Development, analysis and validation of optimal trajectory planning and adaptive control algorithms applicable for multibody dynamical systems operating in microgravity conditions

The number of satellites on Earth's orbit has increased significantly in recent years. Experts predict that the development of technology in the field of space robotics will enable In-Orbit Servicing (IOS) with the use of unmanned satellites capable of performing repairs. Such satellites could also be used for capturing and removing large space debris from orbit in order to stop the growth of debris population. The European Space Agency (ESA) is working on the concept of Active Debris Removal (ADR) in the frame of the Clean Space initiative. The IOS and ADR missions will require capturing of the uncontrolled target object with the use of a robotic manipulator. This will be the most challenging part of these missions because the reaction forces and torques induced by the motion of the manipulator influence the position and attitude of the servicing satellite.

The main scientific goal of the project is: to develop, analyze and validate a class of trajectory planning and control algorithms that will allow the manipulator mounted on the servicing satellite to capture an object in orbit (e.g., malfunctioned satellite). The proposed approach will allow to plan the trajectory in an optimal way, i.e., to find the best possible trajectory that fulfills certain additional goals. The motion of the manipulator influences the attitude of the satellite, so it is possible to find such a trajectory, that will allow to grasp the target object and, at the same time, minimize the changes of the servicing satellite attitude. Due to the fact that the base of the manipulator is free to move and rotate, it is necessary to use mathematical equations that describe the dynamics of the satellite-manipulator system during the trajectory planning stage. This is the main difference between the fixed-base manipulators operating on Earth and proposed manipulators that will be mounted on small satellites. Due to disturbances acting on the system and due to non-perfect knowledge of system parameters a closed-loop controller is needed to ensure realization of the manipulator trajectory. Adaptive controller will be developed for this purpose. Numerical simulations will be performed to analyze the proposed trajectory planning and control methods. The approach developed in the project will be compared with other methods known from the literature. The feasibility of the trajectory planning methods will be demonstrated in experiments performed on the planar air-bearing microgravity simulator. This test-bed uses air-bearings to provide frictionless motion of the satellite mock-up equipped with the manipulator. The air-bearing microgravity simulator will be upgraded: reaction wheel will be added for optional attitude control and a new sensor will allow high precision measurements of the satellite attitude. Additional test campaign will be conducted with the use of an industrial manipulator with 7 joints. The last task of the project will be focused on the critical evaluation of obtained results. It is proposed to introduce numerical criteria that will allow comparison of various trajectory planning methods. An assessment of how the considered method performs in a given scenario, taking into account initial conditions, is the key element of the project.

The strength of the project arises from the fact that the three main research areas (the mathematical modelling of the satellite-manipulator system, trajectory planning and closed-loop control) are considered jointly. The development of the trajectory planning and control methods is inspired by real needs and potential future demand for such technologies. The development of these methods could be continued for their potential application in the IOS and ADR missions.

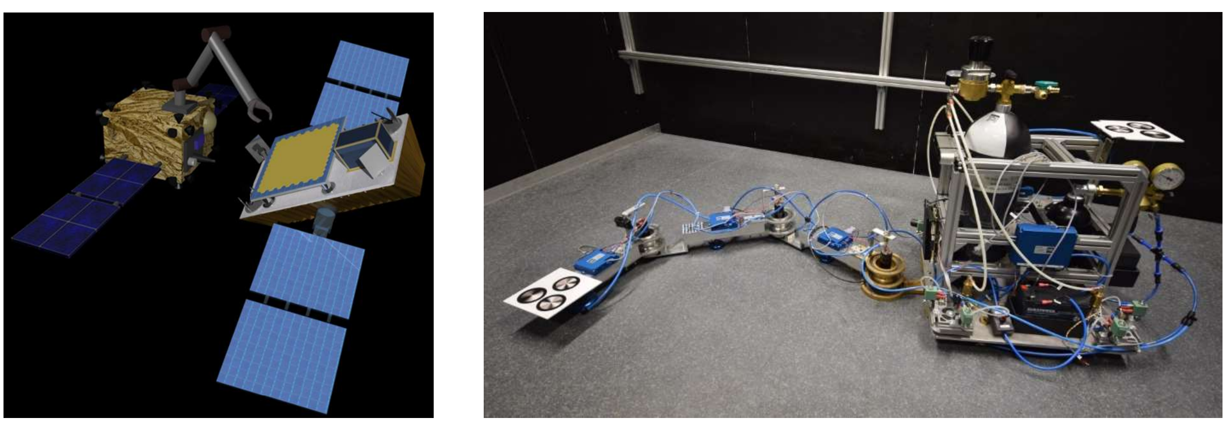

Figure 1. Artistic rendering showing the concept of the in-orbit servicing mission (left panel) and the satellite mock-up on the planar air-bearing microgravity simulator that will be used in experiments (right panel).