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Vibration Simulation and Analysis Teaching Tool (VSATT): An Interactive Learning Tool Based on MATLAB-Simulink GUI

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Abstract
Mastering the mechanical vibrations of a Mass-Spring-Damper system is essential, particularly in structural design where resonance can cause catastrophic failures. However, undergraduate students often face challenges in understanding these concepts, leading to reduced engagement in teaching and learning activities. To address this, the Vibration Simulation and Analysis Teaching Tool (VSATT) was developed as an innovative, interactive platform to enhance comprehension of Single Degree of Freedom forced and free vibrations. Leveraging MATLAB-Simulink and a user-friendly graphical user interface (GUI), VSATT provides hands-on exploration of vibration principles through dynamic simulations and detailed response analysis. Validation results showed an error margin of less than 1%, while feedback from 112 users reported positive outcomes in accessibility, ease of learning, motivation, understanding, and overall effectiveness, with scores exceeding 87%. These findings highlight VSATT's role in advancing interactive learning tools in engineering education by offering a flexible and engaging platform for mastering complex vibration dynamics.
Keywords: Interactive Learning, Vibration Analysis, Simulation Tool, MATLAB-Simulink, GUI.

Introduction

Overview of the importance of vibration analysis

Vibration analysis plays a pivotal role in enabling a profound understanding of the dynamic behaviour of mechanical systems. This analytical tool provides valuable insights into how structures respond to external forces, aiding students in comprehending system dynamics. Engineers must possess the knowledge to predict and control vibrations in diverse applications, spanning from bridges and buildings to automotive and aerospace systems (Sari et al., 2023; Subramaniam & Lim, 2022). Ensuring structural integrity and safety demands the imperative ability to analyse vibrations, requiring students to identify potential issues like resonance, fatigue, and instability that could compromise a system's structural soundness

(Zakaria & Lim, 2022; Akbari-Hasanjani et al., 2015). In machine design and performance optimization, vibration analysis assumes a fundamental role, guiding engineers to consider vibration characteristics for enhanced machine functionality, reduced wear and tear, and extended equipment lifespan (Ghayoor, 2020). Additionally, vibration analysis serves as a vital component in condition monitoring and diagnostics, enabling engineers and students to assess machinery health, interpret vibration data for fault diagnosis, and prevent catastrophic failures (Zakaria & Lim, 2017). In critical aerospace and automotive applications, understanding and controlling vibrations are paramount, with students acquiring knowledge about damping mechanisms, vibration isolation, and control strategies for improved vehicle and aircraft performance and safety. Furthermore, vibration analysis proves integral to the design of control systems, allowing students to develop strategies that suppress unwanted vibrations, ensuring stability and precision across various engineering applications (Ahmad et al., 2016). This interdisciplinary tool transcends disciplinary boundaries, allowing students to seamlessly apply vibration analysis concepts in civil, mechanical, aerospace, and other engineering domains (Henrique et al., 2018). Industries increasingly seek engineers with a solid foundation in vibration analysis, as proficiency in this area not only enhances graduates' employability but also prepares them for roles requiring expertise in structural dynamics and mechanical system behaviour (Lakhlani & Yadav, 2017). The field of vibration analysis opens avenues for innovation and research in developing new materials, damping technologies, and vibration control strategies, with students equipped with a strong foundation contributing significantly to advancements in these areas. In summary, vibration analysis stands as a cornerstone of engineering education, imparting essential skills and knowledge applicable to a spectrum of engineering challenges, empowering engineers to design systems that are not only safer but also more efficient and reliable across diverse industries.

Motivation for developing VSATT.

The development of the Vibration Simulation and Analysis Teaching Tool (VSATT) is rooted in a compelling motivation derived from the current landscape of engineering education and the evolving needs of students and professionals in the field. Recognizing a gap in the availability of interactive and comprehensive tools for teaching vibration analysis, VSATT addresses this educational void by providing a user-friendly platform with hands-on experiences crucial for a profound understanding of dynamic systems. Bridging the gap between theory and practice, VSATT offers a unique opportunity for students to directly apply theoretical knowledge to real-world scenarios, fostering a holistic learning experience. With a focus on enhancing conceptual understanding, the tool utilizes visualizations, simulations, and interactive features to engage students in the complexities of vibration analysis. Motivated by the need to cater to diverse learning styles, VSATT provides a dynamic and engaging environment that complements traditional teaching methods, acknowledging the varied approaches students take in their learning journey. Additionally, VSATT aligns with industry demands for graduates equipped with practical skills, offering hands-on experience in simulating and analysing vibrations. By meeting industry requirements, the tool prepares students for the workforce, recognizing the growing reliance on simulation tools for design, analysis, and optimization. In facilitating self-directed learning, VSATT encourages a proactive approach to mastering vibration analysis concepts, providing a platform for independent exploration. The tool's innovative teaching methodology leverages technology and simulation tools to create a dynamic, engaging, and effective learning process. Serving as a virtual laboratory, VSATT addresses the issue of limited access to sophisticated laboratory facilities, ensuring a practical learning experience irrespective of available physical resources. With an overarching goal of encouraging research and development in the field of vibration analysis, VSATT is motivated by the potential to inspire advancements in educational technology and contribute to the broader knowledge base. In essence, the development of VSATT reflects a commitment to advancing engineering education, filling educational gaps, and preparing students for the practical challenges of their professional careers, ultimately benefiting both educators and learners in the field of engineering.

Existing tools and their limitations

A brief literature review reveals several existing tools in the field of vibration analysis, each with its special features and limitations as shown in Table 1. Among these tools, MATLAB-based simulations are widely utilized due to their versatility and ease of integration with theoretical concepts. MATLAB Simulink, for instance, provides a comprehensive environment for dynamic system modelling and vibration analysis. However, its complexity may pose a challenge for novice users. Commercial software packages like ANSYS and ABAQUS are also prevalent for advanced finite element analysis, including vibration studies. While powerful, these tools can be expensive, limiting accessibility for educational institutions with budget constraints. Additionally, their extensive features may be overwhelming for introductory-level learners. Open-source solutions such as FreeCAD and OpenModelica have gained popularity for their cost-effectiveness and community-driven development. However, their user interfaces may not be as intuitive as commercial alternatives, potentially hindering the learning experience. Virtual laboratories, such as the PHET Interactive Simulations, offer web-based platforms for students to explore concepts in physics and engineering, including vibrations. These tools enhance accessibility but may lack the depth and customization options required for more advanced studies. While these existing tools contribute significantly to vibration analysis education, they often face limitations. These include a steep learning curve for complex software, high costs associated with commercial packages (Morales et al., 2022; Tekes et al., 2021; Oh et al., 2021; Fuławka et al., 2022), a potential lack of interactivity in virtual laboratories, and varying levels of customization. As a result, there remains a need for an interactive, user-friendly, and comprehensive tool that effectively addresses these limitations and caters to the diverse needs of students and educators in the field of vibration analysis. The development of the Vibration Simulation and Analysis Teaching Tool (VSATT) aims to fill this gap by providing an innovative and accessible solution for a more effective learning experience. Table 1 shows the summary of the synthesis matrix, highlighting research gaps and limitations.

Table 1
Summary of Synthesis Matrix – Gap of Research – Limitation

Tool Name, Author, Year	Purpose					Advantages						Limitations			
	Numerical computation	Engineering simulation	Multiphysics modeling and analysis	System design and visual programming	Vibration control and analysis	Open Source	Commercial Software	Block diagram	Visual programming	Vibration testing, analysis, reporting	Data acquisition, analysis tools, reporting features	Complex interface	Limited customization	Expensive	Requires programming knowledge
MATLAB Simulink, Jong-Seok Oh et al., 2021 [12]	X	X			X		X	X				X		X	X
LabVIEW, Ayse Tekes et al., 2019 [11]	X	X		X				X	X	X	X			X	X
Simulink, Soo-Min Kim et al., 2023 [16]	X	X			X			X						X	X
VibrationVIEW, Rodolfo Sánchez-Fraga et al., 2022 [18]		X		X						X	X		X	X	
NI DIAdem, Krzysztof Fuławka et al., 2022 [13]		X	X							X	X		X	X	
ME'scopeVES, Liang Huang et al., 2023 [19]		X	X							X	X		X	X	
ModalVIEW, A. L. Morales et al., 2021 [10]	X		X				X			X	X		X	X	
OpenModelica, Kenji Yoshimizu et al., 2024 [21]	X	X				X									X
VSATT	O	O	O		O		O	O			O			O	O

Methodology

The Graphical User Interface

The interface presented in this work was developed using a built-in MATLAB tool called GUIDE, enabling developers to design Graphical User Interfaces (GUIs) for various applications. GUIDE is a MATLAB application that facilitates the development of parallel scripts with tools for creating graphic designs, process control, and real-time simulation. This tool empowers scientists to simplify high-level codes, making them more accessible for manipulation by novice users.

The demand for easy-to-use tools is a pivotal factor in the development of devices that rely on exploring interactivity as a pedagogical foundation for teaching and learning activities. Interaction constitutes a communication process between individuals and interactive systems. In this study, the user and system engage in a reciprocal exchange where one communicates, and the other listens, interprets, and takes action. Figure 1 illustrates the interaction process between the interface and the user.

The architecture of the Vibration Simulation and Analysis Teaching Tool (VSATT) is meticulously designed to offer an interactive and user-friendly platform for simulating and analysing vibrations in engineering systems. Its graphical user interface (GUI) serves as the gateway for users to input parameters, customize simulation setups, and control the analysis process. The core of VSATT lies in its integration with MATLAB Simulink, leveraging its robust capabilities for dynamic system modelling. Users can model diverse mechanical systems, from single to multi-degree-of-freedom configurations, and customize parameters through the GUI. Real-time plots, including time response analyses, offer users a visual understanding of the dynamic behaviour. The architecture prioritizes user feedback and compatibility across MATLAB versions and operating systems, ensuring broad accessibility and continuous refinement. In essence, the VSATT architecture seamlessly combines the strengths of MATLAB Simulink with a user-centric design, addressing educational gaps and providing a robust platform for mastering vibration analysis concepts in engineering education.

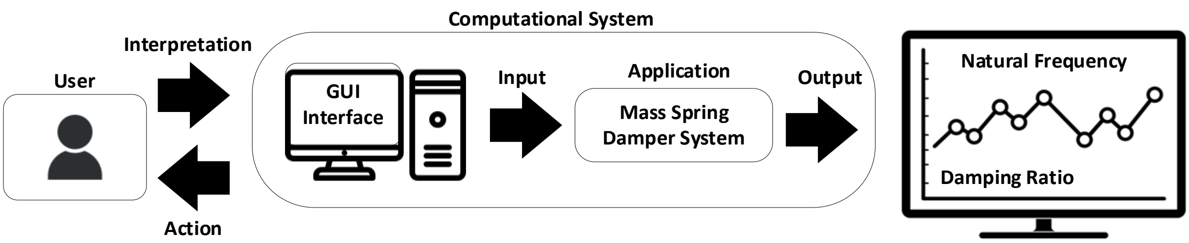


Figure 1: The process of human-computer interaction. A detailed description of the importance of human-computer interaction in mass spring damper system

Development and Tool Description

In a teaching session using the presented tool for mechanical vibration systems, the user needs to specify the studied system and the desired parameters to initiate the simulation. Once the processing is complete, the results are displayed graphically or stored in text files. This approach hides the algorithms and intricate technical details from the user, presenting only the essential graphical and data results.

When the student's needs are established, the interface design process is initiated. Throughout this process, various scenarios are evaluated to establish the interaction with the user. The advantage of conducting recurring evaluations during development is that it helps identify and address interaction problems before the design is completed. Discovering and fixing problems early in the process reduces the cost of required code changes, resulting in higher-quality software. Once the interface design is established, the code is written, and subroutines are organized to represent the mathematical processes necessary for the simulations. Figure 2 illustrates the steps in the development of the GUI.

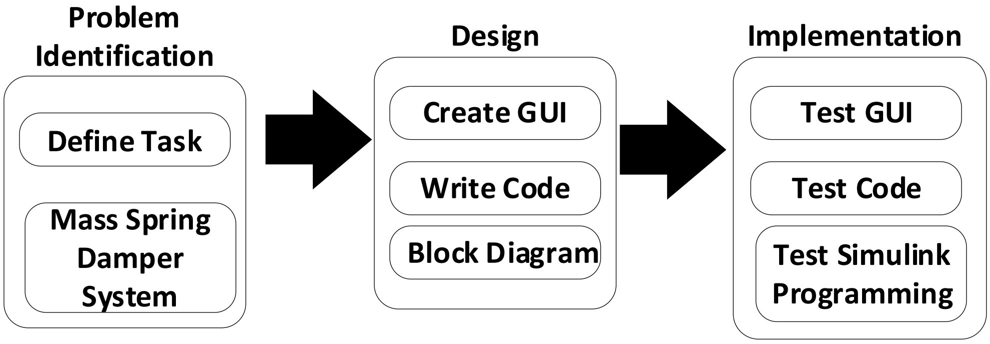


Figure 2: The phase for constructing the graphical interface

The GUI layout and user interaction.

The user interface of the Vibration Simulation and Analysis Teaching Tool (VSATT) is carefully crafted to offer an intuitive and user-friendly platform for interacting with the simulation and analysis features. The tool consists of two sections which are Simulink block diagram, GUI and m-file programming. Using this tool, students can learn the time response behaviour and observe the effect of parameter variation of vibration elements such as mass, spring and damper as it can be repeated several times. At the forefront is the main control panel, prominently featuring buttons for simulation control and input fields for adjusting parameters such as time duration and step size. A dedicated section allows users to input key parameters for mechanical system simulation, accompanied by clear labels and tooltips. Real-time results are visualized in a dynamic area, including time domain plots.

Integration of MATLAB Simulink for dynamic system modelling.

The integration of MATLAB Simulink forms the backbone of the Vibration Simulation and Analysis Teaching Tool (VSATT) for dynamic system modelling. Leveraging the robust capabilities of Simulink, VSATT provides a versatile platform for users to create mathematical representations of complex mechanical systems. Simulink's intuitive graphical interface allows users to design and model systems with masses, springs, dampers, and external forces. This integration enables the translation of theoretical concepts into practical simulations, fostering a hands-on learning experience. The powerful solver options within Simulink offer flexibility in numerical simulations, ensuring accuracy and efficiency in capturing the dynamic behaviour of mechanical systems. Overall, the seamless integration with MATLAB Simulink empowers VSATT to deliver a comprehensive and interactive environment for users to explore, understand, and analyse vibrations in engineering systems.

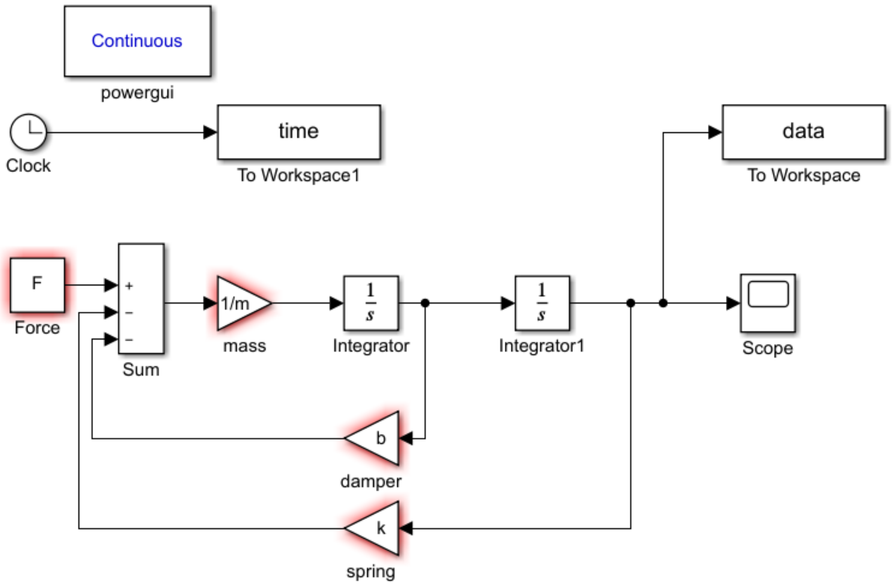


Figure 3: Integration of MATLAB Simulink for mass spring damper system modelling

Equation of motion of mass spring damper system in Forced Vibration Single Degree of Freedom

This VSATT module contains interactive m-file MATLAB scripts and Simulink models that explore mass-spring-damper systems. Students learn to create and work with mass-spring-damper models in guided activities. These techniques are motivated by two applications which are tuning the damping of a vehicle's suspension and analysing a building's response to an earthquake. Throughout the module, students apply Simulink models to study the dynamics of the physical systems.

Newton's laws of motion form the basis for analysing mechanical systems. Newton's second law, Equation (1), states that the sum of the forces acting on a body equals the product of its mass and acceleration. Newton's third law, states that if two bodies are in contact, then they experience the same magnitude contact force, just acting in opposite directions.
Total Force applied to a body = Motion of the body

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

Rearranging the equation (1), The free-body diagram for this system is illustrated in Figure 6. The spring force is proportional to the displacement of the mass, x, and the viscous damping force is proportional to the velocity of the mass, v. Both forces oppose the motion of the mass and are, therefore, shown in the negative x-direction.

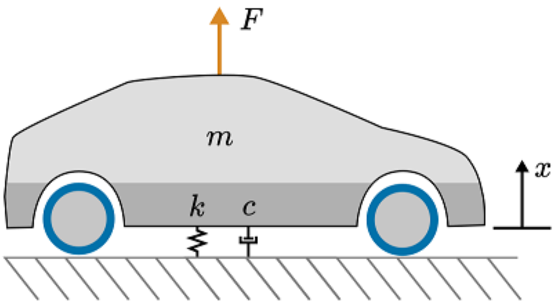
$$m\frac{d^2x}{dt^2} + kx + c\frac{dx}{dt} - F(t) = 0 \tag{2}$$

Rearranging the equation (2), Note also that x=0 corresponds to the position of the mass when the spring is unstretched. Now, proceed by summing the forces and applying Newton's second law in each direction. In this case, the forces act in the vertical direction, however, no forces are acting in the horizontal direction.

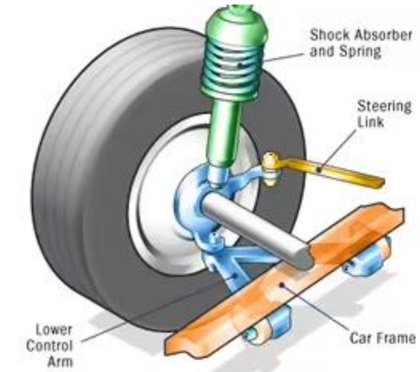
$$m\frac{d^2x}{dt^2} + kx + c\frac{dx}{dt} = F(t) \tag{3}$$

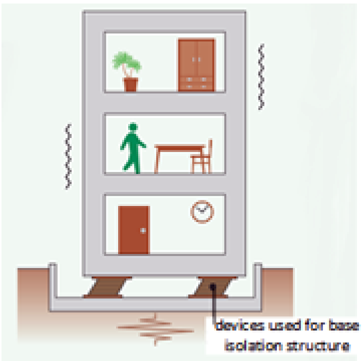
Rearranging the equation (3), and equation (4), known as the governing equation, completely characterizes the dynamic state of the system. Later, calculate the response of the system to any external input, F(t), as well as analyse system properties such as stability and performance.

$$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx=F(t) \tag{4}$$



(a) vehicle's suspension





(b) Seismic base isolation in a building's structure to prevent it from earthquakes

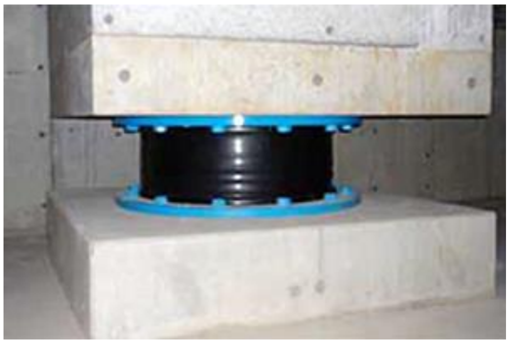
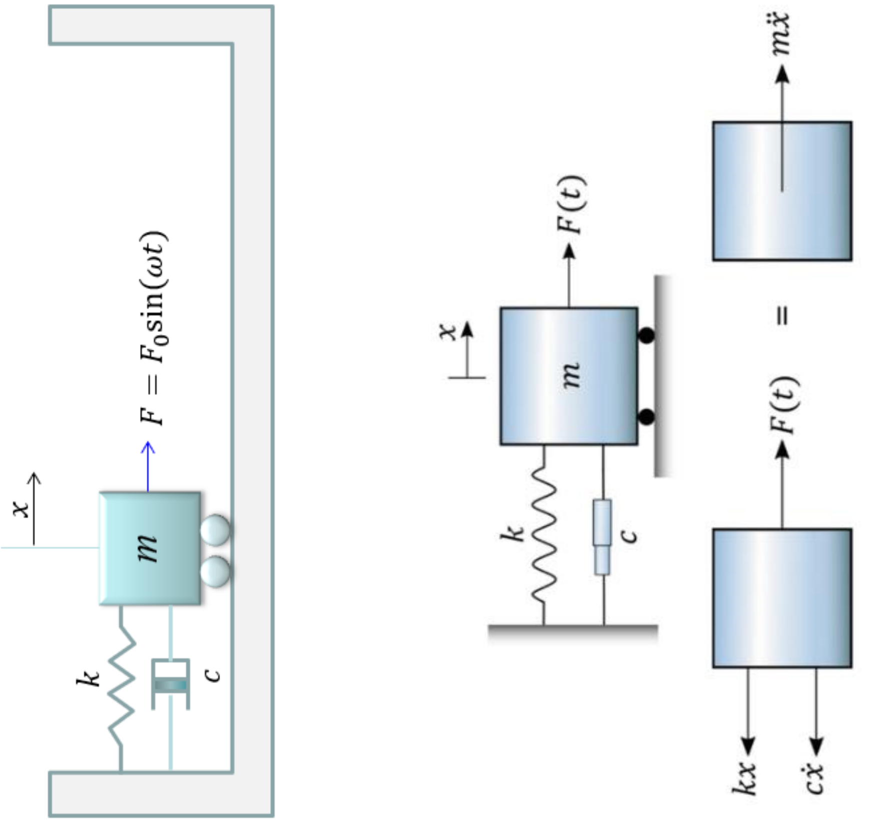


Figure 4: Interactive courseware module that addresses the fundamentals of mass-spring-damper systems, taught in mechanical engineering courses. These techniques are motivated by two applications: tuning the damping of a vehicle's suspension and analysing a building's response to an earthquake. Throughout the module, students apply Simulink models to study the dynamics of the physical systems.



(a) Vehicle's suspension (b) Free Body Diagram (FBD)

Figure 5: Graphical interface available, indicating a Vibration Simulation and Analysis Teaching Tool (VSATT). The process of human-computer interaction. A detailed description of the importance of human-computer interaction in mass spring damper system.

Results and Discussion

The GUI of VSATT

The complete overview of the Graphical User Interface (GUI) of VSATT resulting from the MATLAB code is provided in Figure 3, while the Simulink block diagram is illustrated in Figure 4. The main window of the Vibration Simulation and Analysis Teaching Tool (VSATT) facilitates profile analysis, requiring essential input data such as mass, spring constant, and damping constant for a comprehensive analysis of the time response in both Case Study 1 and Case Study 2 profiles. This user interface serves as a pivotal platform for users to input critical parameters, enabling a detailed examination of the dynamic behaviour in the specified case studies. The inclusion of mass, spring constant, and damping constant ensures the specificity of the analyses conducted, allowing for a nuanced exploration of the time response within the context of the provided case studies.

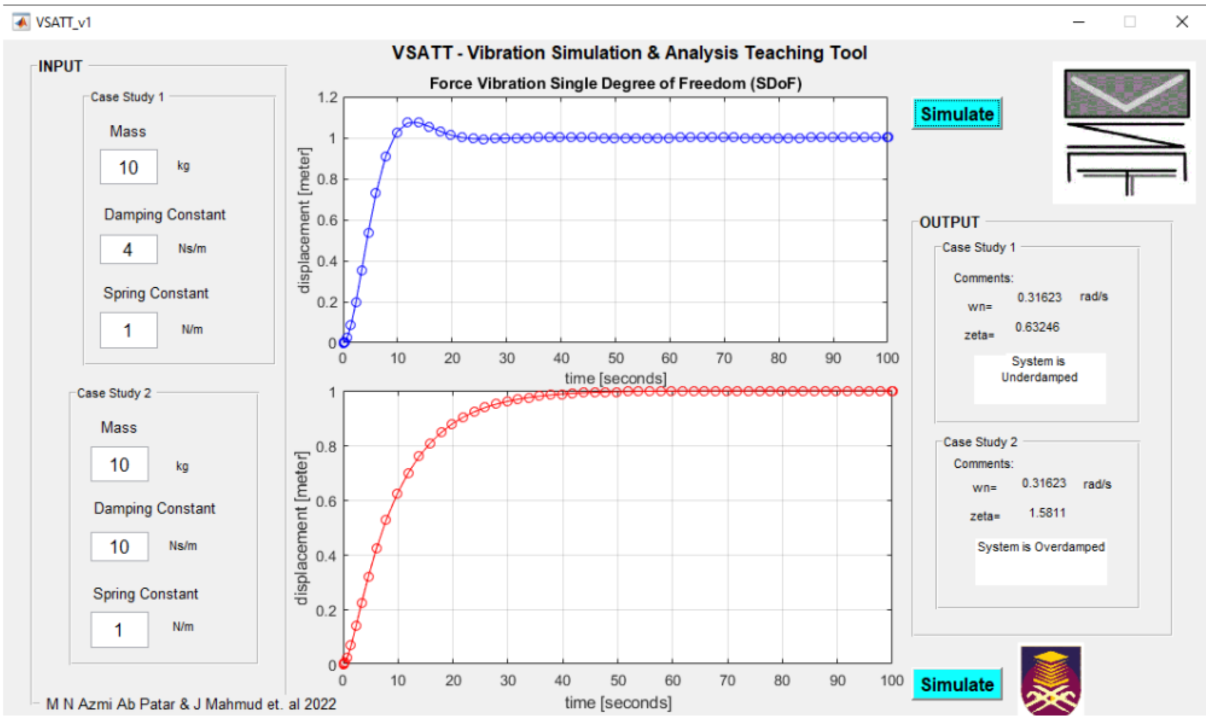


Figure 6: Graphical interface available, indicating a Vibration Simulation and Analysis Teaching Tool (VSATT). The process of human-computer interaction. A detailed description of the importance of human-computer interaction in mass spring damper system.

Numerical Validation

For numerical validation, two case studies were analysed as follows: Case Study 1: k = 2.5kN/m, m=20 kg, c=325Ns/m; Case Study 2: k = 1250N/m, m=20 kg, c=325Ns/m. The results for vibration analysis (natural frequency and damping ratio) are compared with the theoretical calculation and shown in Table 2. The results show that the error for both cases are less than 1%, thus proving that the numerical outputs from VSATT is accurate.

Table 2

Comparison of the results of the MATLAB program with the theoretical calculation

Case Study	Variable	Analytical	VSATT	Error (%)
Case 1	Natural frequency, ω_n rad/s	11.18	11.1803	0.00268
	Damping ratio, ξ	0.727	0.7267	0.04127
Case 2	Natural frequency, ω_n rad/s	7.91	7.9057	0.05436
	Damping ratio, ξ	1.03	1.0277	0.2233

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Special Feature of VSATT

Table 3 presents the special features of VSATT. Vibration Simulation and Analysis Teaching Tool (VSATT) offers a comprehensive set of features designed to provide users with a dynamic and interactive learning experience in vibration analysis. The tool's Graphical User Interface (GUI) allows users to input parameters for modelling mechanical systems, such as mass, damping coefficient, and stiffness. Leveraging MATLAB Simulink, VSATT enables dynamic system modelling, providing a versatile platform for users to simulate and analyse the vibrational behaviour of diverse mechanical configurations. Real-time visualization of time domain plots enhances understanding, while interactive plots illustrate the behaviour of the system. VSATT incorporates analysis tools for calculating the natural frequency, and damping ratio, empowering users to delve into the behaviour of dynamic systems. The educational aspect is strengthened by guided examples, and a user-friendly interface catering to varied learning styles. Concurrent results for on-the-spot comparison and revisiting case study simulations, while a feedback mechanism ensures continuous improvement. In essence, VSATT's main features, rooted in MATLAB Simulink, offer users a powerful and accessible tool for mastering vibration analysis concepts across diverse engineering applications.

Table 3

Special Feature of VSATT

Feature	**Description**
Simple and easy to use	The program employs an analytical approach (exact solution), with direct input and can produce results with good accuracy. The interface has been constructed to be user-friendly. The choice for inputting parameters includes an editable text area, a drop-down menu, and click-on buttons.
Concurrent results for on-the-spot comparison	The basic program provides the possibility for the user to change parameters and observe how different parameters would affect the response of the vibration system
Visual representation	The visual representation of displacement offers the user a better understanding of the response of the vibration system.
Easy for Editing	The program could be edited to include new and remove current parameters/components.
Interactive and Exciting Learning Platform	The real-time outputs, graphics and interactive environment will allow the users (students) to be involved in active learning. Therefore, the students could understand better the forced vibration problems, as they input the variables and then visualize the response immediately.
Customizable parameters for mechanical systems.	Few mechanical systems can be customized, particularly regarding mechanical properties such as mass, spring constant, and damping coefficient, which are essential parameters describing the physical structure. These properties dictate how the system vibrates, exhibiting specific patterns of displacement. Furthermore, they allow for the calculation of the natural frequency and damping ratio, crucial for analysing the system's vibrational behaviour. The damping ratio, in particular, specifies the mechanical behaviour, indicating whether the system is underdamped, overdamped, critically damped, or undamped.

VSATT provides users with a flexible and user-friendly platform by offering customizable parameters for modelling various mechanical systems. The tool allows users to tailor key parameters such as mass, damping coefficient, stiffness, and external forces, enabling the creation of dynamic simulations that represent real-world engineering scenarios. This customization capability not only accommodates a wide range of mechanical configurations but also empowers users to explore the impact of different parameters on the vibrational behaviour of systems. Whether simulating a single-degree-of-freedom system or a more complex multi-degree-of-freedom configuration, the customizable parameters in VSATT ensure that users can adapt the tool to their specific educational or analytical needs, enhancing the tool's versatility and applicability in diverse engineering contexts.

Time domain analysis capabilities.
VSATT boasts robust time domain analysis capabilities, providing users with a comprehensive toolkit for studying the dynamic behaviour of mechanical systems. In the time domain, the tool offers real-time visualization of the system's response over a specified duration, allowing users to observe the evolution of vibrations. This feature enables a detailed examination of transient phenomena, facilitating a deeper understanding of the system's dynamic response to external forces. This capability proves invaluable in identifying resonance frequencies and analysing the system's behaviour under different excitation frequencies. The seamless integration of time domain analysis within VSATT enhances its utility for users seeking a holistic view of vibrational characteristics in engineering systems, contributing to a more nuanced and insightful learning experience.

Educational Application
Cases and scenarios for incorporating VSATT into engineering courses.
VSATT could be integrated into coursework to illustrate theoretical principles with hands-on simulations, providing students with a deeper understanding of dynamic system behaviour. Case studies include fundamental concepts such as resonance and damping characteristics. The tool is particularly valuable in laboratory sessions, allowing students to experiment with different parameters, visualize the effects of various forces, and analyse the resulting vibrations in real-time. Incorporating VSATT into engineering courses enhances the overall educational experience, aligning theoretical knowledge with practical applications and preparing students for the complexities of vibrational analysis in real-world engineering scenarios.

Comparison with traditional teaching methods.
In comparison to traditional teaching methods in engineering education, the Vibration Simulation and Analysis Teaching Tool (VSATT) offers a transformative and dynamic approach to learning. Unlike conventional methods that often rely on theoretical lectures and static illustrations, VSATT introduces an interactive, hands-on experience. Traditional teaching may face challenges in effectively conveying the intricacies of vibration analysis, especially when it comes to visualizing dynamic behaviours. VSATT addresses this limitation by providing a user-friendly graphical interface, allowing students to directly engage with simulations and witness real-time responses of mechanical systems to external forces. This tool bridges the gap between theory and practice, offering a more comprehensive understanding of concepts like resonance, damping, and mode shapes. Moreover, VSATT accommodates diverse learning styles by incorporating visualizations and interactive features, catering to the needs

of students who benefit from practical, experiential learning. The tool's ability to simulate a wide range of scenarios ensures that students gain valuable insights applicable to various engineering applications, making it a valuable complement to traditional teaching methods and enhancing the overall effectiveness of vibration analysis education.

Student feedback and learning outcomes.

Students were given a few feasibility feedback questions regarding the Vibration Simulation and Analysis Teaching Tool (VSATT) (Table 4). The outcome is more favourable as the score increases. The rating scale is dependent on popularity, with 1 being the lowest and 10 being the highest. This study demonstrated a positive impact on learning outcomes associated to vibration analysis. The average score ranges from 8.79 to 8.91 out of 10 (SD: ± 1.27–1.51). Through hands-on simulations and interactive features, students express an enhanced understanding of dynamic system behaviour, resonances, and damping characteristics. The visualizations and real-time plots provided by VSATT empower students to grasp complex concepts with greater clarity. The tool's user-friendly interface and customizable parameters contribute to a more engaging learning experience, accommodating diverse learning styles. Additionally, the incorporation of guided examples and educational resources within the tool fosters independent exploration and proactive learning. Overall, the feedback suggests that VSATT not only enriches the educational experience by bridging theory and practice but also cultivates a deeper comprehension of vibration analysis concepts, leading to improved learning outcomes for students in engineering courses.

Table 4

Survey applied to students who participated in the study in the classroom. The questionnaire has been applied to 112 students. It demonstrates the average and standard deviation for each question.

Question	**Average Score / 10**	**Standard Deviation**
Q1. Is the Teaching Tool (VSATT) accessible to students?	8.85	1.37
Q2. Does the Teaching Tool (VSATT) complement and make it easier to learn the theory of Free Vibration system? (Chap 2 & Chap 3: Free and Forced Vibration of Single Degree of Freedom systems, as in the Test Question)	8.88	1.27
Q3. Has the Teaching Tool (VSATT) motivated the study of related concepts and theory of the related topic (Vibration system)?	8.91	1.31
Q4. How important is the aid of the animation and the execution of the graphs in the Teaching Tool (VSATT) for understanding the Vibration system?	8.88	1.34
Q5. Is observing graphical data through the Teaching Tool (VSATT) more beneficial than manual calculation for understanding the concepts of Vibration system?	8.79	1.51

Comparison with existing simulation tools.

In comparison to existing simulation tools, VSATT distinguishes itself by providing a unique combination of user-friendly features, educational emphasis, and versatility in vibration analysis. Unlike some traditional simulation tools that may have steep learning curves and lack interactivity, VSATT integrates seamlessly with MATLAB Simulink, offering a familiar and accessible environment for users. The tool's emphasis on educational support, including guided examples and documentation links, sets it apart by facilitating a more engaging and comprehensive learning experience. Moreover, VSATT caters to diverse learning styles through its visualizations, animations, and interactive features. While open-source solutions may lack user-friendliness, and commercial packages can be cost-prohibitive, VSATT strikes a balance by delivering a cost-effective yet powerful tool. Its compatibility with different MATLAB versions and operating systems further enhances accessibility. Overall, VSATT emerges as a distinctive and valuable addition to the landscape of vibration analysis simulation tools, prioritizing both effectiveness in engineering education and practical usability in real-world applications.

Table 5
A comparison review of the software under analysis: I – VFT System Configuration (Bai & Ganeriwala, 2019), II – Javalab Science simulations (Limon et al., 2006), III – Mechanical Vibrations with Python (Aziz et al., 2007), IV – Interactive Educational Tool for Mass Spring Damper (Ingale et al., 2018), V – Scilab Xcos Modelling of Spring Mass Damper System (Nandini, 2017).

Features	**VSATT**	**I**	**II**	**III**	**IV**	**V**
Free of cost	✓	-	✓	✓	-	✓
Organised Documentation	✓	✓	✓	✓	✓	✓
Friendly interface	✓	-	✓	-	-	-
Use of animation	✓	✓	✓	-	-	-
Save numeric data	✓	✓	-	-	✓	✓
Save graphic	✓	✓	-	-	✓	✓
Change Parameter	✓	✓	✓	✓	✓	✓
Updated Software	✓	-	-	-	-	-
Plot tools (e.g. Zooming)	✓	✓	-	✓	✓	✓
MATLAB Support	✓	-	-	-	✓	-
Exercises and examples	✓	✓	✓	✓	✓	✓

Conclusion

Summary of the contributions of VSATT to engineering education.

The Vibration Simulation and Analysis Teaching Tool (VSATT) significantly enriches engineering education by providing a dynamic and interactive platform for mastering vibration analysis concepts. Its integration with MATLAB Simulink allows students to bridge theoretical knowledge with practical applications, offering hands-on experiences in simulating and analysing diverse mechanical systems. VSATT's user-friendly interface, coupled with customizable parameters and real-time visualizations, fosters a deep understanding of system dynamics, resonance, and damping. The tool's educational features, including guided examples and documentation links, cater to varied learning styles, while modal analysis and mode shape animations enhance comprehension. By seamlessly incorporating sensitivity analysis and robustness testing, VSATT prepares students for real-world challenges in engineering design. Overall, VSATT's contributions to engineering education lie in its ability to demystify complex concepts, offer an engaging learning experience, and empower students with practical skills applicable to a broad spectrum of engineering disciplines.

Implications for the broader field of interactive learning tools.

The implications of the Vibration Simulation and Analysis Teaching Tool (VSATT) extend beyond the specific domain of vibration analysis, offering valuable insights for the broader field of interactive learning tools. VSATT demonstrates the effectiveness of integrating simulation tools with educational objectives, providing a model for how hands-on experiences can enhance understanding in complex engineering concepts. Its user-friendly interface, real-time visualizations, and customization options underscore the importance of tailoring interactive tools to diverse learning styles. The incorporation of guided examples and documentation links exemplifies how contextual guidance can facilitate self-directed learning. Furthermore, VSATT's emphasis on collaboration, compatibility, and continuous improvement sets a standard for interactive tools to remain adaptable and responsive to user needs. The success of VSATT suggests that future interactive learning tools can benefit from prioritizing user engagement, flexibility, and a seamless integration of theoretical principles with practical applications to maximize educational impact across various disciplines.

The significance of integrating simulation and analysis in education.

The integration of simulation and analysis tools in education, exemplified by the Vibration Simulation and Analysis Teaching Tool (VSATT), marks a transformative shift in how students engage with complex engineering concepts. This integration transcends traditional teaching methods, offering an immersive, hands-on learning experience that fosters a deeper understanding of dynamic systems. The ability to simulate and analyse real-world scenarios empowers students with practical skills essential for their future roles in engineering. By seamlessly blending theoretical knowledge with interactive applications, students are better equipped to comprehend the intricacies of system behaviour, resonance, and damping. As the educational landscape continues to evolve, the significance of such tools lies in their capacity to bridge the gap between theory and practice, preparing students to tackle the challenges of the rapidly advancing engineering field with confidence and proficiency. The success of VSATT underscores the broader importance of integrating simulation and analysis tools, paving the way for a more dynamic and effective educational paradigm across various disciplines.

Future Developments

Proposed enhancements and features for future versions of VSATT.

For future versions of VSATT, several enhancements and features are proposed to further elevate its effectiveness and user experience. Firstly, expanding the library of pre-built examples and case studies would offer users a broader range of applications and real-world scenarios for exploration. Additionally, integrating advanced analysis tools, such as nonlinear dynamics simulations and parametric studies, could provide a more comprehensive understanding of complex mechanical systems. Enhanced visualization options, including three-dimensional animations and virtual reality compatibility, would add a new dimension to the learning experience. Introducing a collaborative mode for multi-user interaction in real-time could foster teamwork and shared exploration. Furthermore, the inclusion of a comprehensive documentation section within the tool would serve as a quick reference for users, reinforcing independent learning. Continuous user feedback mechanisms and regular updates to incorporate the latest advancements in simulation technology would ensure that future versions of VSATT remain at the forefront of delivering an innovative and enriching platform for vibration analysis education and practical applications.

Integration with other educational tools or platforms.

To enhance its educational impact, future versions of VSATT could explore integration with other educational tools or platforms. Seamless integration with learning management systems (LMS) would enable instructors to incorporate VSATT simulations directly into their course modules, facilitating a more cohesive learning experience. Compatibility with virtual laboratories or collaborative platforms would encourage interactive engagement and experimentation among students. Integration with online assessment tools could allow educators to create quizzes or assignments based on VSATT simulations, providing a means for evaluating students' comprehension of vibration analysis concepts. Moreover, compatibility with popular engineering simulation software packages could extend the tool's capabilities, allowing users to import and export models between platforms for more comprehensive analyses. By fostering interoperability with a variety of educational tools and platforms, VSATT could further enrich the educational landscape, catering to diverse teaching methodologies and preferences.

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