Experimental Low Earth Orbit Surveillance Stereoscope – LEOSCOPE

- in short -

The combined tasks of the detection, characterization, correlation, and orbit determination of space objects describe the scope of ”space object surveillance”. For the most part, detector technology is sufficiently advanced to build the kind of capability required for satisfactory identification of space objects. However, accurate determination of the track's position requires correlation of data from more than one passive sensor (a single passive sensor suffers from an inability to get unambiguous range data, even against fairly deterministic tracks such as satellites).
During the last 3-4 years, NASA, US Air Force and Canada Air Force supported several R&D projects which explore applications of stereoscopy in space objects observation.

Stereo vision is very important in astronomy and space surveillance as well as to our primary sense. Besides the requirement to create 3-D images, an additional use of stereo imaging systems is to measure distance to objects remote from the system. Astronomers use parallax to determine the distance to stars close to Earth (pseudo-stereoscopy). The idea is to take images of stars when the Earth is on opposite sides of its orbit (i.e. 6 month apart). The shift of the nearer star against the farther stars is measurable. Since the stereo base is known (two astronomical units), it is a simple matter of trigonometry to determine the distance to the near star. Earth Observing Satellites, such as IKONOS, use pseudo-stereoscopy for photogrammetric extraction of 3D feature coordinates, digital elevation models (DEMs) and orthorectified imagery.

This project examines recovering the depth of LEO orbits and acquisition of space object metric data from stereo images by correlating matching feature points. Images will be collected by autonomous pairs of small aperture ground-based electro-optical sensors with a long base line (20 km+).

The main purpose of the LEOSCOPE project is to prove the concept for a next generation of wide area space surveillance sensors which make use of stereoscopy. A secondary purpose is to develop Romanian scientific capabilities and to join ongoing international initiatives in the field of Space Surveillance research.

LEOSCOPE is organized in three main areas, each of them having a specific objective and corresponding work package:

- Electro-optical imager setup
- Long base line stereoscope test and validation
- Scientific applications development and LEO objects data acquisition.

This space surveillance system will detect and provide information concerning the orbital parameters of LEO satellites or other bright space objects (meteors, comets, boosters, etc). In the case of big objects in its FOV, the LEOSCOPE can provide photometric and shape parameters.
Other applications are related to stereoscopic astronomy.

DESCRIPTION OF MAIN PROBLEMS TO BE SOLVED

- Observation base line and sensor locations

Reasonable range accuracy for 500 – 1000 km altitude objects involves a base line in the range of 20+ Km. One sensor will be located at the Feleacu Astronomical Observatory of the Romanian Academy (750 m altitude). The pair sensor will be located at the BITNET space surveillance testbed in Marisel (1.200 m altitude). During space data acquisition campaigns, the base line can be increased (using temporary locations).

- Sensors alignment procedure

The alignment of the imagers determines the accuracy of the information that is produced, which is used to calculate distances of an object from the stereo camera. Typical astronomy alignment techniques will be used.

- Sensors synchronization procedure

Since LEO objects are fast moving (typically cross the sky in 10 min or less), the accuracy of metric data is dependent upon the synchronization of the two acquisition devices. This is not a trivial problem when dealing with very long base lines (from several Km to hundreds of Km) and especially in the case of small FOV sensors. The possibilities are to use GPS satellites to synchronize the sensor clocks or a direct radio link between the sensors. The delay involved by an internet connection or by a satellite radio link is too big for these fast moving objects.

- Sensor field of view (FOV). Space object search vs. tracking strategy

That's another critical parameter. There are two fundamental choices for the imaging device, which are application dependent:

a) Wide area search of LEO objects with unknown orbital parameters involves wide area FOV. In order to have a realistic probability to detect such a fast moving object in real time, the FOV should be in the range of tens x tens sq. degrees. This is an enormous FOV for a telescope (usually in the range of tens of sq. minutes). It is why fisheye lenses or similar devices can be used only.
b) However, for high accuracy of metric data, sensors with small FOV (less than 1sq. degree) must be employed. Such a second imager can use as input orbital search parameters the metric parameters derived from the wide FOV stereoscope.

- Required sensor tracking capabilities

a) No object tracking capabilities are required for the wide FOV imager for short time exposures and if the base line is in the range of tens of Km. Star mode tracking for long exposures is necessary, i.e. for small magnitude object detection. As well as for sky scanning apps.
b) The small FOV imager must have space object tracking capabilities, otherwise the object will cross its FOV very fast. Another problem is that long exposure for small magnitude objects detection requires tracking capabilities.

- Sensor angular resolution

a) The angular resolution for a good commercially available fisheye-like camera is in the range of 0,2 degrees/pixel.
b) The angular resolution of the small FOV imager depends on its FOV and the CCD camera performance. A compromise between FOV, angular resolution and costs has to be decided during the project first phase.

- Detected object magnitude

a) The expected detection magnitude for a good commercially available fisheye-like camera is $+4^{th}$. This magnitude strongly depends on surrounding lights (artificial lights, Moon light), air pollution, and clouds. It is why the sensors will be located in mountain areas, far from cities. The sensor sensitivity could be further increased with image intensifiers.
b) Detection magnitude for a small FOV imager can be expected in the $+11^{th}$ to $+14^{th}$ range (typical GEO satellites magnitude range).

- System command and control. The architecture has to be decided in the first phase of the project. Several choices being possible.
- Image processing software development for space stereoscopy:

1. One camera related:
   - Intrinsic photometric and geometric calibration and errors removing (such as variations in pixel sensitivity, dirt/scratches on the lenses, noise etc).
   - Matches of detected stars with an astronomical catalogue of stars in order to identify them.
2. Stereoscopy related:
   - Extrinsic calibration (translation and rotation parameters of the pair cameras with respect to a common, astronomic reference system).

- ➢ Image rectification: based on the camera parameters, images taken from the two cameras will be warped in such a way that the images appear to be taken from a canonical setup (parallel looking cameras).
- ➢ 3-D reconstruction and orbital metric data extraction from pairs of images.

Project impact

It is important to point out that Romania is completely dependent on space object, mission and orbit information provided by international organizations. For instance, Romania is not able to detect a reconnaissance satellite that surveys its territory. This serious capability gap may be reduced, and ultimately resolved, with the installation of a (future) operational facility and the participation to the European Space Surveillance network. LEOSCOPE is the first stereoscopic LEO surveillance system developed by Romanian organizations. The main security applications of such a system are:

- ⇒ track and acquire orbital metric data of LEO satellites (such as reconnaissance satellites)
- ⇒ track and acquire orbital metric data of other bright space objects
- ⇒ verify the application of international treaties in outer space
- ⇒ provide decision makers with pertinent information regarding the situation in space within the decision process or the planning/conducting of operations.

The project gives an opportunity for national and international expertise exchange, know-how, organizational and human resources development in the field of space surveillance technologies and their applications, in order to join existing international projects and further develop them.

<u>Involvment of the project theme in European projects</u>

a) “Area 9.2.3: Reducing the vulnerability of space assets” within FP7 Cooperation Work Programme: Space. First bid of project proposals: probably 2009.
b) The ESA Space Surveillance Program Proposal (2006-2009).
c) As well as many EU state government supported space surveillance projects and NATO projects.

PROJECT CONSORTIUM

BITNET Research Center on Sensors & Systems (project co-ordinator) is a 15 years old private technological research company with national and international experience in space technology applications. BITNET CCSS is involved in the activities of the FP7 “Integral SatCom Initiative” technological platform and has cooperation agreements with international telecom satellite operators.
BITNET CCSS has significant knowledge in space surveillance techniques, being directly involved in projects in this field and is developing the first Romanian space surveillance testbed.

UT-Cluj: The Image Processing and Pattern Recognition research group of the Technical University of Cluj Napoca, has extensive experience in the field of stereovision and stereovision-provided 3D data processing. A seven-year research collaboration with Volkswagen AG covered multiple fields, such as camera calibration, edge-based general geometry stereovision, image rectification, perceptual 3D points clustering into meaningful objects, dense stereovision processing, unstructured and structured environment estimation and model-based probabilistic tracking.

AROAC - The Astronomical Observatory of The Romanian Academy / Cluj Branch has a very long tradition in space geodesy, astronomical observation techniques and in scientific electro-optical sensors deployment. The Feleacu (Cluj) Observatory was included in the COSPAR World List of Satellite Tracking Stations (station no. 1132).

Over the last years, AROAC was involved as significant partner in several Romanian space surveillance R&D projects.