A General Purpose Co-Simulation C++/Python Framework for Strongly Coupled Electro-Mechanical Phenomena: ChElectronicsLib

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A general purpose co-simulation C++/Python framework for strongly coupled electro-mechanical phenomena: *ChElectronicsLib*

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Introduction

Multibody system dynamics (MBSD) represent an essential and consolidated tool for the comprehensive kinematic and dynamic analysis of general mechanic assemblies, involving both rigid and flexible bodies interactions. The effectiveness of a standard MBSD simulation software can lose its reliable applicability in presence of strongly coupled phenomena, in other words when these models incorporate interactions stemming from events of various physical natures that are closely interconnected, such as the case of electro-mechanical phenomena. A possible approach to the problem could be to consider one main macro-domains at time and thus solving different phenomena through their own dedicated software [1]. However, in some applications, the interdependence between the different domains present strong intercorrelations and thus a decoupled solution cannot be adopted. This work proposes a novel C++/Python framework (*ChElectronicsLib*) based on a two-way coupling between the multi-physics library Project Chrono (PC) with the general-purpose circuit simulation engine NGSpice (NGS) to solve complex interaction problems between mechanical and electronic domains. In order to validate the proposed co-simulation library, the results of an experimental test, that takes under analysis a simple miniature DC motor, are compared with the numerical results obtained through the presented multi-physics model. In detail the DC motor system allows to highlight the strict dependency between mechanical and electric parameters (like inertia, friction, current and back e.m.f.), while maintaining a simple showcase scenario. In conclusion, as reported by the results, *ChElectronicsLib* allows to solve through a general purpose MBD-ECA coupler, strongly interconnected mechatronic and electro-mechanical phenomena.

1 Main problematics, methodology and algorithm logic

The dynamics of multibody systems composed by rigid bodies is described and solved in PC by a system of a index-3 [2]:

$$\frac{d\boldsymbol{q}}{dt} = \boldsymbol{L}(\boldsymbol{q})\boldsymbol{v} \tag{1a}$$

$$\boldsymbol{M}(\boldsymbol{q})\dot{\boldsymbol{v}} = \boldsymbol{f}_t(t,\boldsymbol{q},\boldsymbol{v}) \tag{1b}$$

$$\boldsymbol{f}_t(t,\boldsymbol{q},\boldsymbol{v}) = \boldsymbol{f}_e(t,\boldsymbol{q},\boldsymbol{v}) - \boldsymbol{f}_c(t,\boldsymbol{q}) \tag{1c}$$

Where $\boldsymbol{q}$, $\boldsymbol{v}$, and $\boldsymbol{L}(\boldsymbol{q})$ are respectively the vector of generalised positions, the vector of generalised velocities and a linear transformation matrix. $\boldsymbol{M}$ is the mass matrix, while $\boldsymbol{f}_t$ is the vector of generalised total force and it is composed by $\boldsymbol{f}_e$ and $\boldsymbol{f}_c$ that are respectively the external and constraints forces. The main target is to introduce through the proposed coupling framework a classic force elements that comes from the interaction with the electric domain. Thus the vector of the generalised external force can be written as:

$$\boldsymbol{f}_e = \{\boldsymbol{f}_{e,mech}, \boldsymbol{f}_{e,elec}\}^T \tag{2}$$

Where $\boldsymbol{f}_{e,mech}$ are the external mechanical forces, while $\boldsymbol{f}_{e,elec}$ are the generalised force elements coming from electro-mechanic interactions. Figure 1 presents a block diagram of the proposed two-way coupling behind the co-simualtion multi-phisycs architecture. As shown, Project Chrono is the core of the simulation frameworks, it solves the multibody dynamics and controls the flow events with the calls, via *ChElectronicsLib*. In detail the algorithm allows the bi-directional communication of the effort and flows variables, receiving the instantaneous state of the mechanical system, that allows to compute the influenced parameters and update consequently the electric circuit NETLIST. The electronic network is then solved and integrated through PySpice that manages the electronic domain and execute NGSpice engine allowing the computation of the voltages and currents at every nodes and branches of the circuit. Finally the related electro-mechanical forces and torques are computed and passed back to the multibody model.

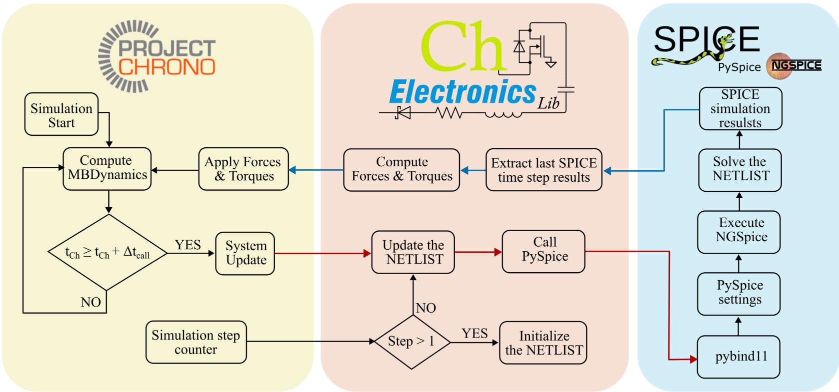

Figure 1: Flowchart of the NGSpice-Chrono coupling.

2 DC-Motor case-study

To validate the coupling procedure a benchmark have been proposed. A simple electro-mechanical system composed by a brushed DC motor have been tested. All the parameters of the electro-mechanical system have been estimated through experimental measurements as far as the main electrical parameters concerns and through 3D CAD models for the geometric and inertia information. Figure 2 shows the experimental curve of the current that is absorbed during a the actuation and the feeding voltage of the motor versus the results obtained using the proposed coupling co-simulation framework. As can be noticed from the comparison reported in Figure 2, the agreement between the simulation result and the measurement can be considered satisfactory and highlights the potentiality of the coupling co-simulation framework.

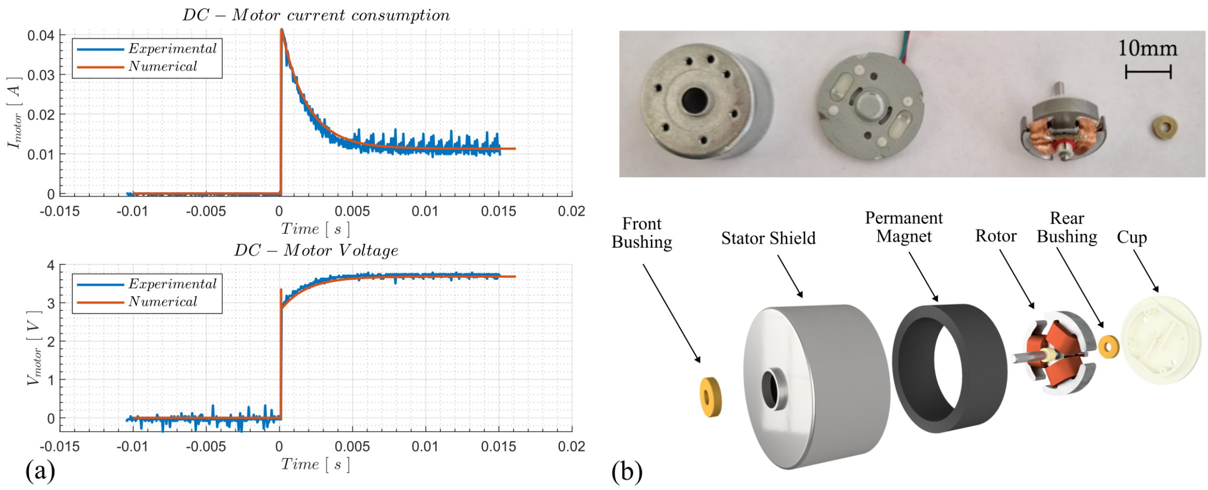

Figure 2: a) DC-Motor current and voltage absorption - b) Tested miniature DC-Motor.

3 Conclusions

The presented two-way coupling formulation allows merging electric and analog electronics models with complex multibody system where co-simulation is required due to strongly coupled physical phenomena. The main advantages of the proposed methodology is represented by the new two-way coupling communication interface *ChElectronicLib*, introduced to exchange data between Chrono Project and NGSpice, to improve the simulation capabilities of complex and highly coupled electro-mechanical systems.

References

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