Use of multi-body co-simulations for the optimisation of mechatronic systems - A drone case

Daan Bortels[1,2], Jari Peeters[1,2], Mathias Bos[1,2], Frank Naets[1,2]

[1] DMMS Core Lab
Flanders Make

[2] Dept. of Mechanical Engineering
KU Leuven
Celestijnenlaan 300, 3001, Belgium
daan.bortels@kuleuven.be

EXTENDED ABSTRACT

1 Introduction

The field of mechatronic design is constantly evolving, each day design teams try to optimise their designs to reach the highest performance levels. To reach their goals, optimisation algorithms/programs are being used more frequently, often providing promising design improvements. On top of this, a mechatronic system may consist of different components (mechanical, electrical, controller, etc.), each typically designed by a different team. Furthermore, every team will model their designated design in the best applicable software. For example, an electric drivetrain is often constructed as a lumped parameter model, while the movement and vibrations of a mechanical body are preferably calculated using a flexible multibody model.

In this paper a co-simulation interface is set-up to bring the different design domains together, while still maintaining the benefits of using the best suited software. To achieve this goal, a generalized interface is used in the form of the 'Functional Mock-up Interface (FMI)' [1], which allows the different designs to be imported as computational elements in the multibody model. This co-simulation set-up allows the optimisation algorithm to account for parameter changes along the various domains.

A drone case is used to both demonstrate the performance of the multi-body co-simulation and to showcase an example of an optimisation case. The optimisation algorithm will determine the optimal battery weight for a drone to achieve the longest possible time of flight.

2 Multi-body co-simulation using FMI

In this paper the co-simulation is limited to two contributions, a dynamical simulation of the drone using the in-house 'Multi-Body Research Code (MBRC)' from the Leuven Mecha(tro)nic System Dynamics department [2], and a lumped parameter simulation representing the drone blades, motors, batteries and controllers. This lumped parameter model is constructed in the commercial software package 'Siemens Amesim'. The main principle is that the MBRC acts as the master, while a Functional Mock-up Unit (FMU) representing the Amesim model is simultaneously running as the slave. This is possible by adding the FMU as an external force element to the dynamical multi-body simulation. As shown in figure 1, the multibody model provides position, velocity and acceleration data at intersect nodes, mimicking real-life measurement systems. Next, the FMU uses this input to calculate the corresponding forces or torques, which can be considered as input for the MBRC. The master-slave communication is depicted in figure 2.

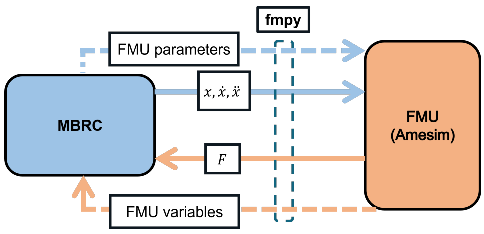

Figure 1: Schematic overview of the communication

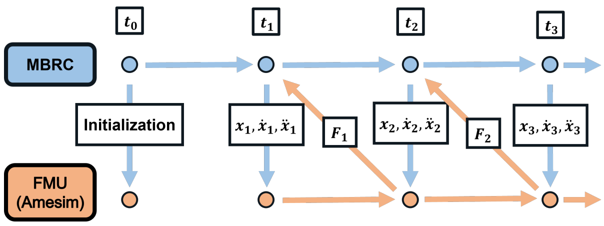

Figure 2: MBRC-Amesim master-slave relation

In general, when adapting parameters in the Amesim model, it is required to recompile the FMU. However, this would highly increase the simulation runtime. To overcome this problem a method is used that highlights important parameters or variables when the FMU is compiled. These important parameters are externalized in the MBRC allowing the FMU to be adapted internally. Furthermore, the relevant internal variables of the FMU are monitored and employed for the objective function of the optimization.

Using the adjoint state method, the sensitivities of the different parameters are determined. These can be used for the drone battery optimisation case.

3 Drone case - Battery optimisation

The selection of a battery for an optimal time of flight (TOF) seems straightforward, as a larger battery means more energy, means a longer travel time. But can it be that at some point a larger battery consumes more energy than it provides?

Using an heuristic approach it is possible to set-up an equation to describe the TOF in function of the battery mass. Deriving this equation to the battery mass can be used to find an optimal value for the battery mass. The presence of an optimum is highly dependent on the relation between the mass of the battery and its energy . But this is a simplification of the system, as a larger battery also has an impact on the controller parameters, the working regime of the motors and limits the possible acceleration. By using the multi-body co-simulation, these effects can be taken into account which might lead to different optimal values. Figure 3 depicts the relevant multi-body drone model, accompanied with the Amesim model of one of the rotor units in figure 4.

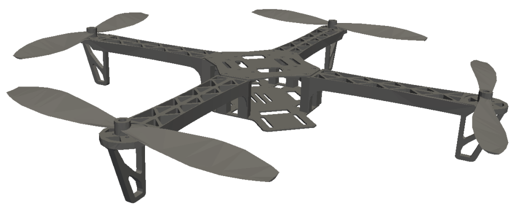

Figure 3: Visualisation of the multi-body drone

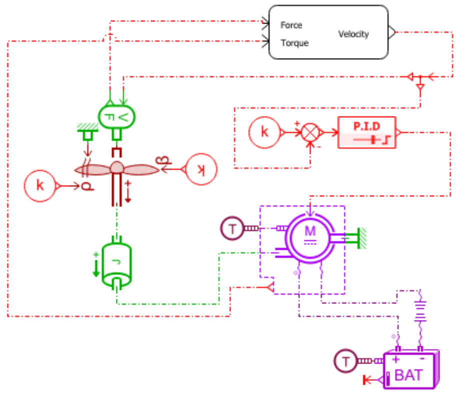

Figure 4: Amesim model of a rotor unit

4 Results

For the determination of the optimal value of the battery weight a different measure is used then the TOF, namely the percentage of battery usage during a 30 second flight. This represents the inverse of the time of flight, meaning that the optimal battery weight should correspond to the lowest battery usage. Figure 5 depicts the vertical velocity of the drone which is set to 5 m/s from standstill using a PID controller. This figure is added to confirm the working of the multi-body co-simulation using the FMU as an additional external model representing the motors, blades and batteries of the drone. Figure 6 depicts the battery usage in function of the battery weight, using both the simulation and the heuristic approach described in the previous section. As described before, the simulation takes into account the working of the controller, the motor and the rotor blades, this leads to the difference between both curves. The difference between the optimal values for both curves is minimal. In this simple case, the equations are limited but the simulation already shows it value in creating more accurate results.

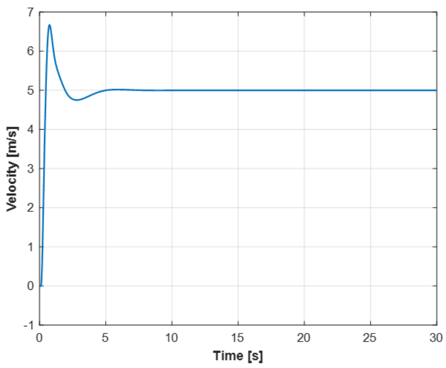

Figure 5: Vertical drone velocity from multi-body simulation

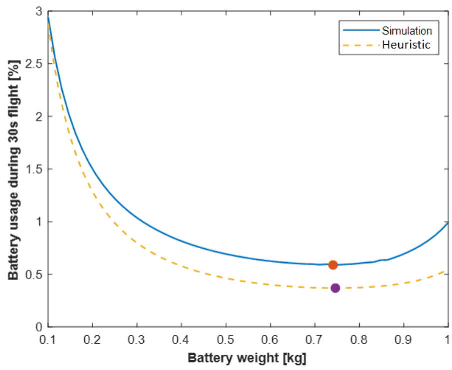

Figure 6: Battery usage in function of the battery weight

Acknowledgments

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References

[1] T. Blochwitz, et al., "The Functional Mockup Interface for Tool independent Exchange of Simulation Models Proceedings", 8th Modelica Conference, Dresden, Germany, March 20-22, 2011

[2] M. Vermaut, W. Desmet, F. Naets, "Flexible Natural Coordinates Formulation (FNCF): Towards Simpler Equations of Motion for Flexible Multibody Models", 2022, Ph.D. thesis, KU Leuven