electronic Engineering.

The software GNU Octave, as conceptualized by Eaton et al., [2008]. is presented as a high-level language designed for performing mathematical computations, comparable to MATLAB, making it a flexible and accessible option for computational simulations and data analysis. Its versatility in addressing both linear and nonlinear problems strengthens its utility in modeling dynamic systems across various engineering fields.

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Octave facilitates the teaching of mathematical concepts and their application in engineering, as seen in the work of Flores et al., [2024], which shows how the software was applied in teaching Calculus to Environmental Engineering students. In his study, both meaningful and mechanical learning approaches were used, combining theoretical classes and computer lab sessions to solve analytical and numerical exercises, allowing for the comparison of results and evaluating its pedagogical impact. On the other hand, Aguilar [2022], in his article, presents the basic commands of Octave and its usefulness in solving systems of linear equations, structural analysis, automatic control, and signal processing, which are key areas of engineering.

These examples, ranging from programming differential equations to obtaining the roots of polynomials, are crucial for Electrical, Mechanical, and Telecommunications Engineering. Furthermore, in Deutsch [1972]. Study on octave generalization, the applicability of Octave in signal processing is highlighted, as demonstrated by its use in manipulating and analyzing data in dynamic simulations, reinforcing its potential to analyze physical phenomena and complex dynamic systems in various branches of engineering. These studies show how Octave can be integrated into both the teaching and practical application of engineering-related problems, supporting both learning and solving real-world issues across multiple disciplines.

In the field of computer vision and image processing, Kovesi [2010] highlights how Octave, by integrating advanced MATLAB functions, can be used to perform complex analyses such as image segmentation and feature detection, facilitating its application in dynamic systems and optimization of dynamic computing experiments. Furthermore, Alberts & Dorofee [2001], in his work on security risk assessment, introduces a methodological approach that, although not directly related to Octave, presents principles applicable to security in computational simulation environments, suggesting that these approaches could be extrapolated to the development of dynamic models and their simulation on platforms like Octave. These publications demonstrate how Octave operates effectively when applied in advanced fields of image processing and risk analysis, expanding its potential in simulating and modeling complex dynamic systems, beyond its traditional use in mathematical calculations.

Octave has been recognized as an essential tool for solving mathematical problems and performing numerical calculations, especially in modeling physical systems. According to Eaton et al., [2025], being an open-source software compatible with MATLAB, Octave provides an accessible and efficient option for the numerical integration of differential equations, optimizing computational solutions across various engineering fields. Solving these equations aims to determine the "Primitive Functions," which are fundamental in solving differential equations and have key applications in dynamic system simulation [Romo, 2005].

The concept of damping, described by Huirse [2015], is essential in mechanical systems, where a system's ability to dissipate kinetic energy prevents conditions of high vibration and instability, as occurs in resonance systems. These principles are fundamental to understanding how dynamic systems respond to stimuli and how Octave can be used to model, simulate, and analyze these complex behaviors in engineering. Viscous damping is one of the most widely used mechanisms in vibration analysis, particularly when a mechanical system vibrates in a fluid medium such as air, gas, water, or oil, where the resistance of the fluid dissipates the system's energy. In this context, the amount of energy dissipated depends on various factors, such as the size and shape of the vibrating body, the viscosity of the fluid, the vibration frequency, and the velocity of the body.

Due to analytical simplifications, viscous damping is frequently used in dynamic idealizations [Hermes, 2023]. Regarding damping systems, they are classified as overdamped, critically damped, and underdamped. An overdamped system has a damping coefficient greater than the spring elasticity constant k, which prevents oscillatory motion due to high damping. A critically damped system is characterized by returning to its static equilibrium position without oscillations, and any change in the damping force makes it either an overdamped or underdamped system [Cornejo et al., 2016]. In contrast, an underdamped system allows for oscillatory motion before returning to its equilibrium position, where mechanical systems consist of solid elements that transform or transmit motion through forces, allowing them to perform work and movement in various engineering applications [Cortes, 2019].

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These concepts are key to understanding how dynamic systems respond to stimuli and how they can be efficiently modeled and simulated on platforms like Octave for use in engineering.

One of the most common phenomena in kinematics is oscillatory motion, which can be observed in the vibration of a spring when released after being compressed or stretched, generating a repetitive and predictable displacement known as oscillation [Ardila et al., 2009]. Newton's Second Law states that the force applied to an object is directly proportional to the object's mass and the acceleration it experiences. Additionally, Hooke's Law states that the force exerted by a spring is proportional to its elongation.

This relationship allows for the establishment of a second-order differential equation that describes the behavior of the mass-spring-damper (MRA) system. The solution to this equation provides valuable information about the spring's elasticity constant, which helps understand its behavior under different applied forces [Arcila & Caicedo, 2023]. In the case of the MRA system, which involves a mass mmm, a spring constant *K*, and a damper with a viscous damping coefficient, the equation governing its behavior, in the absence of external forces, is: $m\frac{d^2x}{dt^2} = -B\frac{dx}{dt} - kx,$ here x is the displacement of the mass from its equilibrium point. The negative sign in the equation reflects the opposing action of the spring and the damper on the movement [Escalante et al., 2016].

This MRA system remains a central topic in the study of mechanical vibrations, being a fundamental model in simulating and analyzing dynamic phenomena in engineering.

The development of interactive programs involves creating graphical interfaces that allow the user to input data and receive results, which enhances interaction with the software. In many programs, like those used in Octave, user-provoked events trigger specific actions, optimizing the user experience [Sánchez, 2021].

Octave is an interactive computational tool designed for performing numerical calculations, particularly in matrix handling, and it originated as software for chemical engineering courses at the University of Texas.

Its main features include vector and matrix calculations, complex arithmetic, statistical analysis, and control system design [Chan, 2018]. As a free alternative to MATLAB, Octave offers an interactive interpreter that allows for executing numerical commands, such as solving linear systems, nonlinear problems, and initial value problems, facilitating the resolution of complex mathematical problems [Telesford, 2018].

The use of differential equations is essential to describe the behavior of dynamic systems, where the order of the highest derivative and the degree of the equation are key factors in solving these problems, as the solution to a differential equation provides a function that satisfies the conditions of the modeled system [Pozo et al., 2015].These principles allow Octave to be a powerful tool for simulating and analyzing dynamic systems in engineering.

Octave is widely used in engineering and applied sciences for its ability to perform calculations with vectors, matrices, and complex numbers, in addition to generating 2D and 3D plots [Chávez, 2018]. Octave has proven to be more reliable than other software like Python in terms of the number of iterations required to meet error criteria in simulations, though it presents higher processing times compared to Matlab and Python. However, its ability to perform simulations with high precision and reliability, especially in scenarios that require exact results, makes it invaluable in scientific and engineering applications where the accuracy and reliability of results are paramount.

According to Guedes and Nepomuceno [2019], this combination of reliability and precision, even with longer execution times, underscores its relevance in simulating and modeling complex dynamic systems in various engineering fields.

García [2025] states that it is possible to propose interactive environments to facilitate the learning of complex simulation-related concepts, such as the generation of pseudo-random numbers and statistical testing. Through educational software with a graphical user interface, students can observe the behavior of various algorithms in real time, allowing them to analyze results and strengthen their theoretical understanding.

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This becomes a comprehensive educational strategy that links theory with practice.

For his part, Capacho [2025] highlights the importance of modeling and simulation as key strategies for strengthening learning in engineering and robotics. Various approaches have demonstrated that, whether through the analysis of dynamic systems such as the mass-spring-damper, the generation of pseudo-random numbers, or the development of autonomous vehicles in structured environments, the use of accessible technological tools improves the understanding of complex concepts.

Environments such as Octave, pseudocode, or platforms like Arduino make it easier to translate physical and computational models into visual and interactive experiences. Meanwhile, Mármol [2025] explains that the dynamic analysis of physical systems necessarily begins with a rigorous mathematical formulation based on fundamental principles—unlike proposals focused on immediate visualization or the development of basic algorithmic skills. His approach requires students to deeply understand the differential equations governing the system, as well as the boundary conditions and physical parameters involved.

While promoting visual interaction with dynamic phenomena through a graphical interface, it starts from the premise of facilitating learning using accessible computational tools. However, without necessarily delving into the physical-mathematical origin of the model, the author asserts that conceptual mastery of the structural elements of the mass-spring-damper system and its mathematical relationships is essential before proceeding with its simulation.

This ensures that the student does not merely visualize a result, but can interpret, validate, and adjust the model with scientific grounding.

Objective

Develop and implement an interactive graphical interface in Octave for the simulation of dynamic systems, specifically the mass-spring-damper system (MRA).

This tool will facilitate the creation of digital teaching materials for the teaching of physical phenomena and theoretical models in the Electrical and Electronic Engineering program at the Faculty of Higher Studies Aragón, UNAM. The system will allow students to apply programming knowledge in open-source software like Octave, intuitively solving fourth-order ordinary differential equations and using the ODE45 adaptive step solver. Additionally, it will provide graphical representations of position, velocity, and acceleration, thereby improving the teaching-learning process.

Hypothesis

At the higher education level, the vast majority of students in the Electrical and Electronic Engineering program do not have access to software licenses due to their high cost. As a result, they tend to resort to open and free software. Implementing an interactive graphical interface in Octave for simulating dynamic systems and the automatic generation of reports in PDF format, which integrates mathematical analysis and simulation results, will enable students to intuitively and effectively understand the theoretical concepts associated with the MRA systems. This will facilitate the simultaneous visualization of position, velocity, and acceleration, thereby strengthening the teaching-learning process and facilitating the creation of digital teaching materials that contextualize theoretical models.

Methodology and Development

In the Electrical and Electronic Engineering program, the analysis of MRA systems is of great importance, as it is a commonly used model to describe vibration and damping phenomena in mechanical systems, as shown in Figure 1.

Box 1

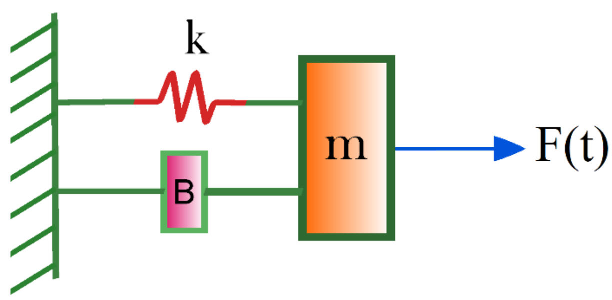

Figure 1
In the diagram, the mass m is the object being displaced in the system, which has inertia and responds to the applied force.

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The spring is represented by the red spiral line, and it exerts a restoring force on the mass when it moves from its equilibrium position. Representing Hooke's Law, the spring's force is proportional to the elongation x, that is , $F = -kx$, where k is the spring constant and x is the displacement of the mass.

The damper, represented by the pink block labeled "B," dissipates energy from the system, typically in the form of heat, by reducing the amplitude of the vibrations. In this case, the damping force is proportional to the velocity of the mass, and is represented as $F = -B\dot{x}$, where B is the damping coefficient and $\dot{x}$ is the velocity of the mass.

The blue arrow pointing to the right indicates an external force applied to the system, which may be a force that drives or moves the mass. This is an important factor in analyzing how the system responds to external forces, where the system is fixed at one end, as represented by the green line connecting the spring and the damper. It is indicated that the system is restricted in that direction, allowing the mass to move forward and backward. Figure 2 shows the representation of a block diagram of an MRA system with an analysis of its components in terms of inputs and outputs.

Box 2

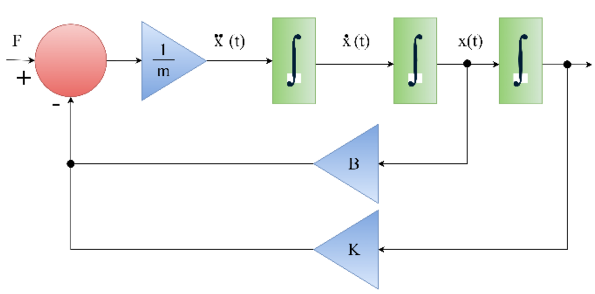

Figure 2

In this diagram, the analysis of dynamic systems is shown, where differential equations are used to model the evolution of displacement

This type of model is generally used to study the behavior of vibrations, damping, and resonance in mechanical systems. The system receives an external force $F(t)$, which acts on the system, and this is the input signal to the system, representing an applied force to the mass at a given moment, allowing us to observe the dynamics of the mass.

The block with $\frac{1}{m}$ indicates the relationship between the applied force and the acceleration the mass experiences, which, according to Newton's second law, is related to acceleration as $a = \frac{F(t)}{m}$.

The result of this operation is the mass's acceleration $\ddot{x}\ (t)$. The damping block B shows how the system's velocity $\dot{x}\ (t)$ influences the damping force. The damping force $F(t)$ is proportional to the velocity $\dot{x}\ (t)$, according to the equation: $F = -B\dot{x}$. This force opposes the movement and dissipates energy from the system.

The spring block k represents the relationship between the displacement $x(t)$ of the mass and the force exerted by the spring, following Hooke's Law, which provides a restoring force to the system. The blocks with $\dot{x}(t)$ y $x(t)$ indicate that the system has two outputs: the velocity $\dot{x}(t)$ and the displacement $x(t)$ of the mass.

These outputs are the result of the system's dynamic behavior as the external force $F(t)$ interacts with the mass, spring, and damper. Signals flow from the input force $F(t)$ towards the MRA inversion blocks and finally to the displacement and velocity outputs. This shows how both internal and external forces affect the system and how the signals are transmitted through the model.

To analyze the dynamic behavior of the MRA system, we use the second-order differential equation that describes the motion of the mass under the influence of the applied force, spring constant, and damping, as shown in Equation 1:

$$m\ddot{x}(t) + B\dot{x}(t) + kx(t) = F(t) \qquad [1]$$

Where: m is the mass of the object. B is the damping coefficient, k is the spring constant, x(t) is the position of the object at time t, and F(t) is the applied external force.

Rearranging the differential equation, we have:

$$\ddot{x}(t) = \frac{1}{m}[F(t) - B\dot{x}(t) - kx(t)] \qquad [2]$$

This system can be analyzed in terms of its damping behavior.

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Another way to represent the homogeneous differential equation:

$$m\frac{d^2x}{dt^2} + B\frac{dx}{dt} + kx = 0 \quad [3]$$

If the exponential solution is assumed $x_h(t) = e^{rt}$ deriving and substituting in Equation 2 we have:

$$mr^2e^{rt} + Bre^{rt} + ke^{rt} = 0 \quad [4]$$

If we factor the exponential, we have Equation 5:

$$e^{rt}(mr^2 + Br + k) = 0 \quad [5]$$

If we divide the entire equation by the inverse of the exponential of the previous equation we have:

$$mr^2 + Br + k = 0 \quad [6]$$

Having the quadratic equation as shown above we can obtain the solution r:

$$r = \frac{-B \pm \sqrt{B^2 - 4mk}}{2m} \quad [7]$$

If the system is underdamped, the square root is negative, so the solutions are complex:

$$r = \alpha \pm j\,\omega \quad [8]$$

$$r = \frac{-B}{2m} \pm j\sqrt{\frac{4mk - B^2}{4m^2}} \quad [9]$$

$$r = \frac{-B}{2m} \pm j\sqrt{\frac{k}{m} - \alpha^2} \quad [10]$$

$$\alpha = \frac{-B}{2m} \quad [11]$$

$$\omega = \sqrt{\frac{k}{m} - \alpha^2} \quad [12]$$

$$xh(t) = e - \alpha t(C_1 cos(\omega t) + C_2 sin(\omega t))$$

Damping ratio:

$\alpha = \frac{-B}{2m} \rightarrow$ Damping ratio:

Indicates how quickly the oscillation loses energy.

If B is large, the system damps faster.

If B=0, there is no damping, and the system oscillates indefinitely.

$\omega = \sqrt{\frac{k}{m} - \alpha^2} \rightarrow$ Damped natural frequency

It is the actual oscillation frequency when there is damping.

If B=0, then $\omega = \sqrt{\frac{k}{m}}$, which is the undamped natural frequency.

If B is large, the system oscillates more slowly or stops oscillating if $B^2 \geq 4mk$.

In Table 1, the types of damping are shown. Underdamped occurs when the damping coefficient B is smaller than the critical value B_{crit}. In this case, the system oscillates and shows a decrease in the amplitude of the oscillations over time.

Critically Damped: The system has exactly the right amount of damping at the critical value B_{crit}, which allows it to return to equilibrium as quickly as possible without oscillating. Overdamped: In this case, the damping coefficient B is greater than B_{crit}, causing the system to stabilize, but more slowly and without oscillations.

Box 3

Table 1

The image shows a table describing the types of damping and their relationship to the damping coefficient B and the form of the roots of the characteristic equation associated with the mass-spring-damper (MRA) system.

Damping Type	Condition (B)	Shape of the Roots
Underdamped	B < Bcrit	Complex conjugate roots
Critically Damped	B = Bcrit	Matching real roots
Overdamped	B > Bcrit	Distinct real roots

Table 2 shows the types of damping, which can be visualized in the first column and starts with an Underdamped system, meaning that the amplitude of the oscillations decreases over time due to the damping. Critically Damped: The system returns to equilibrium without oscillations, meaning the system returns to equilibrium as quickly as possible without overshooting the equilibrium position.

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Overdamped: The system settles without oscillations, but more slowly than in the critically damped case.

Box 4

Table 2

The table details the damping coefficient, angular frequency, and behavior for three different types of damping in a mass-spring-damper (MRA) system.

Damping Type	Damping Coefficient (α)	Angular Frequency (ω)	Behavior
Underdamped	$\alpha = \frac{B}{2m}$	$\omega = \sqrt{\frac{k}{m} - \alpha^2}$	Damped oscillations
Critically Damped	$\alpha = \frac{B}{2m}$	$\omega = \omega_o$ $\omega = \sqrt{\frac{k}{m}}$	Return to equilibrium without oscillations
Overdamped	$\alpha = \frac{B}{2m}$	$\omega = \sqrt{\frac{k}{m} - \alpha^2}$	Stabilization without oscillations

Figure 3 shows the flowchart that describes an interactive process to simulate and analyze a mass-spring-damper system based on the damping coefficient B. Depending on its value, the system is classified as underdamped, critically damped, or overdamped. The process allows visualization of how the mass, spring, and damper interact under different damping conditions.

Box 5

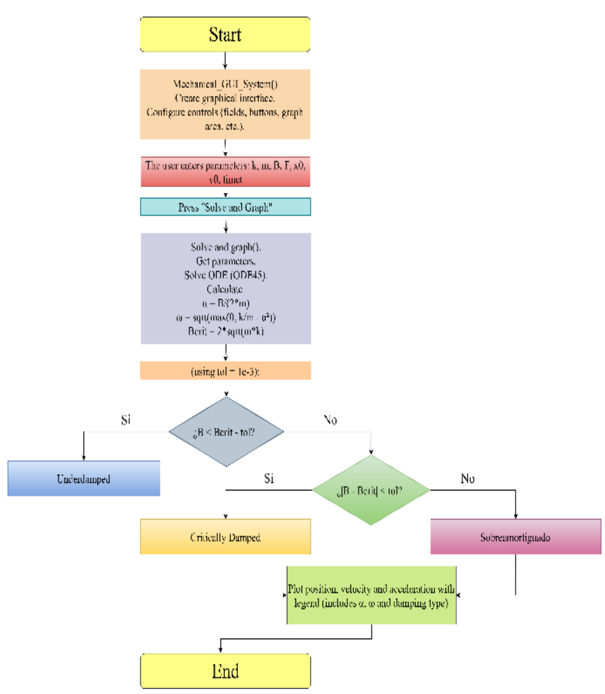

Figure 3

The diagram shows the initialization of a graphical system in Octave, which configures the graphical interface with controls (fields, buttons, area for graphics, etc.).

Figure 4 shows the flowchart describing how to classify a mass-spring-damper system based on its damping coefficient B, determining whether the system is underdamped, critically damped, or overdamped.

Depending on the classification, the system will plot the position, velocity, and acceleration of the system, along with the legend showing the damping type and other parameters such as α and ω.

Box 6

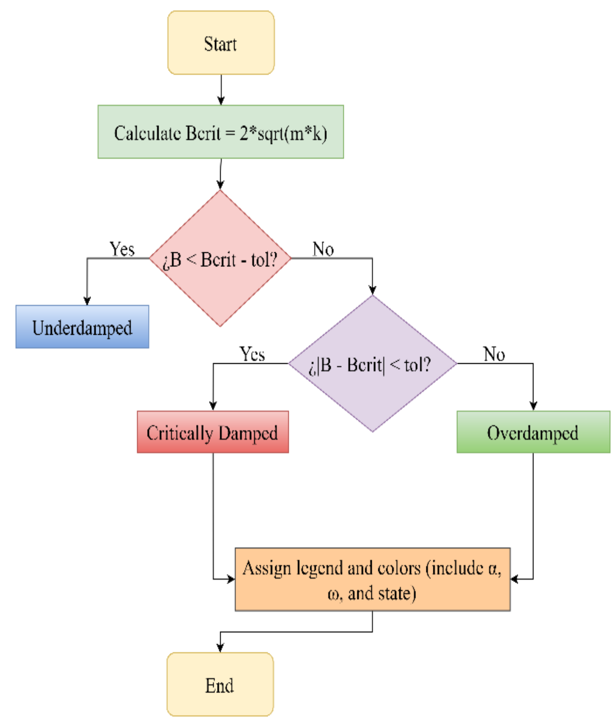

Figure 4

The flowchart describes the process of classifying a mass-spring-damper system based on its damping coefficient B.

The graphical interface developed in Octave allows users to input key parameters to simulate a mass-spring-damper system. The generated graphs help visualize the dynamic behavior of the system, showing amplitude modulation and frequency response, among other important variables. The control buttons facilitate the execution of calculations and the export of results. The design of this interface enhances the understanding and visualization of dynamic systems, making it ideal for the analysis and teaching of physical phenomena in engineering, as seen in Figure 5.

Results

Figure 5 shows the window of the graphical interface. In part one, the input parameters for the MRA simulation are introduced, including values for mass (m), spring constant (k), damping coefficient (B), applied force (F(t)), initial position (x_0), initial velocity (v_0) and simulation time, all of which are needed to define the behavior of the mechanical system.

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Part 2: This is where the system's behavior over time will be graphed, showing the different curves corresponding to the system's positions under different damping types (underdamped, critically damped, and overdamped). The graph illustrates how the magnitude of the position changes over time. Part 3: This is the area where the control buttons are located. Clicking the first button "Solve and graph" will calculate the system's behavior and display it on this graph, showing how the damping varies with time for different parameters.

The second button "Export to PDF" will export the graph in PDF format, allowing it to be saved in a folder predefined by the user. The third button "Close" will close the graphical interface, and the fourth button "Clear Graph" will delete the generated graph and clear the interface data.

Box 7

Figure 5

The graphical interface developed in Octave is described below.

The behavior of a mechanical system with three types of damping is shown. The blue curve represents an underdamped system, where the oscillations gradually decrease over time, indicating that the damping is not sufficient to completely stop the oscillations. The light blue curve shows a critically damped system, where the oscillations stop as quickly as possible without the system oscillating more than necessary, reaching equilibrium without excessive delay. Finally, the black curve represents an overdamped system, where the amplitude decreases rapidly without oscillations, stabilizing without crossing the equilibrium value due to damping greater than the critical value, as shown in Figure 6.

Box 8

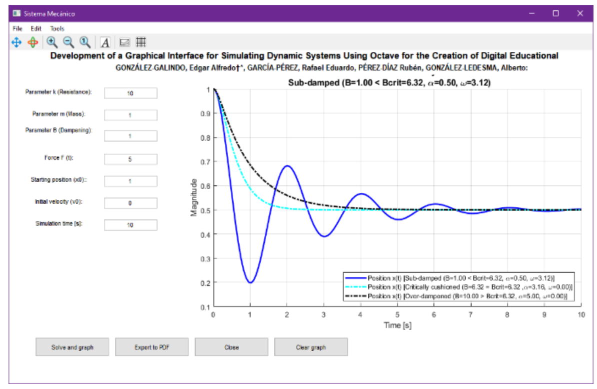

Figure 6

The graphical interface shows the three types of damping in an MRA system developed in Octave.

The velocities of a mechanical system for three types of damping: The red curve, as shown in Figure 7, represents the velocity of the underdamped system, where the oscillations decrease over time but still exist for a period. The dashed purple curve represents the velocity of the critically damped system, where the oscillations stop as quickly as possible, reaching equilibrium without excessive delay. Finally, the dashed red curve shows the velocity of the overdamped system, characterized by a rapid decrease in amplitude without oscillations, stabilizing without crossing the equilibrium value. The significance of this graph lies in comparing the velocities of the three systems, which allows us to observe how the stabilization speed varies between each damping type.

Box 9

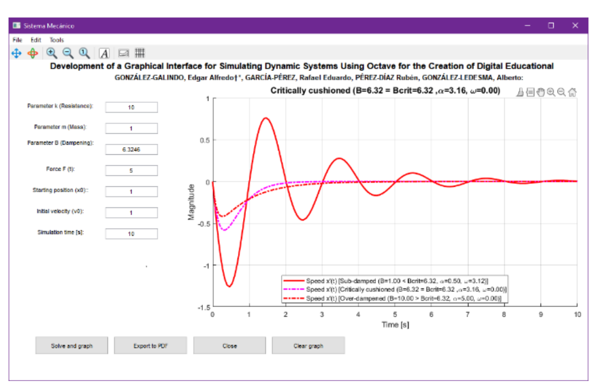

Figure 7

The graph shows the velocity functions for each damping type, recalling that velocity can be expressed as the first derivative of position.

The results obtained after assigning specific values to the parameters of the MRA system. The user defined these values with the objective of analyzing the system's behavior under different damping conditions.

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https://doi.org/10.35429/JCT.2025.9.21.3.1.14

As a result, three representative curves of the system's acceleration were obtained: The green curve corresponds to the underdamped case, where the system presents decreasing oscillations due to insufficient damping. The dashed pink curve represents the critically damped case, where the system returns to equilibrium in the shortest time possible without oscillating.

Finally, the dashed purple curve reflects the behavior of the overdamped system, characterized by a return to equilibrium without oscillations, as shown in Figure 8, but slower than in the critical case. This visualization allows us to graphically contrast the three classic damping regimes in second-order dynamic systems, demonstrating the usefulness of the tool developed for educational purposes.

Box 10

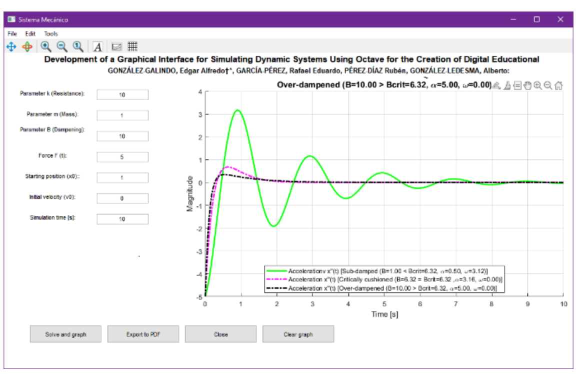

Figure 8

The graph shows the acceleration functions for each damping type, recalling that acceleration can be expressed as the second derivative of position

The temporal evolution of the three fundamental variables of a second-order MRA dynamic system subjected to a constant force is presented. In Figure 9, a blue curve is observed representing the position, which oscillates with decreasing amplitude toward an equilibrium value.

The red curve represents the velocity, alternating more rapidly between positive and negative values. The green curve corresponds to acceleration with larger and more sensitive oscillations, reflecting the second derivative of the motion.

If we pay attention, we can assert that all three graphs represent only one damping type, which is the underdamped.

Box 11

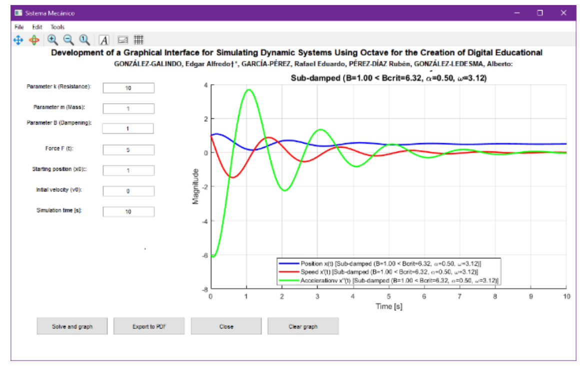

Figure 9

In this graph, the three main concepts of the system's dynamics are combined: position, velocity, and acceleration. Keep in mind that it exclusively shows the behavior of the system with underdamping.

The temporal response of an MRA system under critical damping conditions is obtained when the damping coefficient equals the critical value. The dashed light blue curve represents the position, which decreases smoothly until stabilizing. The dashed pink curve shows the velocity with a decreasing response, with no crossings of the horizontal axis. The dashed black curve represents the acceleration, with an initial steep slope that quickly tends to zero, as shown in Figure 10.

Box 12

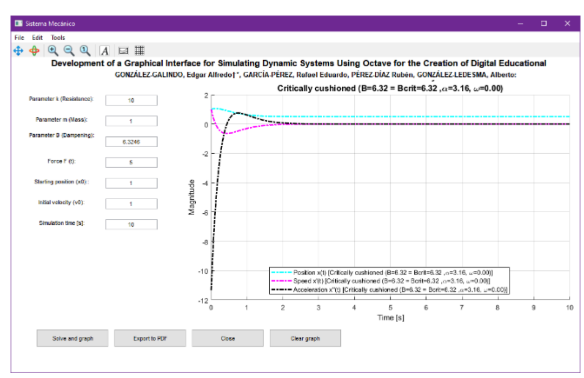

Figure 10

In this graph, the three main concepts of the system's dynamics are combined: position, velocity, and acceleration. Keep in mind that it exclusively shows the behavior of the system with critical damping.

Figure 11 shows the temporal response of an MRA system under overdamped conditions. Under this condition, the system does not oscillate and returns to its equilibrium position slowly and monotonically.

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It can be observed how the system's response tends asymptotically toward an equilibrium value without crossing that point, which is characteristic of the overdamped behavior.

Additionally, the system shows a rapid decrease in initial acceleration, followed by a stabilization of velocity and position as time progresses. The interface allows for easy modification of the system's parameters, real-time result visualization, and export of the data for subsequent analysis, thus facilitating the interactive study of dynamic systems in educational environments.

Box 13

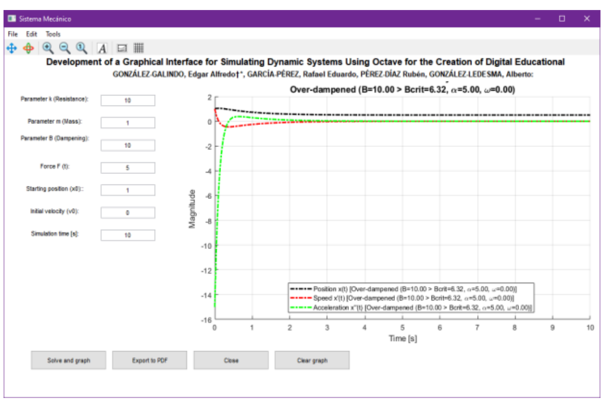


Figure 11

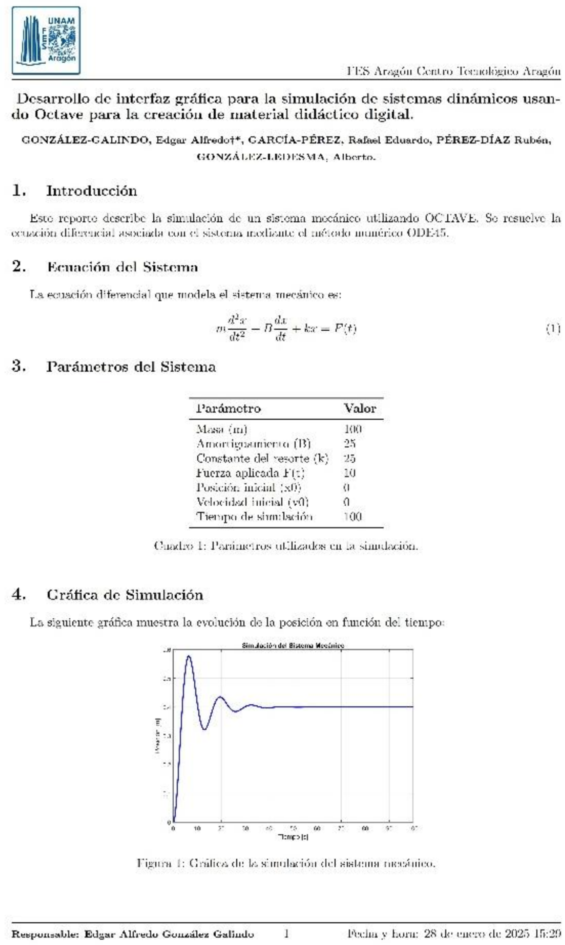
In this graph, the three main concepts of the system's dynamics are combined: position, velocity, and acceleration. Keep in mind that it exclusively shows the behavior of the system with underdamping.

The document presents a PDF that includes the introduction, where the purpose of the study is outlined, which is the simulation of dynamic systems using Octave to create digital teaching materials.

The equation of the system is shown, which describes the behavior of the dynamic system in terms of force, mass, and acceleration as observed in Figure 12. In the system parameters section, the variables and constants used in the simulation are detailed, such as mass, numerical arrangement, and spring constant.

Additionally, a simulation graph is included, which illustrates the evolution of the system's position as a function of time, demonstrating how the simulation reflects the system's behavior under certain conditions.

Box 14



FES Aragón Centro Tecnológico Aragón

Desarrollo de interfaz gráfica para la simulación de sistemas dinámicos usando Octave para la creación de material didáctico digital.

GONZÁLEZ-GALINDO, Edgar Alfredo†*, GARCÍA-PÉREZ, Rafael Eduardo, PÉREZ-DÍAZ Rubén, GONZÁLEZ-LEDESMA, Alberto.

1. Introducción

Este reporte describe la simulación de un sistema mecánico utilizando OCTAVE. Se resuelve la ecuación diferencial asociada con el sistema mediante el método numérico ODE45.

2. Ecuación del Sistema

La ecuación diferencial que modela el sistema mecánico es:

$$m\frac{d^2x}{dt^2} - B\frac{dx}{dt} + kx = F(t) \quad (1)$$

3. Parámetros del Sistema

Parámetro	Valor
Masa (m)	100
Amortiguamiento (B)	25
Constante del resorte (k)	25
Fuerza aplicada F(t)	10
Posición inicial (x0)	0
Velocidad inicial (v0)	0
Tiempo de simulación	100

Cuadro 1: Parámetros utilizados en la simulación.

4. Gráfica de Simulación

La siguiente gráfica muestra la evolución de la posición en función del tiempo:

Simulación del Sistema Mecánico

Tiempo [s]

Figura 1: Gráfica de la simulación del sistema mecánico.

Responsable: Edgar Alfredo González Galindo 1 Fecha y hora: 28 de enero de 2025 15:20

Figure 12

This image shows the first page of the PDF generated by Octave, including all the relevant data captured in the interface, as well as its corresponding graph.

In the PDF file generated, the conclusions of the interface created in Octave highlight that the analysis of the dynamic system allows us to observe, in Figure 13, how the position of the object changes over time.

The importance of parameters such as mass, spring constant, and applied force in the system's evolution is emphasized. These simulations facilitate the understanding of dynamic systems.

It is important to highlight the application of these studies in engineering and physics, as numerical simulations, such as the one performed in Octave, offer valuable results for the understanding and teaching of complex concepts.

Box 15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5. Conclusión

El análisis del sistema mecánico permite observar cómo varía la posición en función del tiempo, considerando la influencia de la amortiguación, la constante del resorte y la fuerza aplicada. Este estudio facilita la comprensión de los sistemas dinámicos y su aplicación en la ingeniería.

Responsable: Edgar Alfredo González Galindo 2 Fecha y hora: 28 de enero de 2025 15:29

Figure 13

The second page of the PDF generated by Octave is shown, where the conclusion of the project is observed.

Conclusions

The development and implementation of the interactive graphical interface for simulating dynamic systems using Octave has proven to be a highly effective and accessible tool for learning and teaching physical and mathematical phenomena in the field of Electrical and Electronic Engineering.

This project highlights the potential of open-source software, such as Octave, to facilitate the creation of digital teaching materials that allow students to understand theoretical concepts related to dynamic systems and differential equations more deeply and visually.

The developed interface allows users to input specific parameters, perform simulations of MRA systems, and visualize the results clearly and precisely. Additionally, the ability to export these results in PDF format encourages the production of automated reports, which is a valuable educational tool for the evaluation and analysis of dynamic systems.

The analysis of systems with different types of damping (underdamped, critically damped, and overdamped) through this interface reinforces students' practical learning by providing an interactive environment where they can observe and compare the system's behavior in real-time.

This approach facilitates the understanding of complex phenomena, such as energy dissipation and mechanical system stability, significantly contributing to the development of analytical and programming skills. Finally, the use of Octave and the developed graphical interface opens new possibilities for engineering learning, providing an accessible and cost-effective alternative to commercial software, and promoting more effective education in the field of engineering.

This project represents an important step in integrating computational tools into the teaching of dynamic systems and provides a solid foundation for future research and applications in areas such as vibration analysis, automatic control, and simulation of physical systems.

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Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Author contribution

González-Galindo, Edgar Alfredo: Main coordinator of the project and responsible for the overall design of the Octave graphical interface, defining the architecture of the application. He is responsible for developing the core of the simulation (e.g., the integration of ODE45 to solve the mass-spring-damper model) and the design of the modules that integrate both graphical visualization and result export (including the LaTeX report). He conducts the mathematical analysis of the system, defining the transformation to state space and the dynamic parameters (α and ω), and supervises the achievement of the project's overall objectives.

García-Pérez, Rafael Eduardo: In charge of delving into the theoretical foundations of the implemented dynamic system, reviewing and documenting the formulation of the differential equation, its conversion to state space, and determining the damping conditions (underdamped, critically damped, and overdamped). He defines and explains the methodology for calculating α and ω, ensuring that the theoretical interpretation is accurately reflected in the implementation and the final report. He collaborates in writing the "Mathematical Analysis" section of the document, providing bibliographic references and theoretical support for design decisions.

Pérez-Díaz, Rubén: Responsible for the development and adjustment of the interactive simulation modules, allowing real-time visualization of the position, velocity, and acceleration evolution of the system. He implements user tests to verify the correct parameterization and response of the interface, ensuring that the graphs and legends (including the differentiation of damping types) are clear and precise. He performs validation tests by comparing the results with theoretical analyses and proposes adjustments to optimize visualization and simulation performance.

González-Ledesma, Alberto: Develops the technical-practical documentation of the project, including a user guide and a tutorial explaining the functioning of the interface and the interpretation of the simulation results. He writes the conclusions and results of the project, highlighting how the tool facilitates the understanding of dynamic systems in an educational context. He suggests improvements for the interface report, ensuring that the design is intuitive and accessible for students in the Electrical and Electronic Engineering program for the Electronic Instrumentation course, and collaborates in the preparation of the final report, writing it in LaTeX and exporting the file in PDF, including the graphical interface.

Availability of data and materials

The data for this research is available according to the sources consulted.

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Abbreviations

ODE45: 4th order Runge-Kutta method with adaptive step size for solving ordinary differential equations.
Octave: Open-source software platform for numerical calculations, similar to MATLAB.
GUI: Graphical User Interface.
ODE: Ordinary Differential Equation.
Ns/m: Newton-seconds per meter, unit of measurement for the damping coefficient.
N/m: Newton per meter, unit of measurement for the spring constant.
m: Mass (kg), the unit of measurement for mass in the International System of Units.
k: Spring constant, also known as the spring stiffness.
B: Damping coefficient.
F: Spring force.
x: Elongation.

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