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DEOS – DEUTSCHLANDS ROBOTISCHER ANSATZ ZUR KONTROLLIERTEN SATELITTEN-RÜCKFÜHRUNG

- THE GERMAN ROBOTICS APPROACH TO SECURE AND DE-ORBIT SATELLITES -

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Abstract
There are many concepts how to serve and lift malfunctioning satellites from their operational orbit to avoid large scale damage caused by uncontrollable satellites. For many years now Germany has been developing robotic techniques especially to handle its spacecrafts to the very end of life – just until their disposal. The German approach is based on berthing techniques using a manipulator system accommodated on a servicing satellite (Servicer) operated semi-autonomously and from Earth.

1. INTRODUCTION

The number of satellites orbiting around the Earth is increasing rapidly. Nowadays hundreds of satellites used for navigation, television-broadcasting or earth observation purposes populate the Earth orbits. Many of them will reach the end of their lifetime in near future. The Inter-Agency Space Debris Coordination Committee (IADC) requires self-removal [1]; Satellites on/near the geostationary orbit should lift themselves up to a higher altitude, the so-called graveyard orbit. Satellites on low Earth orbits shall de-orbit to a lower altitude where atmospheric drag would cause them to re-entry within a defined number of years (within 25 years at most).

Although satellites should by definition be able to remove themselves from their orbits many of them don't because of a malfunction or lack of fuel. For maintenance, repair or refuelling satellites must be captured in a safe and secure way avoiding any damage in the process. Rendezvous, inspection flies around and servicing by means of a robotic agent is Germany's approach to serve and de-orbit uncontrollable satellites.

Beside the robotic technologies and tools there are also other aspects to be taken into account. E. g. operational procedures, communications or approach techniques play a vital role on how to capture an uncontrollable satellite in a safe and secure manner. These aspects are within the scope of DEOS (Deutsche Orbitale Servicing Mission), Germany's on-orbit servicing satellite concept, to find and evaluate procedures and techniques for rendezvous, capture and de-orbiting of an uncontrollable satellite from his operational orbit.

2. DEOS – A ROBOTIC SERVICING MISSION

Germany researches the field of maintenance and repair technology for space systems and On-Orbit-Servicing (OOS) by the means of robotics technology for many years. Step by step light weight robotics joints, concepts for their intuitive remote control from ground (tele-presence) as well as the maintenance capability of space robotics tools and general technologies were explored, improved and space qualified, now ready for demonstration in DEOS, a comprehensive technology verification of an OOS application.

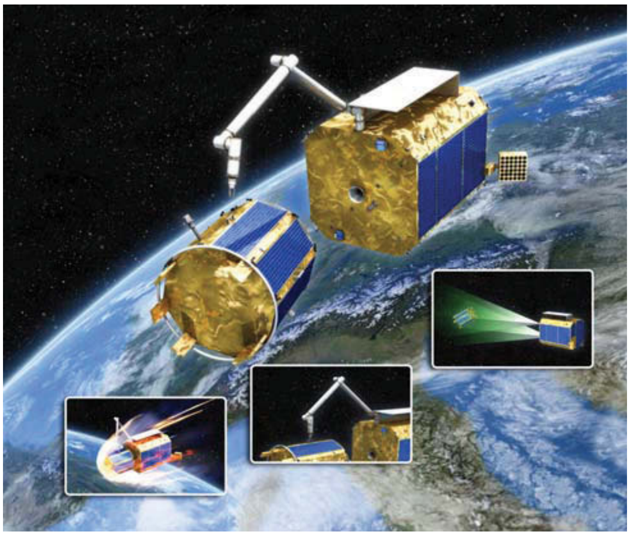

FIGURE 1. DEOS – Satellite On-Orbit-Servicing

2.1. Mission Objectives

Taking all programmatic aspect on On-Orbit-Servicing (OOS) into consideration DEOS should validate and demonstrate the technical feasibility of (tele-) robotic, on-orbit reconfiguration and perhaps refuelling concepts for advanced space maintenance and servicing systems. To form the basis for a mission the overall primary goals of DEOS are to capture a tumbling, non-cooperative satellite using a manipulator mounted on a free flying service-satellite, to demonstrate a servicing application and to de-orbit the captured satellite within a pre-defined re-entry corridor. Non-cooperative satellites do not provide the rendezvous and capture process with any supporting signals or features.

The overall space segment of DEOS consists of two satellites who will perform and demonstrate all aspects and core maneuvers needed to handle future satellite servicing tasks. One spacecraft surrogates a passive, non-cooperative and tumbling target satellite (Client) to be caught by the second, the active free flying servicing satellite (Servicer), by means of a robotic arm (manipulator). The core spacecraft maneuvers to be performed are far rendezvous, close approach, inspection fly around, formation flight, capture, stabilization and calibration of the spacecrafts compound, compound flight maneuver and controlled de-orbiting of the compound, the finally rigidly coupled satellite configuration.

Herein, robotics is highly involved in capture, stabilization, orbit maneuvers and even the de-orbiting. The main objective of the capture experiment is to investigate different control strategies and AOCS (Attitude and Orbit Control System) control modes, as well as to determine suitable maneuvers for soft docking and the subsequent stabilization of the spacecraft compound.

Depending on the task and the technology readiness spacecraft operations of the Servicer will be planned and initiated from ground but should be performed autonomously when ever possible. During passive ground control spacecraft operations are only monitored by the human operator on ground (supervised-autonomous control mode). An active ground control mode enables tele-operation services which let the human operator immediately command and control the remote service-spacecraft instead of only monitoring it.

2.2. Mission Description

Both spacecrafts are designed for an injection into an initial low Earth near polar orbit of about 600 km taking an inclination of 87° into account. The near polar inclination of the orbit offers variable illumination conditions over the life time for the planned complex demonstration program. The initial orbit altitude will be decreased stepwise during the planned one year orbit lifetime in order to increase the operational complexity caused by reduced contact time to the communication network.

The Mission is divided into four standard operational phases: Launch and Early Orbit Phase (LEOP), Commissioning Phase, Operations Phase and De-Orbiting Phase. A stack configuration is chosen as a rigidly connection to inject both spacecraft together into the initial orbit by the same launcher. After the launch and early orbit phase (LEOP) the commissioning of both spacecrafts will also be performed in the stacked configuration. Typical activities of the LEOP as the separation from the launcher, the activation and establishment of the TM/TC links and the validation of basic system checks are performed to end up with a stable operational status of the satellites.

At the end of the commissioning phase both satellites will have completed the most important calibration activities. All parts of the commissioning that are not possible or only possible with hard constraints in the stacked configuration will be postponed to a later delta-commissioning, either during the berthed configuration after stack separation, the initial departure as part of the rendezvous phase or in the far formation flight (see FIGURE 2).

At the beginning of the mission operational phase (see 2.3) both spacecraft will fly for a certain period of time in the launch stacked configuration to execute first OOS activities (see 2.4) without the need and risk to exercise any rendezvous and berthing maneuvers before. Attitude and orbit control of the stacked configuration is done by the Servicer.

Leaving the launch stack configuration both spacecrafts will finish the delta-commissioning and start to perform maneuver and experiments to demonstrate the various mission objectives. Once the spacecrafts are separated the initial launch stage cannot be entered again as the stack separation mechanism is not reversible. A rigid reconnection can only be achieved via the unified berthing and docking port mechanism (see 4.1.4) which defines a different state, the rigidly coupled configuration.

In general the complexity of the demonstration program during the operational missions phase is required to be stepwise increased over the mission period. The major interest to demonstrate and explore with DEOS is to capture a non-cooperative, tumbling satellite using a manipulator, the so called berthing approach. At berthing all capture tasks are controlled by the manipulator, while at docking all this is done by the reaction control system of the Servicer.

According to the mission objectives the berthing approach implies spacecraft operations and manoeuvres (see 2.3) to be fulfilled including far formation flight, rendezvous manoeuvres, fly-around and inspection flight, up to the capturing of the Client with the manipulator under different environmental and operational conditions as well as different attitude states of the Client.

At the end of one year mission operations time both spacecraft should have decreased the orbit altitude stepwise to de-orbit and re-entry (from about 400 km) within a given re-entry corridor. The re-entry configuration of both spacecrafts is a rigidly coupled one defined by the manipulator arm as mechanical fixture because current satellites are not designed with special handles to grabble and stack two spacecraft rigidly together. The space segment should divide, break into peaces and burn out in the Earth atmosphere during the re-entry phase. Attitude and orbit control of the rigidly coupled configuration during de-orbit maneuvers is done by the Client to explore flight maneuvers with respect to the center of mass located outside of the lighter spacecraft (see 2.4).

2.3. Mission Operational Phase

The in-orbit operational phase of the mission is divided into several sub-phases as shown in FIGURE 2. During the operational phase both spacecrafts will perform a comprehensive demonstration and verification program on the low Earth near polar orbits covering all typical situations of a satellite servicing mission (see FIGURE 3).

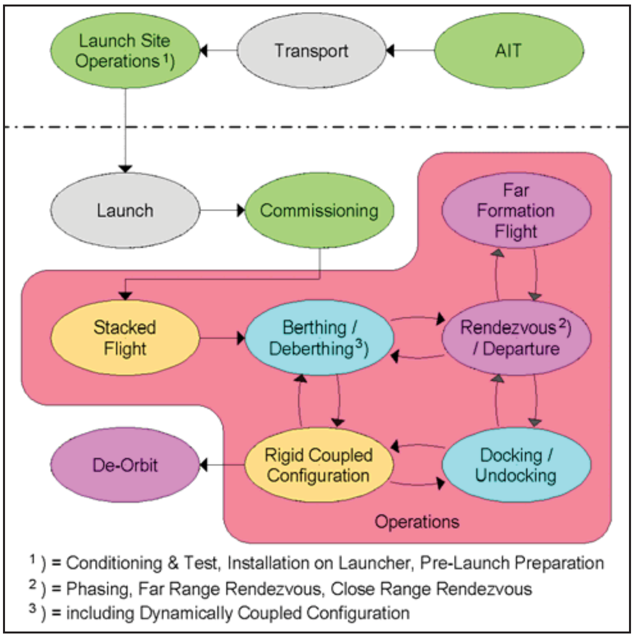

FIGURE 2. Operational phases and transitions

The demonstration and verification program starts with the separation of both spacecrafts with the Client being grappled by the manipulator of the Servicer. In this berthed configuration the close range sensors can be tested and calibrated by moving the Client in the maneuvering range of the manipulator arm. Furthermore, initial experiments concerning the dynamically and fixed coupled configuration can be executed without the need for any rendezvous maneuver before.

After this sequence the two spacecraft will be de-berthed and brought to a safe point, where the Client is still in the range of the rendezvous sensors. From the safe point the close range rendezvous and berthing is tested, before the Servicer departs for a second time to the far formation flight distance.

In the far formation flight, Servicer and Client are flying in a constant distance from each other within pre-defined tolerances using absolute navigation sensors. The distance between both spacecraft is greater than 2 km and takes a safe condition into account with respect to potential collisions even without ground control over a couple of days. During the far formation flight the dynamical behavior of the individual spacecraft may be determined and the spinning and tumbling motions of the Client can be tested.

The far formation flight is the starting point for the rendezvous (phasing) operation. Starting from the far formation flight state the Servicer has to find, navigate and approach the Client. At the end of the rendezvous approach the Servicer has to take a close, safe parking or mating position which places the Client in the operating range of the manipulator as shown in FIGURE 8. The mating position for capturing is maintained using the relative navigation sensors. The grappling target has to be in the field of view of the manipulator cameras to be seen and tracked by the operator on ground via tele-operation or supervised-autonomously by means of on-board image processing.

During berthing the Client has to be grappled by the manipulator and latched onto the unified berthing and docking port mechanism (UBDM). The various tasks controlled by the manipulator are to capture the Client, to stabilize the grappled compound, to transfer the Client from the capture position to the UBDM port and to insert it into the UBDM interface for a rigidly coupled connection. Once both spacecrafts are rigidly coupled the manipulator can be released from the Client to be free for other tasks or folded and parked on the Servicer.

The berthing should be performed both autonomously, supervised by the operator on ground, as well as steered via tele-operation by the operator on ground. Other steering maneuvers are also possible, e.g. to move the grappled Client in a position suitable for flight maneuvers in the rigidly coupled configuration.

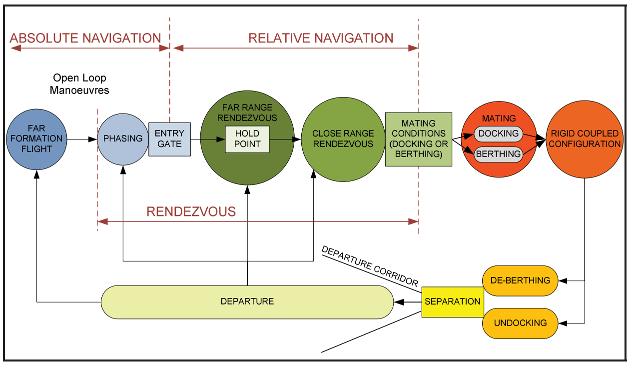

FIGURE 3. Approach and departure concept

The de-berthing is the separation process of releasing the Client from the UBDM port and moving it with the manipulator from the port to a departure location within the range of the manipulator, the mating position.

The docking is based on the reaction control system and the docking camera images of the Servicer. Here, the Client is no longer a non-cooperative but a controlled and supporting satellite. The Servicer slowly approaches along the docking axis from the mating position towards the Client. Marker LEDs on the Client have to be in the field of view of the docking camera to determine the relative position and attitude both board-autonomously or on ground. To latch the Client and reach a rigidly coupled compound the docking I/F of the Client has to be inserted into the UBDM port on Servicer side.

Based on the image processing the Client's docking I/F is kept well aligned with the axis of the Servicer's docking port by means of the Servicer's reaction control system. In case of supervised-autonomous docking the relative navigation is based on the on-board processing of the docking camera images. If the docking is performed via tele-operation the relative position and attitude of the Client are provided by ground instead of the on-board image processing algorithm.

In case of undocking the separation starts when the Client's docking interface is completely released from the docking port of the Servicer. Both spacecraft still drift apart with their AOC actuators deactivated. The movement may be monitored by means of the docking camera images.

The transition to the departure phase is smooth, since the movement is not stopped at the mating position.

The departure starts after separation when the relative navigation sensors are activated at the mating position. A maneuver is initiated that moves the Servicer out of the close range of the Client. In the first part of the departure phase the Servicer monitors board-autonomously that the trajectory is within the departure corridor, otherwise a collision avoidance maneuver CAM is performed autonomously.

The departure may consist of one or several orbit maneuvers. The maneuvers have to take into account that there has to be ground contact to switch the cameras to mid range and far range and to switch to absolute navigation in the range of the rendezvous entry gate. The departure ends at the destination orbit.

2.4. On-Orbit-Servicing Task

The on-orbit servicing task will concentrate on the following major activities:

Using the manipulator on the Servicer, an observation camera should be detached, reattached and activated onboard of the Client. This activity will extend the functionality of the Client. Launched as a blind spacecraft the Client will be able to observe the Servicer during his demonstration program after the camera was successfully brought into operation. The camera will be installed and activated before the first separation of both spacecrafts after launch and commissioning.

Further activities concentrate on experiments investigating the dynamic behavior and parameters (mass, centre of mass, moments of inertia) of the various flight configurations. At the moment two basic strategies are being analyzed: using the actuators and sensors of the AOCS system or the manipulator in combination with the sensors of the AOCS system. The knowledge about the dynamic behavior especially of the coupled configuration is essential for all orbit and flight maneuvers within the coupled state.

Within the scope of the comprehensive rendezvous and capture demonstration program, the de-orbiting (up to the re-entry) of the spacecraft compound performed and controlled by the Client is of primary interest in DEOS. Servicer and Client are switching the roles for these maneuvers to cause the center of mass of the coupled compound to be located outside of the lighter spacecraft and to explore the impact on flight operations.

Before the compound will finally de-orbit to re-entry into the Earth atmosphere a last refueling experiment could be demonstrated. Here, fuel should be transferred between the two spacecrafts using a fuel pipeline which has to be established by the manipulator.

3. GROUND CONTROL SEGMENT CONCEPT

Spacecraft operations are performed from a Mission Control Centre (MCC). Data signals to and from the spacecraft are transmitted and received by the antennas of the primary ground station facility which is directly connected to the MCC. All spacecraft operations must be integrated into the multi-mission commanding chain of the MCC. Thus, a mission specific payload control system as part of the MCC provides all necessary command interfaces for the human operator to tele-operate the servicing satellite and /or monitor the servicing operations.

3.1. Tele-Operation Concept

Germany has investigated the feasibility and limits of technologies and tele-operation concepts for on-orbit servicing within several space missions as ROTEX, GETEX or ROKVISS [4, 5]. As a result it was demonstrated that during (direct) radio link contact a remote robotic manipulator can be commanded by a human operator via improved supervisory control techniques as realized in the Man-Machine-Interface (MMI) of DLR’s MARCO telerobotic ground station [4]. Pre-defined robotic tasks can be performed autonomously by sending a path or trajectory to the on-board system. Even high-fidelity force feedback control is applicable using a direct radio link [3, 6].

While the Client satellite of DEOS will be operated as a standard spacecraft the servicing satellite is operated in different modes. Core satellite functions as collision avoidance or attitude control are board-autonomously performed under responsibility of the on-board data handling system. In spite of higher level servicing operations like rendezvous, berthing or docking maneuvers the human operator is either only monitoring autonomous operations or tele-operates the spacecraft, even directly perform a specific servicing operation like the capture task.

In order to keep the round-trip communication time during tele-operation, especially for mission critical maneuvers or operations, as low as possible the operator on ground shall have access to the space segment using a direct high-performance S-band radio link. An S-band radio link enables closed loop control of the spacecraft. In case of unpredicted system behavior or failures the operator is able to come into action just in time. But as outlined in the S-band link for operations will be available only for a few minutes depending on the path and the ground track abilities. Thus, an operator on ground is limited in time to serve, to monitor and to command the system, especially when complex servicing operations has to be prepared, subdivided and performed over more than one ground station. Using a ground station network also causes other difficult conditions and technical drawbacks.

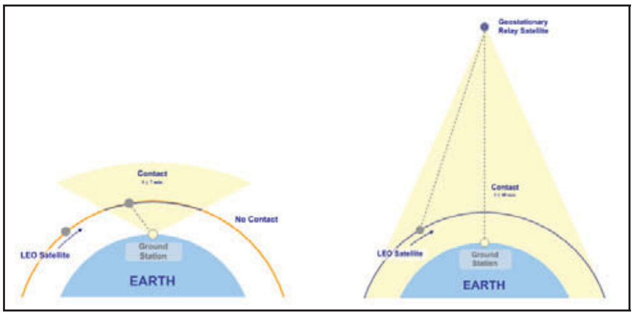

FIGURE 4. Communication concept: (left) access via S-

Band link; (right) access via GEO Relay Satellite

Thus, additional communication via geostationary relay satellites and their operating grounds stations may be utilized whenever it is considered beneficial for the smooth and safe execution of the DEOS mission, especially to increase the time for operational access.

3.2. Communication Architecture

The DEOS mission is planned and operated from the Mission Control Centre as part of the ground segment (see Figure 2) which uses a primary ground station to link and to communicate with both spacecrafts. An adequate supplementary ground station network will temporarily enhance the time of accessibility by the primary ground station during LEOP (Launch Early Orbit Phase) or even critical proximity experiments/mission phases. In addition a communication link via geostationary relay satellites shall be utilized instead to enlarge the time of contact to the space segment especially for critical proximity experiments and mission phases. Thus, each spacecraft maintains a direct link to ground. Furthermore, the Servicer is able to receive the Client telemetry data for board-autonomous mission supervision and verification purposes.

The communication architecture defines S-band as the primary radio link for both spacecraft. In addition, the servicing satellite provides an inter-satellite Ka-Band system to transmit and receive data to and from the MCC via a relay satellite. The complete chain of the communications architecture together with its major components is shown in FIGURE 5. The complete system consists of the Servicer satellite with its inter-satellite Ka-Band system, the GEO Relay Satellite (i.e. ARTEMIS) and a Ka-Band ground station.

The communication concept for telemetry and telecommand (TM/TC) is the same for all three components. Telemetry will be down-linked at the rate of 4 Mbps (including 3,5 Mbit/s video data), while different types of packets are merged in that link (HK, images). Telecommands will be up-linked at a rate of 256 kbps, while different sort of packets are merged in that link (i.e. Satellite commands, Robotics commands, Uplink messages).

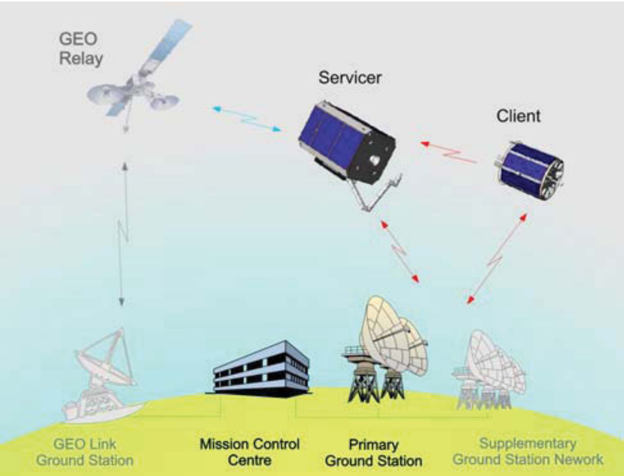

FIGURE 5. Communication Architecture

4. SPACE SEGMENT

The space segment is defined by two satellites, one surrogates a non-cooperative tumbling satellite (a space probe circling Earth on an unstable trajectory) to be caught by the active service satellite (Servicer). For this goal, the Servicer features a so-called “manipulator”, a robotic device mounted on its top. A brief description of the spacecrafts and their payloads as shown in FIGURE 6 is given in the following subsections.

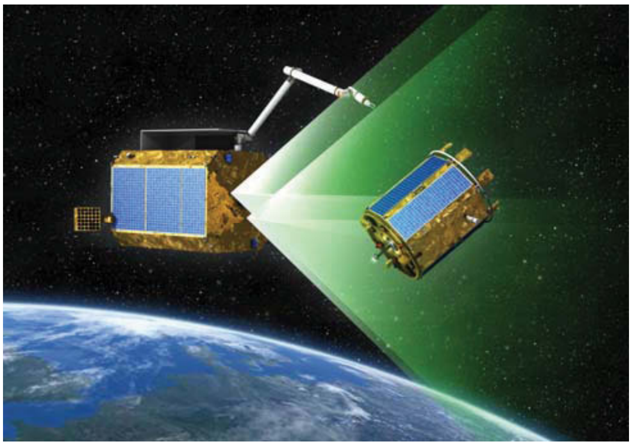

FIGURE 6. DEOS Servicer and Client spacecrafts

4.1. Servicing Satellite (Servicer) Concept

The Servicer is designed and equipped with technologies to act as a servicing spacecraft and fulfill all key tasks necessary for OOS.

4.1.1. Satellite Bus Concept

The core infrastructure of a spacecraft is the satellite platform, typically a mission specific design to provide best locations for the instruments and other payloads. The overall concept of the DEOS Servicer spacecraft is shown in FIGURE 6. The main body of the Servicer spacecraft is designed as a cuboid with four circumferential areas. Three sides as well as the rear side are partially covered with body mounted solar array cells. The chamfered edges as well as parts of the cover plates are used as thermally radiating areas.

The resting place for the manipulator arm in a thermal protective cover as well as the Ka-Band antenna is accommodated on one of the four circumferential plates. The Ka-Band antenna and its associated 2-DoF pointing mechanisms is folded and attached to the spacecraft outer structure for launch reasons. During the demonstration program the antenna has to be unfolded and activated to track and point for the relay satellite. The S-Band antennas, one for the ground link and a second to listening into the Client chatter, are accommodated on the Servicer surface.

One major point of interest is the control strategy of the Servicer during capturing. In the first case, the AOCS reacts to limit or eliminate any spacecraft motion (therefore the spacecraft can be kept stationary in operational space), while in the second case the spacecraft is allowed to move in reaction to the robot movements. While the first case is easier to tele-operate and may be necessary to fulfill spacecraft motion constraints (e.g. attitude motion may be limited for communication purposes), the second case is more interesting for reducing fuel consumption for spacecraft control and may be safer, since jerky motions arising from thrusters are avoided.

4.1.2. DLR's Light Weight Manipulator

The robotic arm (manipulator) bases on DLR's light weight manipulator design as space qualified within ROKVISS [ROKVISS]. Equipped with an appropriate end effector (see 4.1.3), the manipulator is responsible to serve and handle the Client who has to be captured, stabilized and coupled to the UBDM port.

Thus, the arm has to have a sufficient length to allow all tasks to be performed with the Client in any position and spinning or tumbling state. During launch the arm is folded and attached to the Servicer spacecraft outer structure.

The manipulator arm consists of 7 modular, torque controllable joint elements as developed for ROKVISS with slight modifications concerning the implementation of a parking break that is necessary to keep a fixed configuration of the two spacecraft when physically connected via the manipulator arm. This 7-joint arrangement provides kinetic redundancies in order to avoid joint singularities during the capturing or servicing process. The operating envelope in terms of possible gripper orientations of the manipulator arm with its defined allocation on the Servicer spacecraft is depicted in FIGURE 7.

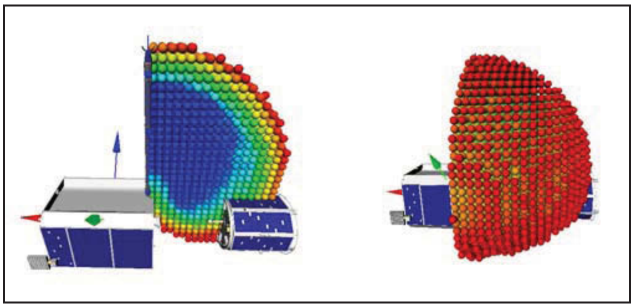

FIGURE 7. Operating range of the manipulator

4.1.3. Grappeling Mechanism (Gripper)

The manipulator arm is equipped with a 3-finger grappling mechanism that allows to capture a moving structural part of the Client satellite and to handle objects during the manipulation/servicing experiments. The layout and main elements of the mechanism are outlined in FIGURE 8 (left). The motor torque is applied via a spindle-gear to a toggle-lever mechanism which allows a very fast closing speed at the beginning and a very high grasp force at the end of the closing motion.

The gripper is equipped with an illumination system and a camera with a field-of-view angle of about 60° to allow any object to be visible until it is within the gripper yaws. The camera and gripper harness will be routed to the interface control unit through the hollow axles of the manipulator joint elements.

4.1.4. Unified Berthing and Docking Adapter

Latching is the final step of capturing in order to achieve a rigidly coupled configuration. Therefore, both spacecrafts have to be equipped with an appropriate interface, a mechanism for berthing and docking. The unified berthing and docking mechanism (UBDM) is designed as a two-part equipment. It consists of an active interface located on the Servicer and a passive interface on the Client spacecraft.

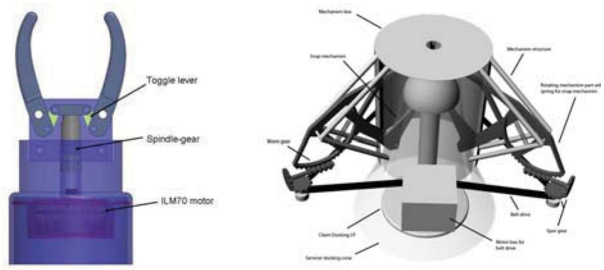

FIGURE 8. (a) Gripper Mechanism (left); (b) Unified berthing and docking adapter (right)

The two-part UBDM design concept is outlined in FIGURE 8 (right) and has two major functions of capturing and latching the Client's passive docking part. The active part consists of a capturing cone and a latching motor to move the capturing mechanisms and to permanently latch the passive part of the UBDM for a rigidly coupled spacecraft compound. In the latched position the induced force is sufficient to hold the Client in close contact with the Servicer. When using the motor in the reverse direction, the passive part will be unlatched and provided with a driving impulse that allows him to leave the docking cone.

4.1.5. Rendezvous Sensor Package and Illumination

During rendezvous the Servicer has to be maneuvered from far formation flight into the close range of the Client. FIGURE 9 gives a brief overview of the sub-phases and the hold points that are mandatory for a rendezvous approach to a non-cooperative satellite. The Servicer reduces the distance to the Client via several Hohmann-like orbit maneuvers ending at distinct hold points. The final approach to the mating position is typically performed via an appropriate v-bar or r-bar maneuver depending on the capture strategy [2].

Starting from far formation flight, the Servicer reduces the phase angle to the Client. In this phase the Servicer relies still on absolute navigation. The phasing terminates at the Rendezvous Entry Gate.

During far range rendezvous the Servicer is brought from the Rendezvous Entry Gate to the safe point in the range of the Client. If the relative navigation is based on camera images, at least one intermediate hold point is required for a controlled switch-over from the far range to the mid range cameras.

If a berthing or docking to a non-cooperative or maybe even unknown target has to be performed, a first motion estimation of the target is conducted at the safe point, followed by a fly-around. Afterwards the close range rendezvous is started with an orbit maneuver from the safe point to the close hold point. At the close hold point the cameras have to be switched from mid range to close range (if applicable). From the close hold point the final approach to the berthing or docking box is performed via a straight line trajectory (v-bar manoeuvre). During the final approach the Servicer has to be kept board-autonomously within a pre-defined approach corridor. If the approach corridor is violated, a collision avoidance maneuver has to be initiated board-autonomously. The close range rendezvous ends at the hold point at the berthing / docking box called mating position.

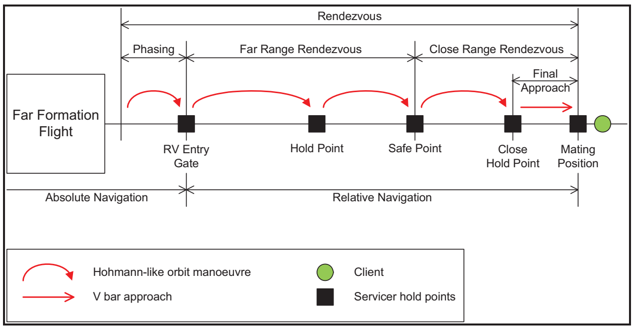

FIGURE 9. Rendezvous and Departure Approach

Depending on the operational phases of the approach different sensors will serve as primary sensor. The rendezvous, docking and berthing (RVDB) sensor package consists of the following individual sensor arrangements: 2 LIDAR heads, 2 far range mono cameras, 1 mid range stereo camera, 1 close range stereo camera, and 1 docking mono camera.

For formation flying and phasing the far range mono camera is supposed to serve as the primary sensor which provides line-of-sight estimations. From a range less than 700m this role will be switched to the LIDAR head which is expected to deliver additional range information and later on a pose estimation of the Client spacecraft. In these phases the mid and close range cameras will be for monitoring and plausibility checking purposes only. The visual inspection of the Client spacecraft will be performed with the mid-range camera, the docking with the docking camera.

Taking redundancy considerations into account all primary sensors are designed twice. Additional to that a Relative-GPS receiver is planned to serve as a safety sensor. In case of malfunction of a sensor the RGPS could deliver line-of-sight and range information, perhaps also pose estimations.

Depending on the illumination conditions during pose estimation, final approach or berthing an additional target illumination might be required. FIGURE 10 shows potential illumination conditions arising from different sun constellations. Under difficult illumination conditions like back-light or complete darkness an artificial illumination source seems to be mandatory to produce reliable results from the cameras. For this reason there are two different target illumination systems available for the close range camera and the manipulator camera.

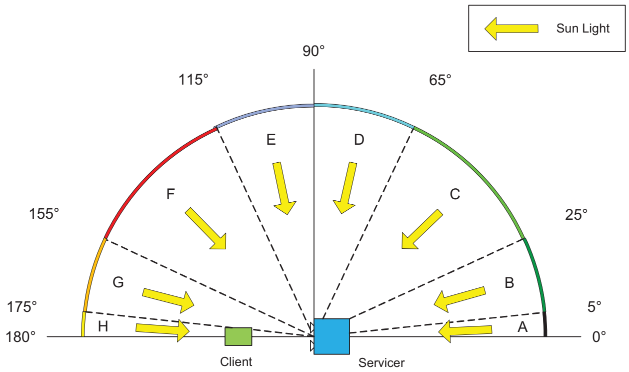

FIGURE 10. Sun light conditions for optical sensors

4.2. Client Satellite (Client) Concept

The Client satellite is designed to act primarily like a non-cooperative, tumbling satellite. In addition, it shall take the control over the rigid coupled stack during de-orbit maneuvers and the final preassigned and well-defined re-entry maneuvers at the end of the lifetime. Acting as a surrogate spacecraft out of control and in need of servicing the Client has to set an artificial tumbling in motion. But the Client must be able to release the tumbling motion and stabilize himself at any time.

The Client spacecraft simulates the multitude of characteristics of a spacecraft in need of servicing and provides the interfaces that are necessary to prove the required Servicer functions in terms of constellation flight (far range, rendezvous and fly-around, coupled configuration), docking, berthing and in-orbit servicing tasks.

The overall baseline design of the Client is shown in FIGURE 6. This satellite concept resembles a regular octagon with its edges chamfered such that in addition to the 8 main circumferential areas 8 additional small surfaces are present. Seven of these eight main circumferential areas are covered with solar array cells. The nadir facing main area is reserved for the allocation of the combined nadir S-Band antenna / magnetometer boom. The small circumferential areas are used as thermally radiating areas.

5. CONCLUSIONS

Nowadays satellites should be able to de-orbit themselves but many don't because of a malfunction or lack of fuel. As long as a maintenance or repair of satellites can not be performed it is essential to remove uncontrollable satellites somehow. Otherwise such satellites could get instable over the time; some of them may even start to tumble. Out of control they may become a hazard for other spacecrafts.

In general, satellites which are not able to remove themselves from their operational orbit for whatever reason are just given up. Scenarios as DEOS shall proof and demonstrate that current robotic technologies has reached a level of readiness to serve malfunctioned satellites in an appropriate manner. A successful demonstration of DEOS technology and capture concepts will open up a broad range of new on-orbit servicing abilities. Even spacecraft design and operation may take a new direction taking refueling, repair and upgrade services into consideration. DEOS shall show the possibility to repair, refuel and re-turn spacecrafts in the sense of a whole on-orbit service application field.

6. FINAL NOTICE REGARDING THE PROJECT

The DEOS project is performed on behalf of the ***Space Agency*** of the German Aerospace Center DLR funded by the ***Federal Ministry of Economy and Technology*** within the framework of Germany’s National Space Program. Taking a feasibility study of the DEOS mission and system concept into account, the program is on the way to explore and define the overall detailed mission and to develop a preliminary technical system design (ground & space segment) for mission preparation.

Since January 2010 a preliminary Design Definition Phase (Phase B) is in progress performed by the space companies EADS Astrium GmbH, Kayser-Threde GmbH, OHB-System AG and SpacheTech GmbH. Technical support is given by DLR’s Institute of Robotics and Mechatronics, Jena-Optronik GmbH, von Hoerner & Sulger (vH&S).

7. REFERENCES

[1] Inter-Agency Space Debris Coordination Committee: “IADC Space Debris Mitigation Guidelines”. IADCIADC-02-01, Revision 1, September 2007.

[2] W. Fehse: “Automated Rendezvous and Docking of Spacecraft”, Cambridge Aerospace Series, 2003, Cambridge University Press

[3] G. Hirzinger, et.al. : “ROKVISS – ROBOTICS COMPONENT VERIFICATION ON ISS”. In: Proc. of the 8th International Symposium on Artifical Intelligence, Robotics and Automation in Space (iSAIRAS), 2005, Munich, Germany.

[4] K. Landzettel, et.al. : “Robotic On-Orbit Servicing - DLR's Experience and Perspective”. In: Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Page 4587-4594, 2006, Beijing, China.

[5] D. Reintsema, K. Landzettel and G. Hirzinger (2007): “DLR’s Advanced Telerobotic Concepts and Experiments for On-Orbit Servicing”. STAR - Tracts in Advanced Robotics, Volume 31/2007, Springer.

[6] E. Stoll, U. Walter, J. Artigas, C. Preusche, P. Kremer, G. Hirzinger, J. Letschnik and H. Pongrac: “Ground verification of the feasibility of telepresent on-orbit servicing”. Journal of Field Robotics, Volume 26 (3), 2009.