Simplifying Control Validation with Modular Physical Models in Simscape

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Due to the pressure to publish, control engineers today must prioritise strategies that increase the likelihood of paper acceptance, either by focusing on expanding theoretical knowledge or by using well-known techniques in emerging application areas. This means that the gap between publications with strong theoretical results and those focused on specific applications remains significant. Among the first category, meticulous control designs are often validated against overly simplified models. This makes them difficult for implementation-focused control engineers to trust, no matter how notable the properties they provide, and limits their applicability to practical scenarios. In contrast, control strategies that are experimentally validated in industry-connected research projects tend to sacrifice interesting properties to minimise risks and ensure that the core technologies that justify the funding are demonstrated. Together, this gap hinders the normal flow of technical innovation from theoretical research to intermediate Technology Readiness Level projects.

Therefore, it is in the best interest of our community to progressively improve this flow. While a comprehensive shift in our research paradigm to address these challenges is not expected in the short term, we can focus on building trust in theoretical innovations. This can be accomplished through realistic control validation to enhance credibility, but without requiring theoretical control engineers to master applied control design too. This last part is crucial and requires validation scenarios to rely on simple, intuitive, and scalable tools. The lower the entry barrier, the easier for researchers to consider it viable. Taking into account the importance of these factors, Simscape [1] stands out as a control validation environment that combines the realism of digital twin models used in industry [2, 3] and the simplicity of a modular block-based interface with official training materials [4]. In contrast, other environments lack a full block-based interface –making them harder to use as a validation-only tool–, like those derived from Modelica [5, 6, 7]) and MapleSim [8]; or provide less direct integration with control design tools, like LabVIEW [9]; and all of them come without extensive official learning resources.

However, a tool will not directly simplify validation by itself, no matter how easy it is to use or how many general resources are available. What we need are materials tailored for researchers, with several workflows to implement any realistic model, support for common validation hardware, and closing the loop with simulated sensors. And this is what this contribution provides: a simple transition from the aforementioned learning resources [4] into control validation covering

1. An introduction on how to develop a basic model with the Simscape native toolset. This includes creating bodies with uniform density (or customised inertial properties), assembling them with homogeneous transformation matrices, adding degrees of freedom with feedback and actuation (including flexible connections), grouping subsystems for modularity, creating additional sensors to simulate the indirect feedback, and showing how to create mobile systems.

2. A collection of well-known robotic systems already implemented in Simscape [10], and how to use them for control validation purposes. These models are completely compatible with the previous workflows, so customised configurations of this common hardware are directly obtainable.

3. A guide to importing CAD and URDF models directly to enable control validation on any hardware with minimal online documentation. This includes a basic example, some limitations of this importation and how to overcome them.

On top of these materials, we discuss how to implement model-based controllers requiring kinematic or dynamic models, e.g., Jacobian or inertia matrices, using Rigid Body Trees and the Robotics System Toolbox [11]. As an example, we transform the model from the introduction materials into a Rigid Body Tree, and compare the feedback obtained using this and what a simulated sensor measures.

Altogether, this contribution enables control validation of any strategy against a target physical system, considering simplifications and sensor configurations. This includes, among others, multi-agent systems –as the environment is completely modular and limited feedback is easily implementable–, morphing systems, and complex models combining commercial and customised hardware.

References

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