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ElectroM: ElectroMechanical dynamic code

Americo Cunha Jr [a,*], Marcelo Pereira [b], Rafael Avanço [c], Angelo Marcelo Tusset [d], José Manoel Balthazar [e,d]

[a] Rio de Janeiro State University, Rio de Janeiro, Brazil
[b] SENAI Innovation Institute, Brazil
[c] Federal University of Grande Dourados, Brazil
[d] Federal University of Technology, Paraná, Brazil
[e] São Paulo State University, Brazil

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ABSTRACT

Electromechanical systems are integral to modern technologies and their accurate simulation is vital for understanding system behavior and optimizing designs. **ElectroM**, a MATLAB-based open-source software tool, provides advanced capabilities for simulating and analyzing such systems, offering two types of coupling formulations between mechanical and electrical domains, and a module for obtaining dimensionless groups, enabling dimensional analysis and a deeper physical understanding of the problem. This multifaceted approach ensures **ElectroM**'s value not only in research but also as an educational tool, assisting in the intuitive understanding and teaching of complex electromechanical dynamics.

Code metadata

Current code version	*v1.0*
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2023-239
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/2532343/tree/v1
Legal Code License	*MIT license*
Code versioning system used	*git*
Software code languages, tools, and services used	*Matlab*
Compilation requirements, operating environments & dependencies	
If available Link to developer documentation/manual	https://github.com/americocunhajr/ElectroM
Support email for questions	americo.cunha@uerj.br

1. Introduction

Electromechanical systems, which involve the interplay between electrical and mechanical components, are essential to many modern technologies [1–4]. These systems are ubiquitous in aerospace, automotive, biomedical, and energy industries, finding application in a diverse range of modern technologies, including micro- and nano-electromechanical systems (MEMS/NEMS) [5–9], small or medium size energy harvesters [10–16], very large devices like drillstrings for oil and gas exploration [17–19], etc. Understanding the behavior of electromechanical systems is crucial for their design and optimization. Simulating electromechanical systems can provide insights into their performance and behavior under different conditions, and can help identify potential issues before the construction of physical prototypes. Thus, the ability to accurately simulate these systems is crucial in applications involving electromechanical components.

In this paper, we present **ElectroM** (Fig. 1), a software tool designed to simulate the behavior of electromechanical systems. The code is written in MATLAB and uses formulations based on nonlinear ordinary differential equations arising from lumped parameters modeling to simulate the system's dynamics [20,21]. The formulations adopted can

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* Corresponding author.
E-mail addresses: americo.cunha@uerj.br (A. Cunha Jr), mardapereira@firjan.com.br (M. Pereira), rafaelavanco@ufgd.edu (R. Avanço), tusset@utfpr.edu.br (A.M. Tusset), jmbaltha@gmail.com (J.M. Balthazar).

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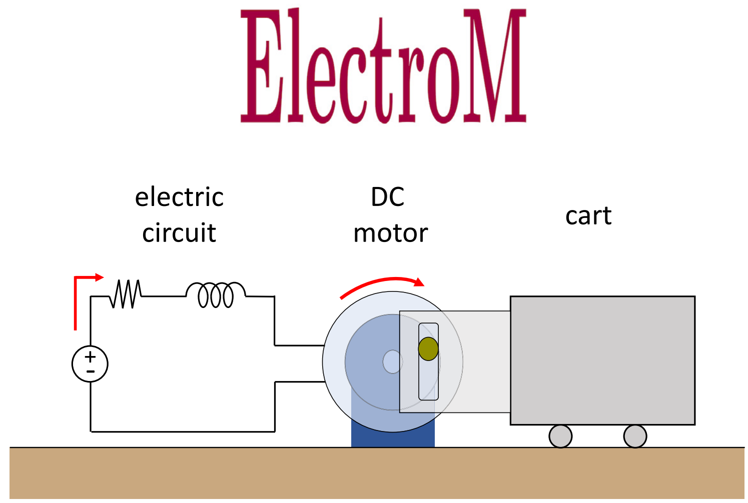

Fig. 1. ElectroM is a tool to simulate the nonlinear dynamics of electromechanical systems.

model systems where both mechanical and electrical components are fully coupled, or where the mechanical components are assumed to influence the electrical behavior only [20,21]. In this paper, we provide a detailed description of the package and demonstrate its capabilities through application examples.

2. Software details

The **ElectroM** software is organized in a modular structure composed of four main modules:

Simulation Module: This module is designed to simulate an initial value problem (IVP) of the electromechanical system composed by a cart under translation, mechanically coupled to a rotating DC electrical motor which is represented by a inductive resistive electric circuit (Fig. 1) [20,21]. The user inputs the system's parameters, which are used to construct a set of nonlinear ordinary differential equations, which are solved using a standard IVP solver. The outputs are time series representing the system's dynamic response and an animation of the system evolution of the corresponding three-dimensional phase-space. Adaptations to the models to accommodate more complex mechanical/electrical subsystems are relatively simple by modifying the differential equations accordingly.

Fourier Analysis Module: This module performs a Fourier analysis on the time series generated by the simulation module. This module allows the user to perform frequency domain analysis, enabling the identification of dominant frequencies and spectral components [22,23].

Dimensionless Parameters Module: This module computes the dimensionless parameters values of the system given the dimensional parameters. The module includes a collection of dimensionless parameters that are commonly used in electromechanical systems [24].

Pi Theorem Module: This module applies the Pi theorem formalism to compute dimensionless groups for the electromechanical problem. The user inputs a matrix with the dimensional variables, and the module computes the dimensionless groups. The resulting groups can be used to identify and predict system behavior under various conditions [25,26].

These modules make **ElectroM** a versatile tool for studying the behavior of electromechanical systems, allowing the user to perform simulations, analyze frequency responses, and compute dimensionless parameters and groups for the system.

In addition to its current capabilities, **ElectroM** has the potential for further extension and adaptation to handle other types of electromechanical systems (e.g. including nonlinear circuit elements like diodes or transistors [27]). The software's modular structure provides a flexible framework that allows for easy incorporation of additional mechanical and electrical subsystems. By modifying the differential equations accordingly, users can expand **ElectroM**'s capabilities to simulate and analyze a wide range of electromechanical systems beyond the current scope. This adaptability enables researchers and practitioners to address increasingly complex real-world problems and explore new application domains.

Furthermore, the open-source nature of **ElectroM** encourages collaboration and contributions from the scientific community, fostering the continuous enhancement and extension of the software. As a result, **ElectroM** has the potential to evolve into a comprehensive tool that can handle diverse and intricate electromechanical systems, further expanding its applications and impact in research, engineering design, and education.

3. Impact overview

By providing a tool for simulating the behavior of electromechanical systems, **ElectroM** presents itself as a valuable tool of scientific research and practical engineering. The software can be used to evaluate the response of systems to various types of excitations and to analyze the impact of different parameters on system behavior, allowing engineers to design and optimize systems with greater accuracy and efficiency.

ElectoM, as an open-source software tool, has not only the potential but also a demonstrated impact on advancing the understanding of electromechanical systems. A comparison between the two types of electromechanical coupling formulations have been a subject of recent discussion in academic literature [28,29], with a deep criticism, despite the validity and limits of applicability of both formulations have been well-established for decades [1,2,30,31]. A recent publication by the authors helped to elucidate such discussion [20]. The software **ElectroM** has played an instrumental role in such work, by providing an effective platform to compare the two formulations, their similarities, differences and limitations.

One of the defining characteristics of **ElectroM** is its ability to address an often-underemphasized aspect in the field of electromechanical modeling: dimensional analysis. Dimensional analysis serves as a potent tool in determining the governing parameters of a system, thereby providing significant physical insight into the problem. Despite its importance, this aspect frequently does not receive the attention it deserves within the community. By including a module for obtaining dimensionless groups, **ElectroM** not only assists in the dimensionalization of the equations but also enables engineers to cultivate a more profound physical understanding of the problem.

The software open-source nature has proven its educational value. A tangible example is its use at Rio de Janeiro State University in the graduate course of Uncertainty Quantification (UQ). Here, students use **ElectroM** for computational practical activities, alongside statistical libraries implementing UQ tools [32,33]. This utilization enhances the understanding of electromechanical systems' behavior, offering hands-on experience with simulation tools and a deeper comprehension of these systems' underlying physics and mathematical modeling.

Moreover, **ElectroM** has also demonstrated its educational capabilities through a tutorial recent published authored by the authors [21]. This tutorial provides comprehensive guidance on the modeling of electromechanical systems, showcasing the software's versatility by utilizing it to generate all the examples presented. This serves as a testament to **ElectroM**'s potential for further development and expansion within the educational field. **ElectroM**'s incorporation into educational curriculums thus furnishes students with an effective tool for learning and research in electromechanical systems.

4. Final remarks

In summary, **ElectroM** is an instrumental tool in the simulation, analysis, design, and optimization of electromechanical systems. It finds application across diverse industries and research disciplines. Its user-friendly interface and open-source nature make it accessible to researchers, engineers, and students interested in the subject. The code modular structure and adaptability facilitate the extension and incorporation of more complex mechanical and electrical subsystems, expanding its potential applications and impact. Additionally, the software's educational capability is noteworthy, as it allows users to gain a deeper understanding of these complex systems' behavior by providing a module to obtain the dimensionless groups and allowing for direct comparison of different electromechanical coupling formulations. Researchers and developers are encouraged to contribute to the ongoing enhancement and evolution of **ElectroM**, incorporating new features and addressing emerging challenges in the field of electromechanical systems.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Disclaimer

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