TECHNISCHE UNIVERSITÄT DRESDEN

AIRBUS DEFENCE & SPACE

Faculty of Electrical and Computer Engineering • Institute of Automation

Testing and Validation of Small Spacecraft Docking Contact Dynamics using Hardware-in-the-Loop Simulation

Background

Docking is one of the most challenging phases during the physical connection of two Spacecraft (S/C) that are separately flying in space. The motivation to research about docking has been increasing recently for different reasons. One of these reasons is On-Orbit Servicing (OOS), which is one of the hot topics of the space technologies nowadays.[1] OOS aims at extending the lifetime of valuable operational satellites (by refueling, changing batteries, etc.) as well as removal of space debris. Before any of these OOS tasks could take place in space between the two flying S/C, a rigid and robust physical connection is required, which is accomplished by docking.

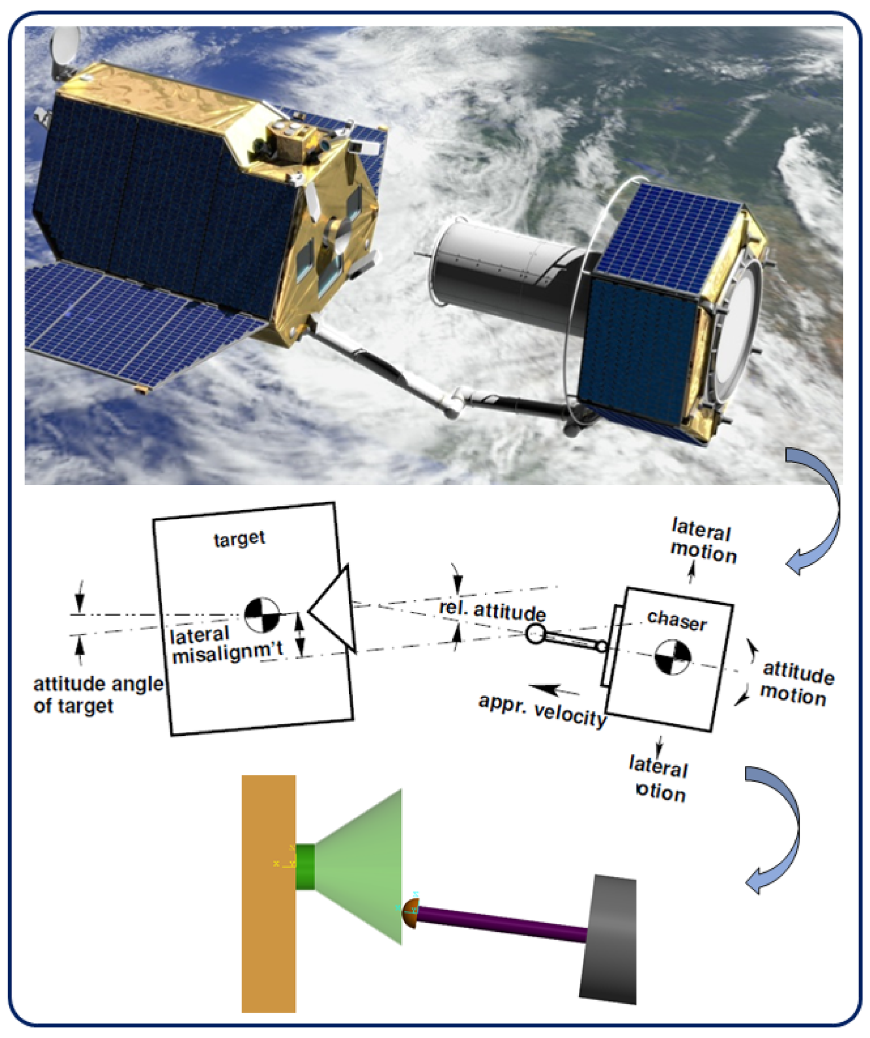

Fig.1: Modeling of two spacecraft during the docking process.[2,3]

Methodology

Many factors need to be taken into consideration, in order to have a successful docking. For example, S/C relative approach velocity, relative pose, and S/C physical properties. Therefore, a robust modelling and simulation of docking is required to verify the docking process, to assure a successful docking in space. Modeling of the docking scenario is mainly focused on two aspects: S/C dynamics and contact dynamics. [4] Contact dynamics is the most challenging and is concerned with the deformations and reaction forces of the bodies that get in contact with each other.
S/C docking multibody simulations need to be complemented and validated by Hardware-in-the-Loop (HIL) simulation using the real docking hardware, see Fig.2.

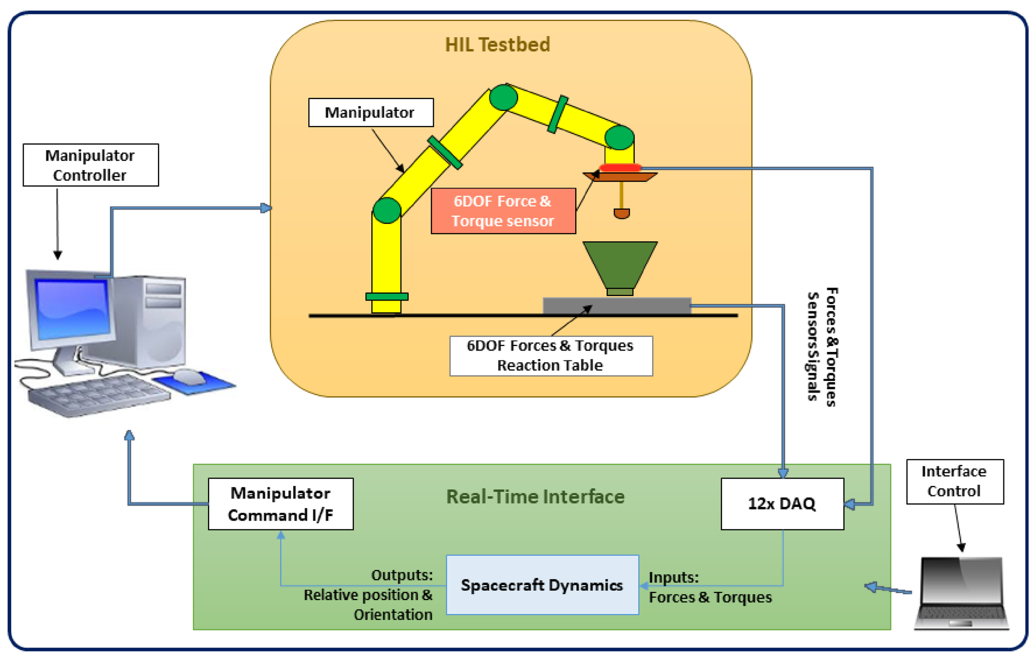

Fig.2: Conceptual HIL Configuration. [5]

Novelty

The novelty of this work will be shown in the following:

- Detailed contact dynamics analysis for small S/C ($<$ 1ton).
- Overcome many shortcomings of the previous docking testbeds, such as: stiff robotic hardware, ignored force feedback, using compliant devices that alters real docking forces.
- Validation of contact dynamics models using Hardware-in-the-Loop (HIL) simulation.

Contact Dynamics

Contact dynamic research has always been quite significant, since the first linear contact model proposed by Heinrich Hertz. Afterwards, many researchers have proposed various non-linear contact models, that consider more detailed aspects, such as, energy-losses due to impact, see Fig.3. Different contact models are implemented in our simulations, tested, and analyzed in order to select the most representative contact model.[5] Validation of the considered contact models using HIL simulation is required.

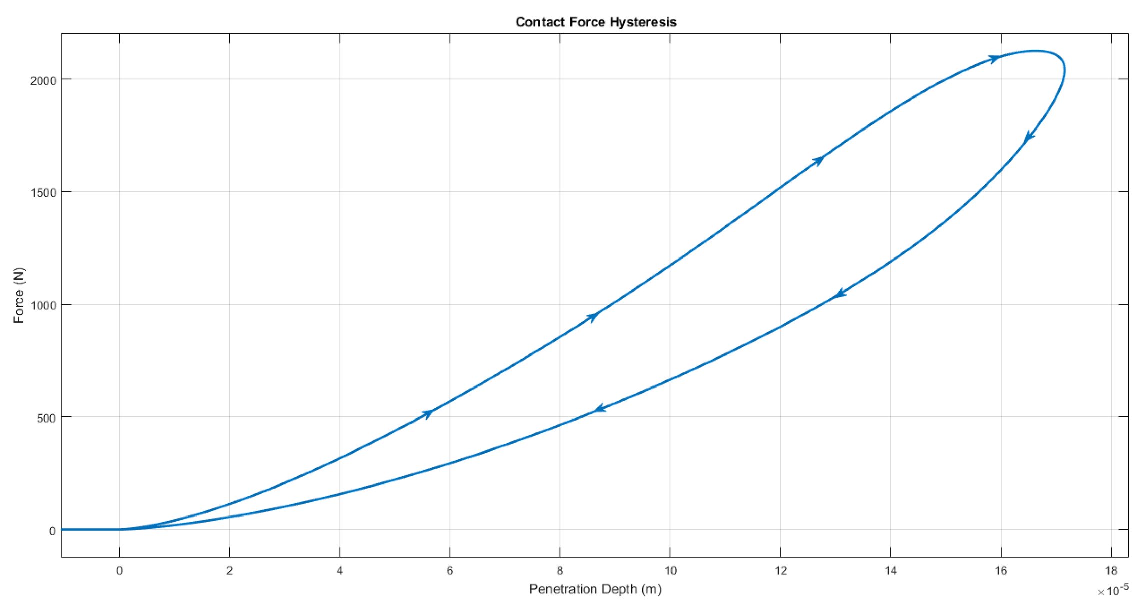

Fig.3: Contact force behavior with hysteresis according to the contact model of Flores et al. [6].

Hardware-in-the-Loop Simulation

As a precursor for the 6 Degrees-Of-Freedom (DOF) docking HIL simulation testbed, a novel 1DOF HIL testbed is designed, and implemented, see Fig.4. The 1DOF testbed demonstrates the feasibility and principle performance of the HIL simulation concept using dSpace real-time system. Most importantly, it is used to experimentally validate docking contact dynamics.

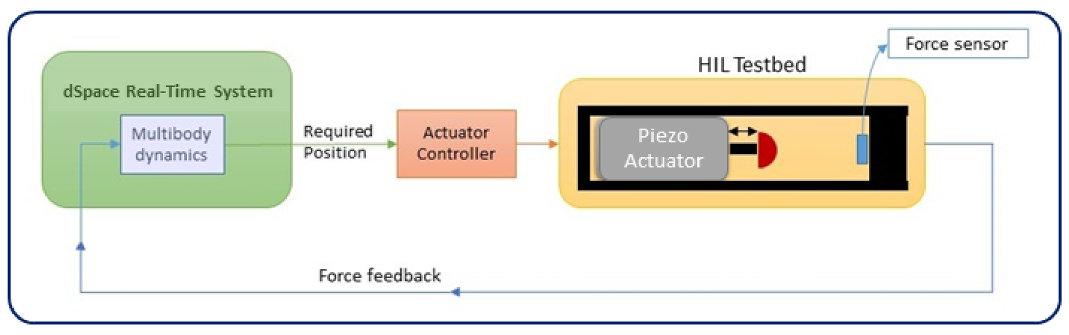

Fig.4: A novel 1DOF HIL simulation testbed for contact dynamics validation. [5]

References

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[2] Airbus DS [2014], PhD-Abstract-Presentation-2014
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[4] Bondoky et al. (2018): Analysis and Modeling of 6dof Docking without Compliance Using Nonlinear Contact Dynamics. AIAA SPACE, Orlando, Florida, USA.
[5] Bondoky et al. (2017): Analysis of Hardware-in-the-Loop setup without artificial compliance for docking contact dynamics of satellites. AIAA SPACE, Orlando, Florida, USA.
[6] Flores et al. (2011). On the continuous contact force models for soft materials in multibody dynamics. Multibody System Dynamics, 25(3), 357-375.

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