Verification Procedures and Results of the Spacecraft Docking Emulation using Hardware-in-the-Loop Simulation

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Introduction

• Domain
  - Assembly in orbit
  - Crew exchange
  - Repairs to the spacecraft
  - Re-supply
  - Retrieval of spacecraft

• Need of docking and capture
• Implies contact forces
Outline of Presentation

• The challenge of spacecraft docking
• Pure simulation and experimental methods used
• Research at the CSA
• Verification procedures
• Future tests to be performed
The challenge of Satellite Servicing

- The need to anticipate the dynamic behavior of the spacecraft during the capture and docking
- Necessity of using a good test and simulation facilities

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Pure Simulation Methods

- MDR Contact Dynamics Toolkit (CDT)
- Contact dynamics in Symofros

Disadvantages
- The contact geometries have to be defined
- Contact models are very sensitive to the set of parameters
- Numerical stability of the model

- Pure simulation methods are influenced by input parameters that can be very difficult to identify

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Experimental Methods Used

- MDR’S docking test-bed
- RDOTS (NASDA, Japan)

Disadvantages
- Inertial parameters are difficult to adjust
- Less than 6 degrees-of-freedom (DOF)

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Hardware-in-the-Loop Simulation (HLS) already use at CSA

Special Purpose Dextrous Manipulator (SPDM) Task Verification Facility (STVF)

Space Robot (Matlab/Simulink and Symofros)

Motion of end-effector

HLS

Force plate

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Extending Capabilities of the STVF

STVF with MDR End-Effector

Chaser

Target

Relative motion

MDR End-Effector attached to gripper of the SMT

Force sensor fixed to ground

Spacecraft

Dynamic of spacecrafts

HLS

CHALLENGE EXISTING SIMULATIONS AT THE CSA VERIFICATION PROCEDURES NEXT STEP

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Docking Simulator Architecture

Verifications made
- General functionalities (parameters, etc.)
- Validation of the satellites' relative behavior (initial vs operational)
- Output value vs input (verification of the force behavior of satellites)

Data preparation for the STVF
Transform the new trajectory to be used in the STVF model
Tests Performed (cont.)

- Pure simulation
  (Direct central impact with the peg probe)

Use of a simplified contact dynamics for point-to-plane collision

**Target mass** = 90 000 kg
**Chaser mass** = 90 000 kg
+ 900 kg (EE)
**Natural freq.** = 1.0 Hz
**Damp. ratio** = 1
**Approach vel.** = 2.1 mm/s

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Tests Performed (cont.)

- Verification of momentum conservation

\[ M_{\text{target}} V_{\text{target}} + M_{\text{chaser}} V_{\text{chaser}} = M_{\text{target}}' V_{\text{target}}' + M_{\text{chaser}} V_{\text{chaser}}' \]

- Target mass = 250 kg
- Chaser mass = 256 kg

Unused data
Tests Performed (cont.)

- Verification of energetic conservation

\[ E = \frac{1}{2} m v^2 \]

\[ E_{\text{final}} > E_{\text{initial}} \]

Mass too small?

Target mass = 250 kg
Chaser mass = 256 kg
Next step

• Try of other inertial parameters
• Find a good filter for the force

Goal: Use MDR End-Effect for the capture of the probe
Questions