Specification

Servicer:
- KUKA KR-120
- Degrees of freedom: 6
- I/O: position/position
- Control frequency: 250 Hz
- Force/torque sensor for physical interaction

Manipulator:
- KUKA LWR 4+
- Degrees of freedom: 7
- I/O: position, torque/position, torque
- Control frequency: 1000 Hz

Gripper:
- Robotiq 3-finger
- Degrees of freedom: 4 + 7
- I/O: position, current/position, current

Client:
- KUKA KR-120
- Degrees of freedom: 6
- I/O: position/position
- Control frequency: 250 Hz
- Force/torque sensor for physical interaction

Haptic manipulator:
- KUKA LWR 4+
- Degrees of freedom: 7
- I/O: position, torque/position, torque
- Control frequency: 1000 Hz
- Force/torque sensor for dynamic compensation

Cameras:
- GigE, 1620 x 1220 px at 25 fps

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DLR at a glance

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 16 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

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DLR OOS-SIM

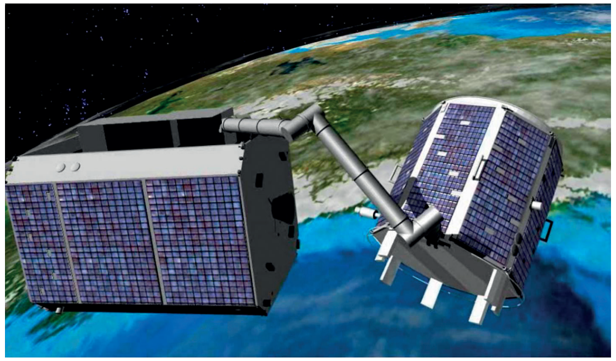
On-Orbit Servicing
SIMulator

On-Orbit Servicing (OOS)

Future space missions must tackle various complex challenges like assembling space structures of space stations. Life extension missions for various satellites are a further example. In case a subsystem breaks down or the tank runs out of fuel, it could be much more reasonable and cheaper to service the satellite than to replace it.

The amount of human-made objects in space has strongly increased over the last decades. Only a minority are working and operating satellites. The rest consists of space debris, like malfunctioning satellites, mission-related objects, parts of rocket stages, or fragments of previous crashes and explosions. With an increasing amount of space debris the danger of collisions increases, too. This scenario could give rise to a domino effect and the orbit, with all its commercial and scientific assets, would not be usable for many years.

The so-called On-Orbit Servicing (OOS) missions stand for a new class of complex space missions, in which a serviver satellite is launched into the orbit of a target object (client). The servicer satellite is equipped with a robotic arm, a gripper, and various cameras and sensors. OOS missions are envisaged either for life extension or deorbiting. After the client is reached, its current tumbling motion must be estimated and predicted for planning a safe and robust grasping. After the grasp, the two satellites must be stabilised and rigidly docked. Now, the robotic arm is free to fulfil potential servicing tasks. In the end, the servicer will either leave the repaired client in orbit, or, if not repairable, it will perform a deorbit together with it to keep the orbit clean.



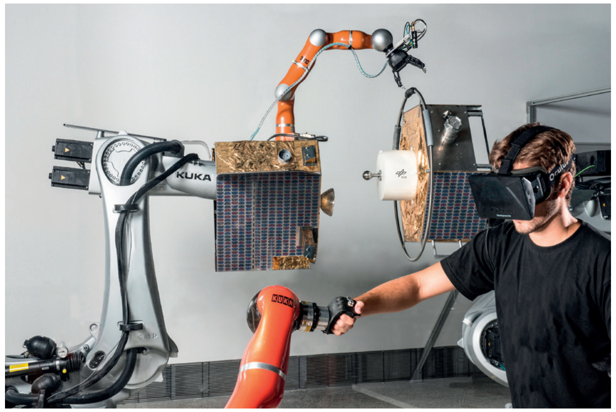
Animation environment of orbital scenario

The OOS-SIM facility

The purpose of the OOS-SIM facility is twofold. Firstly, it emulates orbital robot and free-body dynamics. Reproducing orbital dynamics on the ground is a challenging task. This facility presents a yet worldwide unique solution, with its configuration comprising of an industrial robot and a Light-Weight Robot (LWR) mounted in series (servicer robot).

The second purpose of the facility is to perform testing and analysis of orbital robot control methods for development and validation purposes. Given the gravity-free dynamics, the robot control requires dedicated solutions to master the interaction of the robot motion with that of its base, the servicer. The latter can be controlled following different operational strategies: principally with or without use of its actuators (e.g. thrusters). Both these strategies are current research themes at the RM Institute.

The demonstration of the grasping of a non-cooperative tumbling target satellite is the ultimate goal of the facility. The non-cooperative aspect relates to the fact that the target is not controllable and does not provide any visual aid on its surface. For this complex task, not yet demonstrated in orbit, and goal of space agencies worldwide, the necessary control methods, which account for the sensitive free-tumbling dynamics of the target as well as for the harsh and remote orbital environment, also require the development of dedicated solutions and testing procedures.



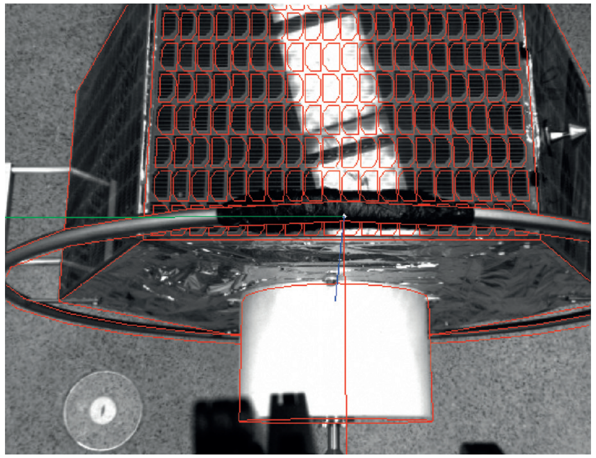
OOS-SIM (in background) with teleoperator (in foreground)

Operational modes

The servicer manipulator can be position or torque-controlled, whereby two main operational modes are possible: telepresence and autonomy.

In the telepresence mode, the operator on-ground receives visual feedback from the stereo camera and haptic feedback of the interaction forces between the servicer manipulator and the client satellite. The operator can command the robot remotely and perform manipulation tasks on the target satellite using a haptic interface. At the RM Institute, methods have been developed to remove the destabilising effects of time delay that are common in long-distance teleoperation with force feedback.

The goal of the autonomy operational mode is to provide extra operational safety with respect to the motion constraints, such as collision avoidance and camera field of view limits. Generally, a reference trajectory is planned based on a motion prediction of the tumbling target. This is derived from the target pose estimates resulting from the stereo camera images. The reference trajectory is computed on the ground and then uploaded to the robot in space, where visual servoing accounts for disturbances as well as for modelling and motion prediction errors.



OOS-SIM target pose estimation