THE LIRIS-2 3D IMAGING LIDAR ON ATV-5

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ABSTRACT

The flight of the European supply vessel ATV-5 "Georges Lemaître" to the International Space Station included a demonstrator for a new set of optical sensors for non-cooperative rendezvous and docking, called "LIRIS" (Laser Infra-Red Imaging Sensors). As part of this project, a prototype for a new 3D Imaging LIDAR was developed, integrated and tested by Jena-Optronik for Airbus Defence ans Space and ESA. This LIRIS LIDAR was based on technology from the DLR project "LiQuaRD" (LIDAR Qualification for Rendezvous and Docking) and allowed for the recording of high-resolution 3D images during the approach of ATV to the ISS. We will describe the design approach, properties and advantages of the LIRIS-2 sensor as well as the types of data returned by the sensor.

1. PREVIOUS ACTIVITIES AND MOTIVATION

LIDAR activities at Jena-Optronik started in the 1990es with the project ARP (ATV Rendezvous Pre-Development), which successfully delivered the prototype rendezvous- and docking sensor ARP-RVS for two flights to the Russian space station MIR on board the Space Shuttle.

The next step was to design, build and qualify the final flight hardware rendezvous- and docking sensor RVS for use within the European ATV program as well as the Japanese HTV. In the meantime, five ATV missions have completed successfully with RVS as one of the two sensor systems. On HTV, RVS is the only sensor for rendezvous and berthing to the ISS. In addition, RVS is also used as primary sensor on the US supply vehicle Cygnus by Orbital Sciences Corporation (now part of Orbital ATK). Up to now, 40 RVS have been delivered with flawless flight heritage on Space Shuttle, ATV, HTV and Cygnus.

In parallel to the supply missions to RVS, the ESA project Imaging LIDAR Technology (ILT) allowed to take the first steps towards next-generation imaging LIDAR technology by introducing a fiber laser as a more powerful and versatile laser source and the gimbal-mount scan mirror with a fully digital control loop.

Building on the experience with RVS and ILT, the DLR project LiQuaRD (LIDAR Qualification for Rendezvous and Docking) had the task to pre-qualify key components of a powerful 3D Imaging LIDAR system for future use in on-orbit servicing and space debris removal missions, like DEOS (Deutsche Orbitale Servicing Mission / German Orbital Servicing Mission). During the project, an advanced, yet compact optical scan head and a fiber laser were built and successfully subjected to environmental qualification test. The LIDAR heritage at Jena-Optronik and these building blocks of a 3D Imaging LIDAR represented the basis for the next step – the LIRIS-2 3D Imaging LIDAR on ATV-5.

The idea to make use of the last European supply vessel to the ISS, the ATV-5 Georges Lemaître, to demonstrate future non-cooperative rendezvous- and docking technologies was developed by ESA, Airbus Defence and Space, Jena-Optronik and SODERN in the course of the ESA project VAC (Versatile Advanced Concept). This last ATV flight would provide a unique opportunity for flight-testing such technology at a low cost by adding to an already existing mission and by having ATV trajectory navigation data available as a reference.

2. DESIGN GOALS

Due to the relatively short timeframe of less than 1 ½ years between start of the project and integration of the final sensor on ATV, the limited budget, as well as the limited interface to ATV (as no significant changes to the architecture and flight software of ATV were possible), the LIRIS-2 project had to concentrate on several essentials in order to reach its goal of demonstrating the capabilities of non-cooperative sensor technology:

- demonstrate 3D Imaging LIDAR technology by gathering 3D point cloud data of the ISS during rendezvous and docking of ATV-5
- provide internal housekeeping and telemetry data of the sensor to verify design assumptions and as a basis for future development steps.

3. DESIGN APPROACH

To fulfil the goals set for the LIRIS project under these challenging boundary conditions, the following approach was selected:

- build on existing LiQuaRD hardware components, like scanning optical head and fiber laser,

- extend the optical head and fiber laser with an updated scanner electronics, a range finder, and a power converter,
- design a separate data storage unit to record all 3D point cloud and sensor housekeeping data for later transport back to Earth,
- avoid in-flight processing and related software on the sensor, but instead devise a set of fixed scan modes based on the known relative trajectory of ATV with respect to ISS.

Due to eye-safety regulations, the maximum available laser power for the sensor had to be reduced, thereby reducing the maximum operating range for non-cooperative targets. Nevertheless, the laser power was still large enough to detect the ISS at larger distances due to the installed retroreflectors used by nominal ATV rendezvous- and docking sensors.
The data storage was designed to provide enough memory for up to three ATV approaches, allowing for operational flexibility and possible contingencies within the qualified ATV perimeter.

4. SENSOR DESCRIPTION

4.1 Sensor Components

The LIRIS-2 3D Imaging LIDAR consists of three separate units, which are connected by electrical and fiberoptic cabling:
- LIDOH: LIDAR optical head, including the fiber laser
- LIDELN: LIDAR electronics box
- LIDREC: LIDAR data recorder located in the ATV pressurized cargo section

Figure 1: LIRIS-2 sensor components LIDOH, LIDELN, LIDREC

The optical head contains the scan mechanism and the send/receive optics for the laser pulse as well as the fiber laser, whereas the electronics box contains the scanner control electronics, the range finder and the power converter. The electronics box also provides the control/status interface to ATV as a set of discrete digital and analog lines, as well as a power/SpaceWire interface to the data recorder.

4.2 Sensor Properties

The following table shows the design parameters of the LIRIS-2 sensor, taking into account the reduced operating range against non-cooperative targets for eye safety reasons:

Parameter	Value
Field-of-View	ca. 40° x 40° (uncorrected)
Operating range against cooperative targets	ca. 3,5 km
Operating range against non-cooperative targets	ca. 260 m
Image frame rate	up to 3 Hz
Power consumption	ca. 25 W…55 W
Data storage	2x 2 GB redundant NAND-Flash solid state memory

4.3 Scan Modes

Based on the dimensions of the ISS and the nominal ATV trajectory, the 3D point clouds resulting from LIRIS-2 operation were simulated and several scan modes were defined for different distances to the ISS:
- Orientation scan: high-density initial scan after switch-on of recording with 4 s scan duration
- Retroreflector scan for distances above 300 m with 120s scan duration,
- Far range scan with 16 s scan duration for distances between 100 m and 300m,
- Medium range scan with 4s scan duration for distances between 30 m and 100 m,
- Close range scan with 1 s scan duration for distances between 10 m and 30 m,
- Object scan with 3 Hz image frame rate for distances below 10 m.

5. THE MISSION

The LIRIS-2 sensor was installed on ATV-5 as part of ATV integration and tests campaign in February 2014 at Centre Spatial Guyanais, Kourou, by Airbus Defence and Space supported by its subcontractor ThalesAlenia Space Italy, and Jena-Optronik. It was successfully completed by the first system test controlled through ATV interface and including all ATV sensors (RVS, VDM, SODERN LIRIS-1 VIS/IR cameras, LIRIS-2 LIDAR).

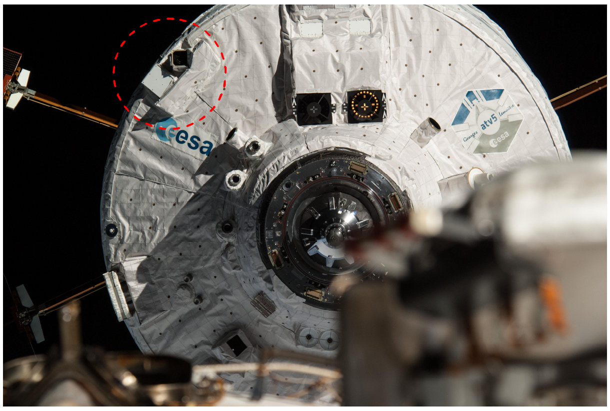

Figure 2: ATV-5 Georges Lemaître with LIRIS-2 sensor visible (red circle)

The launch of ATV-5 took place on 29-July-2014, the switch-on of LIRIS-2 happened on 12-August-2014 at a distance of about 3,5 km to the ISS. Given the nominal trajectory of ATV, LIRIS sensors were accommodated on ATV such that the ISS was visible in the field-of-view of all sensors from this distance up to docking.

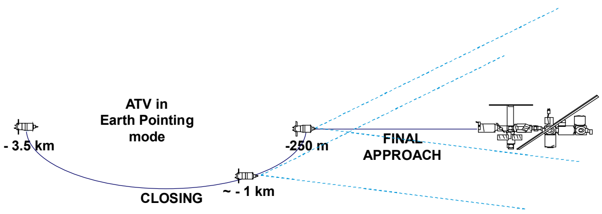

Figure 3: ATV trajectory from switch-on of LIRIS to docking.

Thanks to the flawless performance of ATV, the rendezvous and docking was performed successfully and docking was confirmed by ATV-Control Center at CNES Toulouse, France, about four hours after switch-on of LIRIS-2. During this time, the sensor recorded more than 1,2 GB of 3D point cloud and internal housekeeping data. All telemetry data from the sensor, like temperatures, electrical current and status lines were nominal during the mission.
After docking, the data recorder LIDREC was removed from the ATV pressurized cargo section by the ISS crew and returned to Earth by a Soyuz vehicle, ending up at Jena-Optronik at the end of September 2014 for read-out and analysis.
In order to further verify the functionality of the LIRIS-2 sensor after a period of about 6 months in orbit, the unit was switched on again after undocking of ATV-5 from the ISS. The LIRIS-2 ATV telemetry data again was nominal and comparable to the data recorded during rendezvous.

6. DELIVERED DATA

6.1 Data Post-Processing

The LIDREC data recorder with its two redundant banks of solid state memory was read out at Jena-Optronik, followed by a post-processing of the data in order to correct for geometrical effects of the scan system and to align the time stamps with ATV time, based on periodic synchronization signals transmitted between ATV and LIRIS-2.
The data were then processed into a database for analysis and further exploitation by Jena-Optronik, Airbus Defence and Space and ESA.

6.2 Results

The data showed the successful operation of the LIRIS-2 sensor during ATV rendezvous and docking as well as a nominal transition between the different scan modes in relation to the distance between ATV and ISS. The first return signals from ISS were detected at a distance of about 2,5 km.
At a distance of about 260 m, target returns from ISS surfaces started to become visible in addition to the retroreflector target returns.

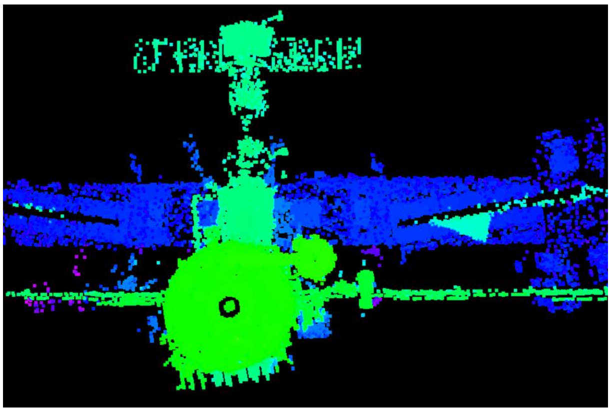

Figure 4: ISS seen by LIRIS-2 at about 30m distance to docking port

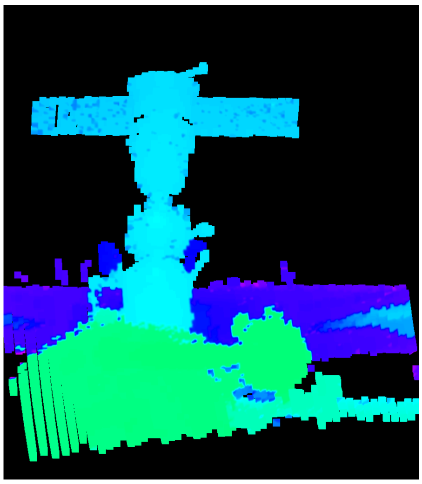

Figure 5: ISS seen by LIRIS-2 at about 10m distance to docking port

The results showed that the high frame rate of 3 Hz were successfully reached at close range operation as an important feature for utilizing a scanning LIDAR sensor for pose estimation of non-cooperative target object like in the DEOS or e.Deorbit scenario.

7. SUMMARY AND OUTLOOK

Overall, the LIRIS-2 3D Imaging LIDAR on ATV-5 showed nominal performance during the ATV-5 mission, fulfilling all its initial goals and demonstrating full performance even after 6 months in orbit. Considering the short development time the LIRIS project has been very successful and provided the project partners a huge database of 3D image data for future use in development and validation of image processing algorithms, refinement of sensor hardware and planning of future space mission using relative navigation.

The results from LIRIS-2 are the foundation for an ongoing DLR project implementing a full sensor data processing hardware and data/command interface in addition to realizing a compact and lightweight one-box-design without the need of external electrical and optical cabling between LIDAR components. Such a sensor is believed to provide an ideal solution for rendezvous- and docking, on-orbit servicing and space debris removal missions, as well as potential use for planetary landing or other space robotics applications. It could also support rendezvous and docking operations of future vehicles supporting post-ISS human exploration plans in a similar way RVS is now supporting logistics vehicles to the ISS.

8. ACKNOWLEDGMENTS

The authors would like to thank the highly motivated teams at Jena-Optronik, Airbus Defence and Space, associated to its subcontractor ThalesAlenia Space Italy, and ESA as well as at the power converter subcontractor ASP (Salem, Germany) and the Fraunhofer Institute IOF (Jena, Germany), without whom the LIRIS-2 3D Imaging LIDAR project would not have been possible. We also acknowledge the support by the Automation and Robotics Department of DLR German Space Agency for being able to use the LiQuaRD results for this project.

The LiQuaRD 3D Imaging LIDAR components were built and qualified within the respective project by DLR German Space Agency under project no. 50RA1002 with funds from the German Ministry for Economy and Technology (BMBF) by enactment of the German Bundestag.