Flash Imaging LIDAR for Space Debris Removal Demonstration Mission

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The project RemoveDebris disrupted the development time frame and risks mitigation for space missions to design and test devices. Within a time period of 4 years we moved from a paper concept to a TRL-8 hardware with a mission budget divided by a factor of 10. CSEM contribution, the vision-based sensor (VBN) was successfully operated in orbit and provided many color and 3D images of targets ejected on purpose by the main satellite.

The RemoveDebris mission is an initiative of the European Commission. This space mission has been the world's first Active Debris Removal (ADR) in orbit demonstration of some enabling technologies, including net and harpoon capture. It involved also the evaluation of CSEM's Vision-Based Navigation sensor (VBN) integrating a flash LiDAR and a color camera, the front-end of the guidance, navigation and control (GNC) of the ADR chain. Ultimately, the mission was terminated with the deployment of a dragsail to de-orbit the 100 kg main satellite. For the purposes of the mission, 2U CubeSats were ejected and then used as debris targets instead of real space debris.

Figure 1: CSEM's VBN sensor. (top right) color camera optics. (bottom center) laser illumination head and above LiDAR receiver optics.

CSEM has a long-term strategy to develop flash LiDARs. For the spatial domain, we achieved a Technological Readiness Level (TRL) of 4 at system level and we started in 2019 an ESA project targeting TRL-5/6 for one sub-system. Additional projects will be necessary to reach TRL-8 or 9, which are the levels where a technology can be considered for a full-scale space mission. Going through the TRLs stepwise with several projects is the traditional ESA development path for space.

RemoveDebris was special in the sense that it disrupted the traditional space approach. Unconventionally, within the same project we started at TRL-2 (paper concept) and ended at TRL-8 with an in-orbit demonstration. In itself, this is quite an achievement with the risks mitigation strategy and the pace of development, fabrication, test and integration involved. The development risk and budget mitigation started right at the beginning of the project with the choice of the components. None of the ones used is space qualified. The cost of such component simply does not match the available budget. Instead, we used commercial off-the-self components that we assessed according to space specifications for a one-year mission in Low Earth Orbit (LEO). The number of sensor versions were limited to one. Hence, the same hardware was used for sub-systems functional and environmental tests. Once the complete sensor assembled, it was qualified and assessed as a full system. After delivery to the satellite provider, the VBN was integrated and further tested on the platform according to functional and environmental requirements. This was made possible only with a careful design involving numerous engineering expertise areas including mechanical, optical, electronics and software.

The number and value of RemoveDebris outcomes are not easily measurable. The space debris environmental concern is appealing to the Medias, hence the project benefits from a large coverage by all kinds of media, including TV channels, radios, newpapers, etc. The website of the project got millions of hits. Technical and operational aspects are more measurable as CSEM possesses now a set of color and 3D images taken in orbit in real space operational conditions.

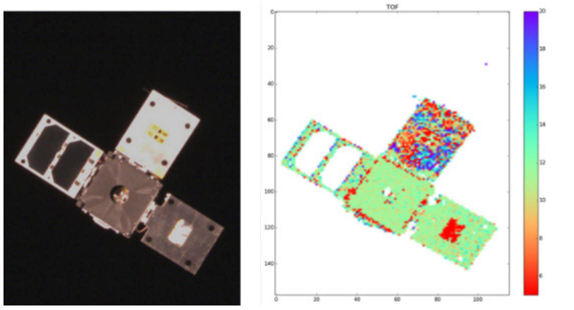

Figure 2: Example of pictures taken with the color camera (left) and the LiDAR at almost the same time (4s offset) of the 2U CubeSat with deployed panels 272 s and 268 s after ejection by the main satellite. The images are cropped and stretched as the field-of-view of the camera is twice the one of the LiDAR. The LiDAR image colors represents the measured time-of-flight (TOF) by each pixel.

In orbit experiments time windows were chosen to favor a strong illumination of the target by the Sun that was on the back of the main satellite compared with the CubeSat ejection direction. Bright areas can be seen in the color camera image (left and top panels, and center area of bottom right panel). The effect of the strong sunlight is visible in the LiDAR image where the same areas appear either with only red or mixed colors spots. They show the detector saturation. The panels hit with less sunlight (center and bottom right ones) appear with mostly green spots in the LiDAR image. The sensor settings defining the image dynamic range (aperture, integration time) were defined on Earth several days before the experiment.

The un-saturated areas provide measurements allowing to get correct TOF and distances. From these measurements several secondary figures can be calculated such as: 3D target image, relative attitude, velocity and rotation of the target, etc. These figures are mandatory to catch a debris in a controlled manner.

In relation with the long term LiDAR development strategy, the RemoveDebris experience is unevaluable as it shows what it takes in a real situation with strong Sun and Earth background perturbations to get proper visual measurements that can be considered with confidence to control the approach of space debris by waste collection crafts or more generally for in space Rendez-Vous between two objects.

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