RICADOS - RENDEZVOUS, INSPECTION, CAPTURING AND DETUMBLING BY ORBITAL SERVICING

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ABSTRACT

The paper presents a system called RICADOS (=Rendezvous, Inspection, CApturing and Detumbling by Orbital Servicing), a new on-board inspection, rendezvous and robotic system for on-orbit servicing (OOS) and a ground system for operating servicing missions including telepresence tasks. The RICADOS system provides robust and reliable inspection, guidance, navigation and control functionality to approach a target satellite in its orbit, and a robotic sub-system for final capturing and detumbling / stabilization of the target. Further, the RICADOS system does not only consist of the OOS payload. For simulation of the space segment two robotic hardware-in-the-loop test facilities are used: the European Proximity Operations Simulator (EPOS) 2.0 and the On-Orbit Servicing Simulator (OOS-Sim). It includes further a satellite simulator where i.a. the orbital and attitude dynamics are computed. RICADOS also simulates the communication path between space and ground and it contains a ground segment, which equals the ground segment of real missions, such that the operating team can perform tests and trainings from real consoles at the control center. Especially, the most critical phases of such a mission, the final close range approach, the capturing process and the stabilization can be tested within a very realistic environment.

1. INTRODUCTION

Safe de-orbiting and increasing the life-time of satellites by on-orbit servicing (OOS) will be of high importance in future spaceflight. The rendezvous and docking/berthing (RvD/B) phase is one of the most complex and critical parts of on-orbit servicing and debris removal missions.

Several missions and developments have been started like the Restore-L mission of NASA [1], the RSGS (Robotic Servicing of Geosynchronous Satellites) program of DARPA [2], the Mission Extension Vehicle (MEV) of Northrop Grumman Innovation Systems [3] and the ESA Clean Space Initiative (e.Deorbit) [4]. Robotic servicing will be of importance also in human spaceflight since rendezvous and docking technology generally plays a major role in all assembly, service and maintenance tasks.

All these missions require robust and reliable guidance, navigation and control (GNC) systems for rendezvous and robotic systems for berthing and maintenance tasks. In a recently started project called RICADOS (= Rendezvous, Inspection, CApturing and Detumbling by Orbital Servicing) the German Aerospace Center (DLR) develops a new on-board inspection, rendezvous and robotic system as well as a ground segment for on-orbit servicing including telepresence capability.

Both on-board and on-ground sub-systems are developed (rendezvous, inspection, berthing, control, communications and operations sub-systems). Further, a unique end-to-end testing environment [5] is used and continuously improved: The space segment is simulated using two robotic hardware-in-the-loop test facilities at the German Aerospace Center: the European Proximity Operations Simulator (EPOS 2.0) [6] at DLR-German Space Operations Center, where the inspection and rendezvous is tested and demonstrated, and the OOS-Simulator (OOS-Sim) [7], [8] at DLR-Robotics and Mechatronics Center, where the capturing and detumbling are performed. The robots' motion is generated by a numerical satellite simulator in software based on orbit and attitude dynamics for service and target satellite, simulation of actuators and of the satellites' environment. The communication path from space to ground and vice-versa is simulated such that different scenarios can be tested: Different channel parameters such as telemetry and tele-command data loss, jitter and delay can be chosen for realistic tests. The ground segment is established just like for a real on-orbit servicing mission with a mission control system (MCS), special data processing and visualization applications, control room infrastructure and the on-orbit servicing specialized consoles (rendezvous console and robotic console). In a multi-mission control room, which is used for real missions at the same time, the operators can train and collect experience how to run a real on-orbit servicing mission including the robotic capture via telepresence.

Figure 1 shows an overview of the RICADOS architecture with all ground sub-systems, all software simulators of the real physical system (communication path and satellite sim-

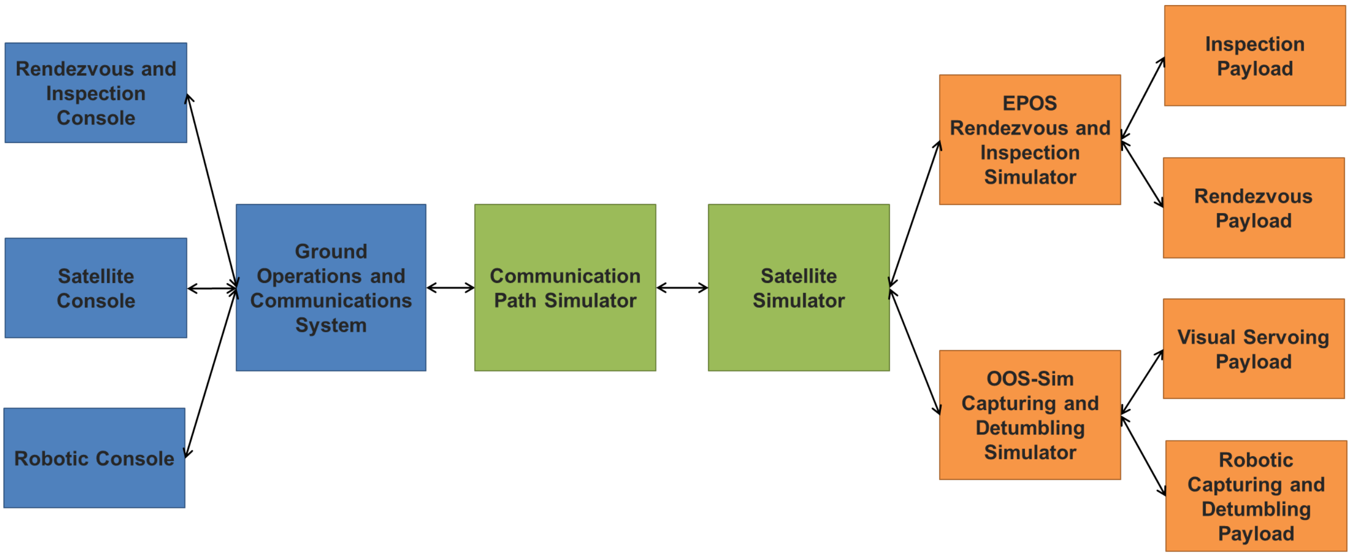

Fig. 1. Overview on the RICADOS system with its main components. Blue: Ground Segment, Green: Software Simulation, Orange: Hardware-in-the-Loop Simulation

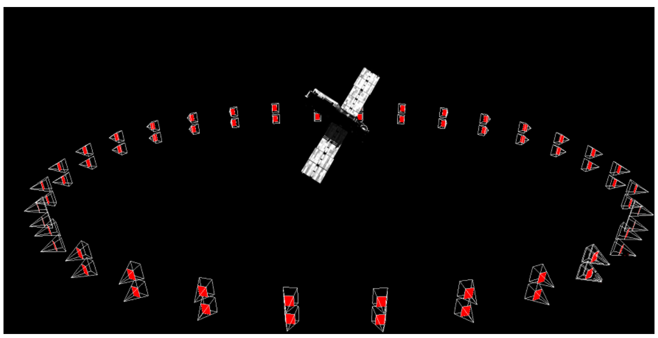

Fig. 2. Depiction of a round trip flight around a satellite [9] with camera poses, based on the software-based image simulation tool.

ulator) and all hardware-in-the-loop test facilities with their payloads.

The paper is structured as follows: First, the individual components of the RICADOS system are presented in chapter 2; this includes the inspection system, the rendezvous system, the capturing / berthing system, the combined control sub-system as well as the communication and mission operation system. In chapter 3, the simulation and test environment is introduced and a first testing scenario is described before giving a final conclusion (chapter 4).

2. RICADOS SYSTEM

2.1. Inspection

The inspection phase is the chronological first part of RICADOS. We assume that a successful far and mid range approach towards the target satellite has been performed (for example via angles-only navigation with monocular far and mid range cameras [10, 11]). RICADOS therefore starts at a hold point at about 15 - 20 meters distance to the target satellite. For far and mid range rendezvous, it is often sufficient to determine the center of the target in camera images and to compute thus the relative position between servicer and target. However, for the next phases of a servicing mission, some more details about the target satellite needs to be known so that 6D pose estimation (position and orientation) can be performed.

The task of an inspection system is to investigate the geometric properties of the target satellite. A reliable, accurate 3D point cloud (the geometric model) of the observed object is generated on the basis of visual inspection sensors, which allows a comparison with a reference model for change detection.

During the inspection phase a round trip flight around the target satellite is performed (see Figure 2) and a stereo camera system mounted on the servicer records images. The data is saved on-board and sent to the ground station during ground contact using standardized space data handling systems (CCSDS, ECSS) described in section 2.5. A geometric model in the form of a point cloud is generated (see Figure 3). Subsequently, the target satellite can be checked for damage based on the images themselves and the generated point cloud. The results are sent back to the servicer to engage the rendezvous phase.

The current research tackles the robust point cloud generation of a small rotating object under strong lightning conditions. Two related photometric methods based on stereo- and monocular-cameras are explored. First, Visual Odometry is investigated in combination with a subsequent dense im-

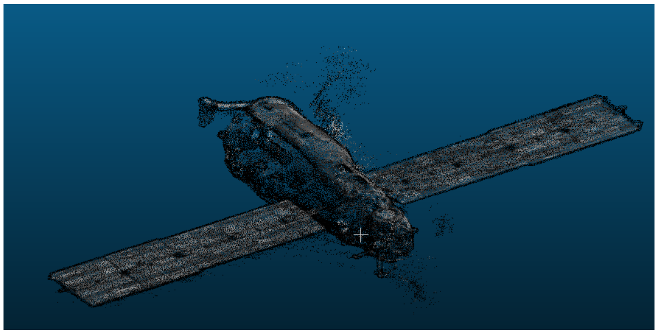

Fig. 3. Exemplary generated point cloud [12] from simulated images with weak lightning effects.

age matching, represented by the visual part of the Integrated Positioning System (IPS) [13]. It detects, tracks and matches distinctive image points such as corners in the images of two subsequent stereo pairs to reconstruct the relative ego-motion of the servicer to the target satellite. A subsequent application of semi-global matching (SGM) [14] provides a dense point cloud. Second, the application of professional bundle adjustment tools for 3D reconstruction [12, 15] from either mono- or stereo images is investigated. They refine the position of the 3D-reconstructed points and all estimated camera poses simultaneously by minimizing a global energy function. The application of a monocular camera simplifies the construction, while a stereo-camera eases the estimation of the models scale.

For the development and validation of the proposed inspection methods, a multi-camera-IPS is used in the DLR's facility EPOS 2.0 for image data capturing during a simulated round trip flight. In order to create diverse data sets to ensure the robustness of the developed method, a software-based image simulation tool of DLR is used and further developed. It allows the simulation of different satellite mockups and a simplified application of different camera system configurations under many possible lighting conditions.

2.2. Rendezvous

The rendezvous GNC system [16, 5] controls the chaser satellite's approach towards the possibly uncooperative target object by processing the information from optical 2D and 3D sensors. Mainly dictated by the capabilities of the associated hardware-in-the-loop environment EPOS (see section 3.1), the GNC system focuses on the final approach beginning at roughly 20 meters up to the mating point close to the target, where the hand-over to the robotic system can take place. Figure 4 shows an overview on the GNC system.

In its current state, the rendezvous GNC system is equipped with a CCD mono-camera and a PMD (3D) camera [17], with the former serving as the primary navigation sensor. An edge tracking algorithm calculates the relative pose of the target with respect to the chaser satellite from the CCD image data, see Figure 5. An Extended Kalman filter computes a smoothed solution from these estimates [5]. The guidance function provides a smooth and continuous trajectory assembled from a succession of automated sub-trajectories. Finally, the position controller computes control forces from filter estimates and guidance trajectory.

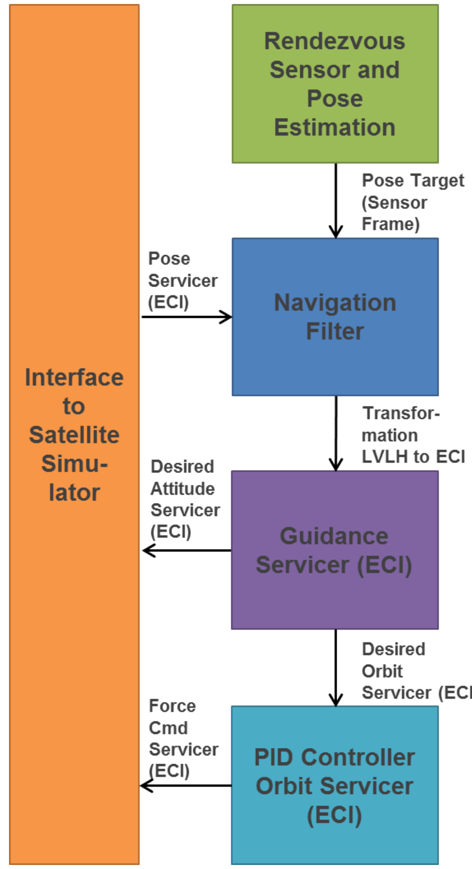

Fig. 4. Overview on the GNC system

The GNC system is designed as highly decentralized software to exploit parallel and asynchronous computer architectures of the future [18]. For example, the Kalman filter processes input data with time stamps, such that a considerable and varying delay, a typical property of non-deterministic pose estimation algorithms in general, can be handled robustly and elegantly.

An operator monitors and controls the approach at the rendezvous console, in a real multi-mission control room at GSOC (German Space Operations Center), using standard communication protocols used in practice. During brief contact times, the operator sends high level tele-commands that have the chaser satellite follow parametrized sub-trajectories autonomously. This means, that the complete approach trajectory is not defined a priori and can be adapted flexibly step by step to the actual situation and the available information

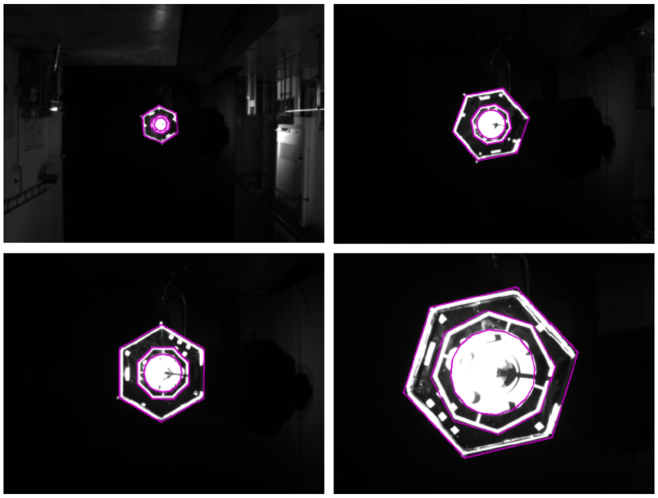

Fig. 5. Exemplary CCD camera images at different distances and detected target

Fig. 6. The operator at the robotic console performs grasping of the target via telepresence.

about the target at that point.

In the future, GNC system development will lead to more sensors, like a scanning LiDAR, more sophisticated pose initialization and tracking algorithms, as well as intelligent fusion of the different pose estimates, to increase robustness, reliability and flexibility.

2.3. Capturing / Berthing

After the close range approach to the mating point is finished, the next step is the capturing of the target. In close proximity conditions the robot manipulator mounted on the servicing satellite performs capturing and berthing operations. The target satellite is assumed to be free-tumbling, in that its attitude control system is no longer active. The geometry of the satellite however is known after the inspection phase has been executed, see Section 2.1 such that a suitable grasping point can be selected prior to the mission. The grasping task involves approaching and grasping a predefined point on the target satellite with the robot manipulator, and stabilizing its motion. The robot commands must be related to the measured pose of the target satellite. The measurement is achieved through a stereo camera at the robot end-effector. However, motion constraints need to be accounted for, to include: limits of the robot workspace; robot kinematic and dynamic singularities; collision avoidance; limits of the stereo camera field of view and pixel velocity.

We solve the given problem by first generating a feasible reference trajectory with an off-line motion planner. Given the complexity of the nonlinear, constrained motion planning problem at hand, and in order to guarantee the feasibility of the solution, we solve the problem off-line using a model of the environment (e.g. geometry of the bodies of interest, tumbling motion of the target satellite). We also generate a database to cover relevant tumbling states of the target satellite [19]. In the on-line setting we then feed the reference trajectory to a tracking controller, together with the sensor measurements [20].

For the approach to and grasping of the grasping point, the controller includes a visual servo in cascade with an impedance controller, to simultaneously achieve a tracking functionality, as well as a suitable compliance to undesired impacts with the tumbling target. The visual servo is fed pose estimates derived from the camera measurements, allowing the controller to account for modeling uncertainties in the model used by the motion planner. For the subsequent stabilization of the relative motion between the two satellites, which follows the grasping phase, the tracking control task is performed in the joint space of the robot. The reference trajectory from the motion planner is updated on-line, to account for deviations from it, which resulted in the previous approach phase from the modeling uncertainty.

But concerning the success of a real robotics mission, we have also developed an alternative to the previously described autonomy approach, using off-line generated trajectories in combination with on-line path refinement (visual tracking). We additionally develop and train an operational mode, telepresence, which keeps the operator in the control loop, see Figure 6.

This additional telepresence mode allows the direct, immersive interaction with the remote situation, using haptic and visual feedback. In this mode, the entire controlled system is distributed between the robot arm on-board (slave) and the haptic console (a force-reflecting master device such as the impedance-controlled DLR light-weight robot) located on-ground. Further, the visual feedback of the hand-mounted camera on-board will be augmented with additional data, to provide the operator with the necessary information, to get a sufficient overview about his/her interaction with the current situation on-board.

2.4. Combined Control

Analyses of on-orbit servicing mission requirements, e.g. for an Envisat deorbiting mission, have clearly shown that classical conservative control approaches are not appropriate anymore [21]. Typically, they split the operations of the servicing system in two parts. In the first part only the satellite is controlled while the robot joints are locked. In the second part the satellite attitude and orbit control system (AOCS) is switched off while the robot arm is controlled. However, the performance of such type of control strategy is not sufficient, in particular if the target is uncooperative and tumbling. Coordinated Control approaches, where satellite and robotic arm are controlled independently at the same time, are currently implemented in the RICADOS simulator. The solution works sufficiently with respect to performance but provides no formal prove of stability which is essential for portability to real space applications.

A technique that exploits the entire installed performance of the servicing system is Combined Control. In this approach all actuators of the satellite and robot joints are controlled within one integrated control system. Due to the nature of the space application the controller has to deal with many uncertainties like inaccuracies of the given system mass and inertia parameters, deviations of nominal actuator performances under space conditions, or inaccuracies and noise of sensor feedback. In order to realize a stable combined controller that has sufficient performance and robustness under consideration of the given uncertainties, a solution based on the H-infinity control technique [22, 23] is now under development.

The selected H-infinity control solution is based on a linear time-invariant (LTI) model of the servicing system. The state space description of it is specifying the plant dynamics at a nominal operations point and is used as initial kernel of the controller design. Since the system is characterized by very different types of actuators (thrusters, electrical arm motors) and sensors (cameras, joint angle resolvers, inertial measurement unit), the input signals and the control errors are scaled in a first step to be prepared for unified handling in the design process. In the second step the system is being augmented. The term augmentation describes an extension of the system by filters that are used to tune the system's frequency dependent sensitivity in terms of control inputs, and the robustness in terms of external disturbances and sensor noise. The augmentation is the first part of the loop shaping process while the second one is the numerical optimization of the augmented plant's state space controller such that the H-infinity norm of the system sensitivity is minimized.

The optimized controller is finally implemented as a mission specific component in the RICADOS real-time simulator. In this context, the combined controller will be part of

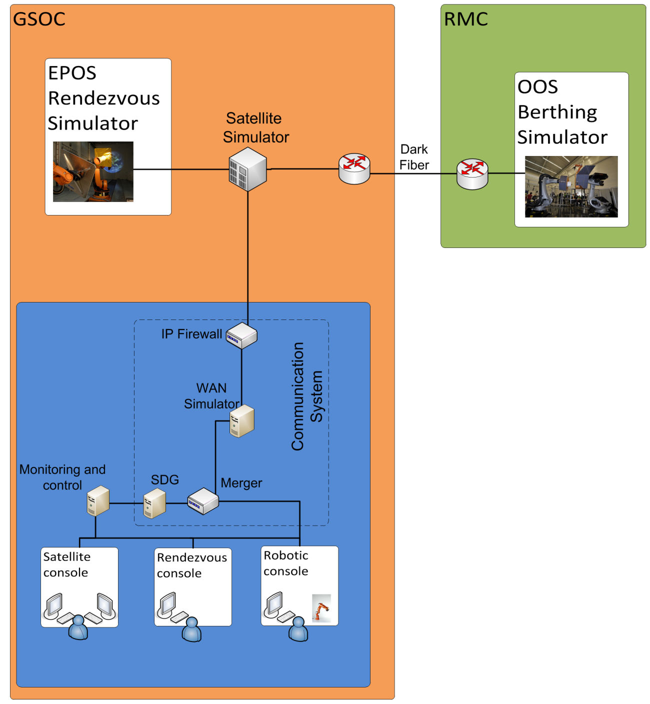

Fig. 7. Overview on the communication system

the AOCS of the satellite bus model and can be activated by dedicated AOCS mode and control reference settings from the RICADOS satellite console in the control center. Housekeeping telemetry from sensors allows for tracking of the control performance on the ground consoles. In the current pilot implementation the combined controller will control the arm deployment after finishing the rendezvous and the arm retraction after finishing the grasping.

2.5. Communications

The communication system interconnects all subsystems and assures respective protocol compatibility.

The system provides near real-time communication capability to send and receive timely deterministic data packets for the robotic payload and the housekeeping (bus) allowing parallel operations.

Figure 7 gives an overview of the communication concept. A so-called dark fiber (dedicated glass fiber) is used to connect the OOS-Sim located at the Robotics and Mechatronics Center to the GSOC buildings. The link is completely separated from any other DLR Site traffic, which fulfills data quality and security requirements. The deterministic (timed) real-time communication is realized mainly through the chain between the robotic console and the satellite simulator. This shall emulate a similar path of a real mission, where the data packets need to travel through the local network at the control center, through terrestrial data links and finally through the

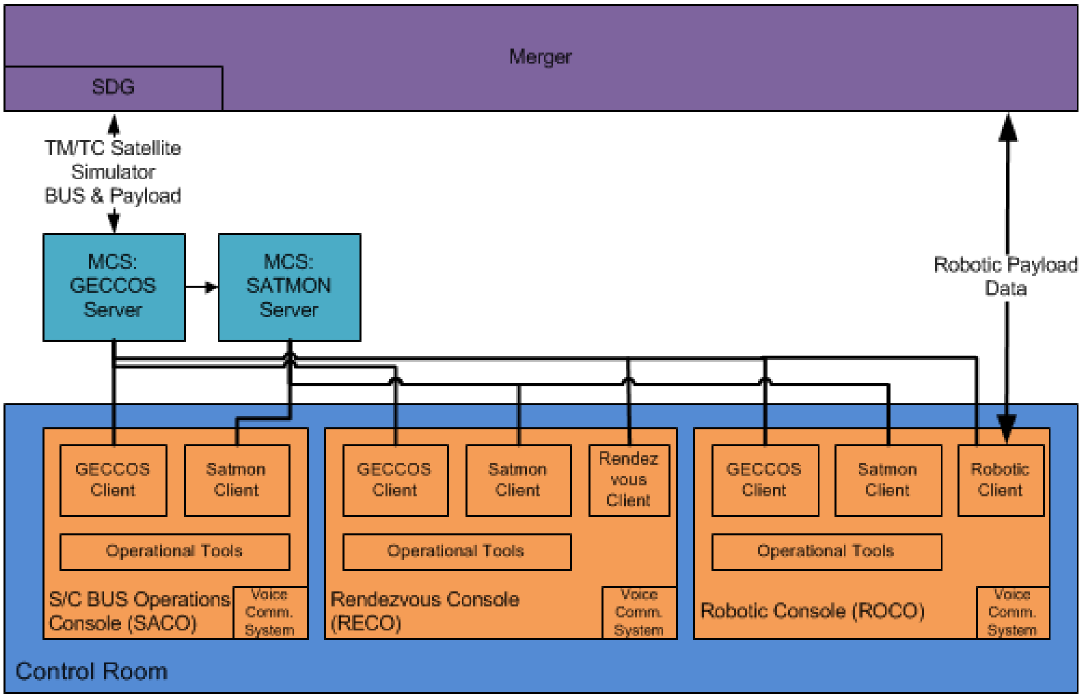

Fig. 8. Setup of the Mission Operations System: three console types for satellite, rendezvous and robotic control are connected to the Monitoring and Control System (MCS) which processes the incoming telemetry and compiles outgoing telecommand data which are received/forwarded to SDG and Merger for routing to the satellite simulator.

antenna, converted to radio waves and to the spacecraft. The communication concept works with timing settings of 2.5 ms period for a single data packet, delay of not more than 500 ms, and jitter lower than 1 ms). It uses the space data link protocol with communications link transmission units-CLTUs for commands and telemetry frames for telemetry. UDP is used for the terrestrial data transfer and a merger. The merger is used for the parallel housekeeping commanding from standard monitoring and control system GECCOS and the robotic console.

The merger device is based on custom programmed field programmable gate array (FPGA), and stringent timing has been developed. It can receive two command streams with CLTUs from two sources, use simple buffers to accommodate for potential delays, and send the CLTUs out at timed fashion (every 2.5 ms. one CLTU) towards the satellite simulator. For the downlink, the merger has a buffer, to compensate for eventual jitter, and forward the telemetry to both outputs.

In addition, another FPGA-based device-the IP firewall-has been developed. It decapsulates spacecraft data (CLTU or telemetry frames) out of UDP/IP datagrams, moves it within internal registers, and packs into new UDP/IP packets. This is performed on a stringent timed base, to not induce any jitter or delays. There is also a WAN simulator as a Linux-based software solution, which allows changes in packet delay and jitter or packet loss. This will be used to simulate different terrestrial or space link conditions. The last component, the SDG is a simple protocol converter between the TCP/IP of GECCOS and the UDP/IP-based simple space link protocol. In order to incorporate the system on the GSOC operational network, the IP Firewall and the Merger must be redundant. The idea is to update these two devices and increase the buffer of the merger and integrate them into the operational network of GSOC being failover and fault tolerant.

For more details on the technical implementation, we refer to [24].

2.6. Operations

One major goal of the RICADOS project is not only to develop an overall system including their payloads but also to make the whole system as realistic as possible to simulate and verify several scenarios in a realistic manner: all operations (recording inspection data, rendezvous, capturing and detumbling) shall be done completely from ground like during a realistic mission in space. All operational constraints, i.e. short spacecraft contacts, remotely accessed ground stations, operations from control rooms, etc., shall be taken into account. Further on, the space segment (the satellite itself including its payloads (see sections 2.2, 2.1, 2.3) has to be accessed via the communication system (see Figure 7, section 2.5) and has to be controlled by the Mission Operations System, the operational back end of the whole RICADOS setup which shall be equal to other missions operated by the German Space

Operations Center (GSOC). This strategy implies also that communications between ground and space segment have to follow Space Standardization on data handling on many layers, (a) not only the communication layer itself (following CCSDS standards), but also (b) on Packet and Application Layer (CCSDS, PUS/ECSS standard). Due to this approach many space flight-proven tools, configuration items, procedures and infrastructure can be re-used from other missions which are able to process the RICADOS specific data.

To fulfill the scenario to be as near as other GSOC satellite mission systems, the operations from a dedicated control room is required. It entails the GSOC generic mission operations console located within the operations LAN (see Figure 7), the voice communications system, redundant electrical and network infrastructure, etc. One component of a console is the Terminal PC which is uniform for all GSOC control rooms. Whenever an RICADOS affiliated user logs in one of the following console setups can be chosen: (i) the Satellite Operations Console (SACO), (ii) the Rendezvous Console (RECO) or (iii) Robotic Console (ROCO). The setup of the Mission Operations System is shown in Figure 8.

All three console types integrate in principle the same set of mission operation tools, which are

- GECCOS, the GSOC generic Mission Control System (MCS) for satellite operations [25],
- GSOCs standard display system called SATMON,
- access to the operational web server (OPSWEB) and file server, where all mission-relevant information is gathered (e.g. mission database definitions, reports, observations, recommendations, flight procedures) and
- RECO- and ROCO-specific tools, each integrated on a dedicated virtualized host.

Drop-boxes communicate between the encapsulated operations LAN and outside to make file based data exchange possible. All mentioned subsystems are implemented in a redundant manner. The mission control system GECCOS forms the heart of the ground segment: it connects to the SDG (see section 2.5) from where the telemetry and telecommand communication to the communication facilities is ensured. The MCS receives its telemetry data in form of telemetry frames, processes telemetry packets and telemetry parameters and provides these data to all consoles. It exports additionally gathered data into files which are transferred to the Inspection Subsystem via automated file transfer services. In turn the MCS also processes and compiles telecommands which are uplinked to the satellite simulator via the SDG. For studying the data visually an instances of the SATMON display system, also part of the MCS, can be launched where individual monitoring pages like plots or alpha-numeric displays can be defined.

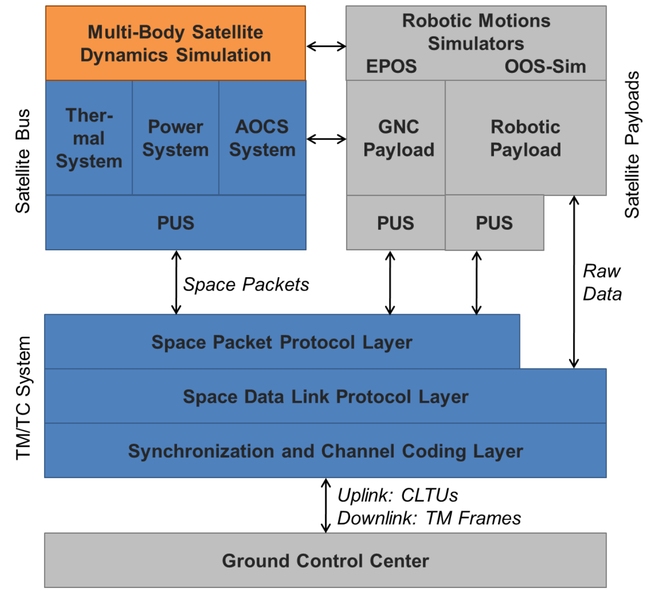

Fig. 9. Overview on the satellite simulator (non-gray components) and its interactions within RICADOS: Simulation-specific components (orange) and mission-specific components (blue)

All described tools of the RICADOS mission operations system, except special consoles (rendezvous and robotic console) or specific software of the communication system, are directly taken from the GSOC tool suite with state-of-the-art software versions. Only the spacecraft database describing its telemetry and telecommand structure and other configuration items had to be adapted as it has to be done at any mission. Tests and first simulations have shown that all communication flows are realized: the telemetry-telecommand link through the communication system from the MCS to the satellite simulator as well as data the flow of processed data between the three consoles including the data delivery to the specific tools for the rendezvous- and robotic console.

3. RICADOS SIMULATION AND TEST

3.1. Test and Simulation Infrastructure

In the following, a short overview on the RICADOS test and simulation infrastructure is given. For a more detailed description, we refer to [5].

For test and verification of the sub-systems of RICADOS described in chapter 2, an end-to-end simulation environment has been develeped and established at DLR Oberpfaffenhofen.

The core of the space segment simulation is a software satellite simulator, see Figure 9. On the one hand, it consists of simulation-specific components such that numerical models of the physical orbit and attitude system (multi-body

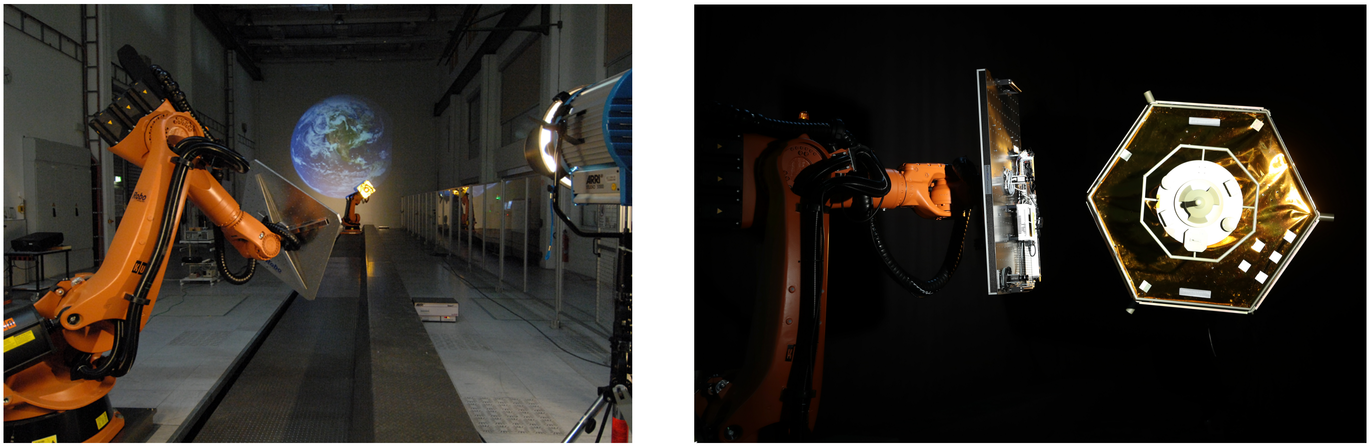

Fig. 10. Hardware-in-the-loop test facility EPOS 2.0 - a rendezvous and inspection test bed

satellite dynamics simulation). On the other hand, it contains also mission-specific components (satellite bus components and telemetry/telecommand (TM/TC) system).

The software satellite simulator has interfaces to the two robotic hardware-in-the-loop facilities used by RICADOS: EPOS 2.0, the European Proximity Operations Simulator [6], see Figure 10, a test facility for inspection and rendezvous simulation, and OOS-Sim, an On-Orbit Servicing Simulator [7], see Figure 11, a facility for capturing / berthing simulation.

EPOS is located at DLR-GSOC and is used to perform first an inspection of the target. Several fly around motions at a constant safe distance can be simulated and images of the target can be stored for later processing. After the inspection phase is finished, the rendezvous and close range approach to the target takes place until the mating point at about 3m distance. These phases are simulated using two KUKA robots (KUKA-KR-100HA, KUKA-KR-240-2), where one robot is located on a linear slide of 25m length. In the scenario used for RICADOS, the robot on the linear slide simulates the servicer. On its adapter plate rendezvous sensors (currently CCD and PMD camera) are mounted. The second robot, wrapped in a black molton for RICADOS with a black molton curtain in its back, carries the mockup of the RICADOS target satellite and simulates its tumbling motion. Further, a powerful spotlight is used as sun simulator and illuminates the target.

The software satellite simulator prescribes the dynamical motion of the two satellites. An external EPOS interface [26] computes the commands to the robots, i.e. it transforms the position and orientation commands from ECI (Earth Centered Inertial) frame to the laboratory frame. During hardware-in-the-loop simulations the sensor data (like camera images) is processed by the GNC on-board system (see chapter 2.2). Its controller commands are used by the actuators simulation (part of the numerical satellite simulator) and determines the next pose of the service satellite during its approach towards the target.

The OOS-Sim, the simulation facility allows simulation of berthing scenarios. The facility is used for developing and validating the robotic part (incl. the robotic manipulators) on-ground. Similarly to EPOS, two 6-axis KUKA robots are used (two KUKA-KR-120), where one robot simulates the motion of the service satellite whereas the second robot simulates the motion of the target satellite. The on-board robotic payload is represented by a 7-axis DLR light-weight robot. One unique simulation scenario is the phase when the light-weight robotc grasps the target robot. The three robots are mechanically connected which results in a kinematic chain of 19 degrees of freedom. Recently, some advances of the OOS-Sim has been performed like curtains, sun simulation, automated calibration of sensors, and ground-truth generation. When capturing the target satellite mockup with the light-weight robot, the forces and torques during contact are measured with a force-torque sensor and are fed back to the control loop (see sections 2.3 and 2.4).

3.2. RICADOS Test Scenario LEO-Hopper

The RICADOS system can be used for many different types of on-orbit servicing missions. As described above, it allows at an early stage of the mission preparation to simulate and validate the most critical phases (i) inspection, (ii) close range rendezvous, (iii) capturing and (iv) detumbling in a very realistic scenario which combines a fully established ground segment with a simulation of the space segment.

In the project RICADOS, we have selected one special test scenario called *LEO-Hopper* for our simulations and tests. In the next years, DLR will regularly launch compact satellites in low Earth orbits. The first DLR compact satellite bus is part of the Eu:CROPIS mission [27]. In the future, there will be a group of possible target satellites with a compact satellite bus in similar LEO orbits which enables fleet servicing: One DLR service satellite could perform service and life time extension tasks for all compact satellites like

Fig. 11. Hardware-in-the-loop test facility OOS-Sim - a capturing and detumbling test bed

Eu:CROPIS and its successors.

In our test scenario LEO-Hopper for RICADOS, the service satellite itself will be based on a DLR satellite bus with a propulsion system and with the necessary RICADOS capabilities. This includes the capability for inspection, for rendezvous, for capturing and for servicing tasks (like reparations or refueling). Most parts of the mission can be performed using one contact to the ground station Weilheim in Germany.

The inspection image data is processed off-line on ground. The service satellite needs sufficient memory to store the image data on-board until it is downloaded during the next contacts after the fly around and data collection are finished. After the off-line on-ground computations of the inspection images are finished, the results of the 3D model generation and change detection are uploaded during one of the next contacts before the close range rendezvous starts.

For the rendezvous phase, single, short contacts via Weilheim are sufficient, since the rendezvous system runs autonomously on-board the service satellite, and only a few telecommands have to be sent when there is contact with the satellite (changing e.g. guidance parameters, changing exposure time of the camera, or changing some other parameters).

During the robotic tasks however, a permanent contact between ground and servicer is needed. For this, we assume for our test scenario, that a relay satellite or a network of ground stations will be used. For final capturing of the target by telepresence, we simulate that the servicer has direct contact to Weilheim to minimize time delays.

During RICADOS simulations, this scenario including the acquisitions and losses of signals can be simulated and tested. The operators currently train all activities at the different consoles (satellite console, rendezvous console, robotic console) regularly every two weeks and the RICADOS system can be further developed and refined in an agile way.

4. CONCLUSION

This paper presented the system RICADOS - Rendezvous, Inspecting, CApturing and Detumbling by Orbital Servicing. It is a cooperation of four DLR institutes at Oberpfaffenhofen and Berlin, Germany. RICADOS allows to simulate and test the most critical phases of an on-orbit servicing mission in a unique simulation environment. RICADOS includes a full ground segment, and a simulation of the communication path and a simulation of the space segment. The space segment comprises a satellite simulator, two hardware-in-the-loop test facilities and the inspection, rendezvous and robotic payloads. Future servicing and space debris removal missions can use RICADOS, for example for servicing of DLR compact satellites. Also single subsystems of RICADOS can be easily replaced due to its decentralized and modular architecture. This allows to integrate for example new sensors or algorithms developed by partner institutes, industry or universities.

5. REFERENCES

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