The DLR On-Orbit Servicing Simulator: OOS-SIM

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Objective
On-Orbit Servicing (OOS) missions stand for a new class of complex space mission in which a servicer satellite is launched into the orbit of a target object. The servicer satellite is equipped with a robotic arm, a gripper and cameras. OOS missions are envisaged for:
- maintenance and life extension of existing satellites
- de-orbiting
- active debris removal

The DLR OOS-SIM

The DLR OOS-SIM is an on-ground robotic facility for simulating and validating on-orbit servicing operations [1], [2]. The facility is composed of:
- Servicer satellite with manipulator arm: a 6 DoF industrial robot (KR-120) performs the simulation of a floating satellite. The robot is equipped with a force-torque sensor. The manipulation task is performed by a light-weight robot (LWR) mounted on its end-effector. The LWR is equipped with stereocamera and a 3-fingers gripper.
- Client satellite: a second 6 DoF industrial robot (KR-120) equipped with a force-torque sensor at the end-effector simulates the dynamics of a floating body.

Control modes

The servicer manipulator can be controlled in position or torque mode. Three main operational modes are possible [3], [4]:

1. Telepresence:
   - the servicer manipulator arm can be controlled remotely with an haptic interface
   - the operator receives visual and haptic feedback
   - control methods have been developed to remove the destabilizing effects of the time delay and tested on a space link infrastructure.

2. Semi-autonomy:
   - provides extra operational safety, with respect to motion constraints
   - reference trajectory is planned based on the motion of the target satellite derived from the estimated target pose

3. Shared-control:
   - torque input from the visual serving component and from the telepresence component
   - weight allocation (a) can be set either by autonomy or the operator

Energy-based methods for simulating free-floating dynamics

The satellite dynamics simulated by the robot is affected by time-delay and discretization effects [2], [5], [6], [7].

1. Time Delay: causes system instability.
   Approach:
   I. Ensure the stability with the passivity criteria: 
   $E(x) = E(0) + \sum_{n=1}^{\infty} \xi_n^T(k)\xi_n \geq 0$
   II. Guarantees the performance of the simulated dynamics with an optimal damper.

2. Discretization: causes activity and position drift.
   Approach:
   I. Identify the energy generated by the integrator
   II. Render the integrator passive.

Energy generated by the Euler integrator

The energy observer:

$E_{E0}(k) = E_{E0}(k-1) - \Delta(t(k)) + b_0(k-1) + b_1(k-1)^2$

The passivity controller:

$\xi(k) = \frac{E_{E0}(k) - \xi(k)}{e(k)} - \beta \Delta P(\xi_{0}) \xi(k) \xi(k)$

Where $P$ is the positive definite matrix and $\beta$ is the feedback gain.

References

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