SVMS STEREO VISION MEASUREMENT SYSTEM
A COMPUTER VISION SYSTEM FOR ROBOTIC SPACE APPLICATIONS

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ABSTRACT

In the next years, space activities will need robotic systems to build and repair orbital platforms, and to service geostationary and low orbit satellites, in order to reduce costs and risks for human operators. Moreover robotic systems (rovers) will help for planetary exploration. Robotic systems require an integrated sensor system providing all the information necessary to perform the foreseen tasks.
Depending on the application, such information can be e.g.: position and attitude ("pose") of objects, pose of the vehicle with reference to the environment, 3D map of the scene, geometric survey of objects (e.g. size, distance, attitude), etc.
A passive stereoscopy system can provide this information. On account of the outputs of previous studies and demo carried out for ASI and ESA, ASI has recently decided to develop a space qualified prototype of a stereovision system, based on technologies and algorithms developed for other hostile environments, such as deep-water and nuclear.
The system will be based, as far as possible, on HW and SW COTS components, and it will be fitted with a remote MMI, and a precision pan & tilt device, allowing to change aiming direction of TV cameras. The reference demo scenario for this system will be the "Europa" mission, which will include telerobotic experiments on an Express Pallet of the ISS.

1 INTRODUCTION

Tasks to be performed in space include e.g. building and operation of ISS, inspection and repair of orbiting satellites, and driving planetary rovers. Some of such tasks are performed by astronauts, but the use of space robots is attractive, due to risks and costs related to EVA operations.
For instance, on the ISS a number of sophisticated robotic arms are going to be used. However, the current approach to control arms in space is either through pre-programmed motion sequence, or direct astronaut control. On the other hand, it may be noted that the main added value of space robots resides in their remote controllability. To achieve this feature, a basic requirement is the availability of measurements on the real world, in order to adapt nominal tasks to the actual environment.

Therefore, such sensors should be able to provide:

- Accurate pose of objects to be manipulated. This would add flexibility of use, allowing a rough off-line definition of tasks to be performed and the accurate on-line task implementation. Generally this is known as "sensor based manipulation".

- Tracking of such objects to allow interventions even with relative motion between arm base and objects. This would enable to carry out RV&D and flying object capturing. It is worth noting that, depending on transmission delay, such operations are hard to manage from remote. Furthermore this function would allow to assess in real time the pose of a robotic vehicle with reference to a known working scenario.

- 3D soil mapping, to allow navigation of rovers on lunar/planetary soil.

- Metric survey. This inspection may be useful to measure actual size and attitude of objects, e.g. in order to define and plan remedial and/or repairing actions.

On the basis of previous results (see section 2), ASI has decided to develop a prototype of a stereovision system able to provide the mentioned capabilities. The project will last three years and will produce as output the EM of the SVMS (Stereo Vision Measuremenmt System).
This development will be performed using the EXPRESS Pallet as reference application scenario. Furthermore the use of HW and SW COTS will be as large as possible. This will allow the easiest way to get the corresponding FM after the end of the project.

The paper is arranged as follows: section 2 reports the previous works and results which form the basis for the current project, section 3 reports the purposes of the system, section 4 describes the technical approach, and section 5 draws the conclusions.

2 BACKGROUND

Tecnomare have been working in the field of telerobotics for hostile environments for many years. Typical applications are, for instance, deep waters (Ref. 1) and experimental nuclear fusion reactor maintenance (Ref. 2). The availability of suitable sensor information on the environment is a key element to allow the "supervisory control" paradigm for the management of telerobotic tasks. With this approach the remote operator is still in the "control loop" of the robot, but the related interface level can range from mere manual control up to task level control (Ref. 1).

A key element to implement the higher control levels is the knowledge of the environment geometric model.
For this purpose a computer stereovision system has been developed, see Ref. 3 and Fig. 1, whose main purposes are:

- 3D measurements of scene points
- fitting of such measurements with a–priori known geometric shapes
- video-tracking of points, to update geometric model in real-time.

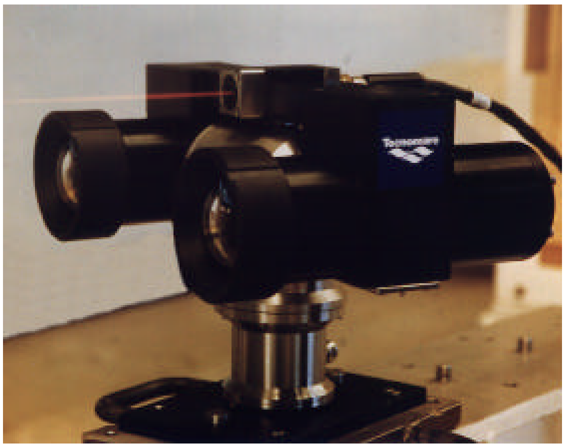

Fig. 1 Underwater stereovision imaging system

Tecnomare performed a study (see Ref. 4), on behalf of ASI, aimed at evaluating suitability of the available technology for space robotic applications.
The results showed the applicability of the algorithms and techniques to the space scenario, by using mock-ups of typical objects, such as truss structures, cylinders, thermal blankets, ORUs, etc.

A further demonstration step (see Ref. 5) was achieved in the framework of a contract with ESA, aimed at demonstrating the applicability of these computer vision techniques to the navigation subsystem of the Geostationary Servicing Vehicle (GSV).
Here the problem was to use computer vision to perform approaching navigation and capturing of a failed GEO satellite.

The study, carried out by Tecnomare and Alenia, included the analysis of the problem and the definition and tests of suitable algorithms to work out the relative pose between failed satellite (target) and robotic intervention system (chaser).

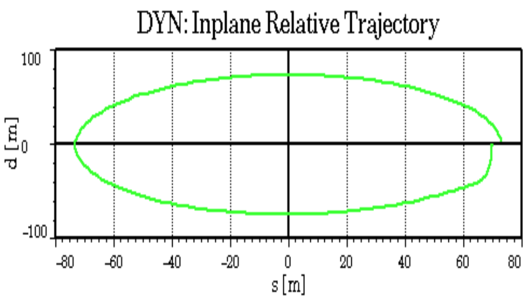

Fig. 2 Actual performed trajectory

It was demonstrated that the computer vision system could provide relative position from a distance up to 7000 km and relative pose from ca. 100 m down to capture distance (3÷4 m). The algorithms were tested through full simulation of all the main items:

- TV cameras and image generation
- Computer vision processing
- Navigation subsystem, including sensor integration
- Dynamics of target and chaser
- Close loop control of chaser

The basic implemented processing consists of the following steps:

- the operator recognises and designates the points to measure/track;
- the computer vision system performs automatically the tracking/measurement function of such points;
- the final processing step evaluates the relative satellite pose through fitting of the measured points with the CAD model of the satellite.

A typical fly-around trajectory is reported in Fig. 2, while the related total error of stereovision algorithms is reported in Fig. 3.

Furthermore tests were carried out using real TV cameras (see Fig. 4), imaging a satellite mock-up, see Fig. 5, where the tracked and measured points are marked with crosses.

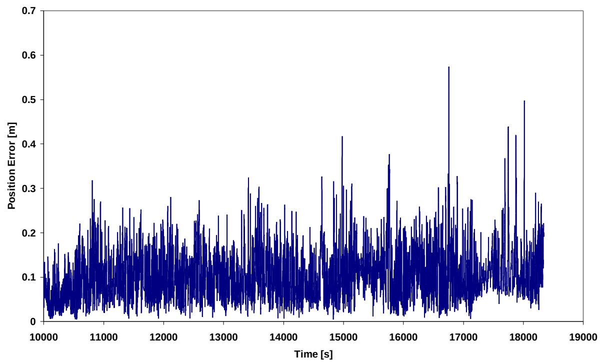

Fig. 3 Total position error during fly around

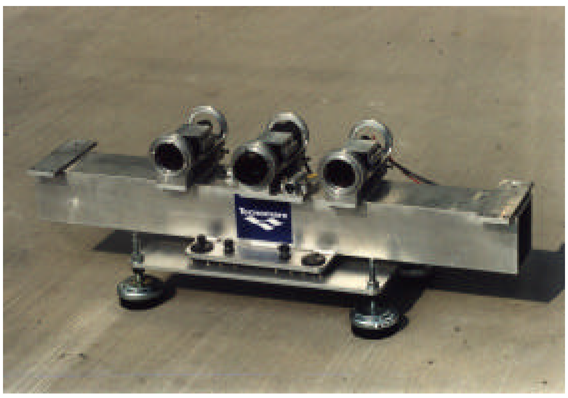

Fig. 4 Laboratory stereo/single view imaging system

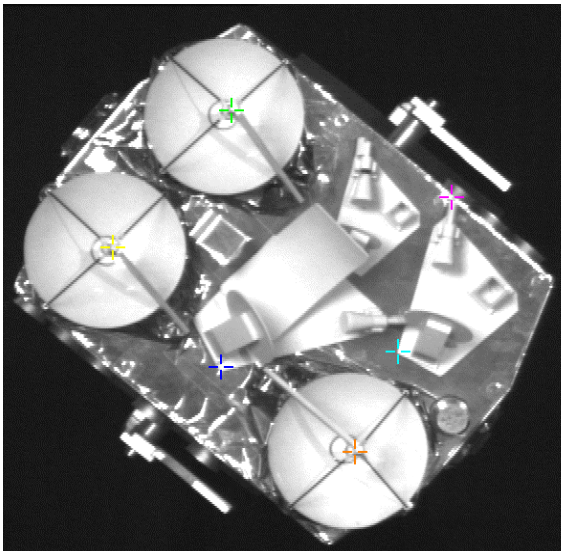

Fig. 5 TV image of satellite mock-up. Tracked points are denoted with a cross.

The achievable accuracy has shown to be satisfactory for the application, and matches the system requirements:

- 1÷2 % of the range has been typically obtained in the different operating modes
- 2° for the attitude during synchronization

A further work is the project ROSED, carried out on behalf of ASI. In this project, Tecnomare developed a computer stereoviosn system to reconstruct the geometry of a typical "truss" structure.

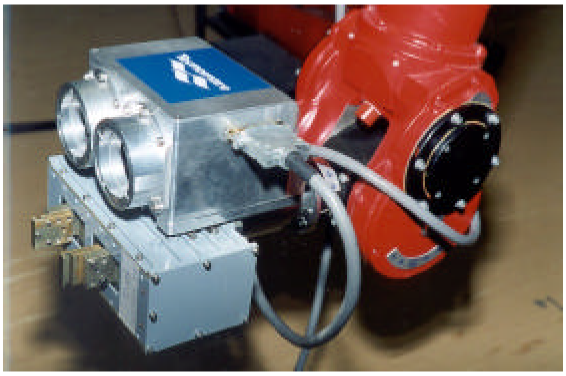

Fig. 6 The stereovision imaging system installed on an industrial arm end effector.

The imaging system (see Fig. 6) was installed on the wrist of an industrial manipulator to allow scene reconstruction from different points of view.

3 SYSTEM REQUIREMENTS

3.1 General constraints

The current development includes the design, assembly, integration, and tests of the SVMS Engineering Model.
The flight segment EM will be implemented using as far as possible COTS components for which an "off-the-shelf" flight model (FM) version exists. For those components for which no COTS is available with a FM version counterpart, an Engineering and Qualification Model (EQM) will be developed and tested for qualification purposes.

The EM will be easily upgradable to implement a flight model able to sustain the demo mission described below. This upgrading phase will be performed in a subsequent phase, replacing the EM components of the flight segment with the corresponding commercial FM version. For the components for which no commercial FM version exists, a FM version of the qualified EQM parts will be used.

3.2 Demo scenarios

The reference scenario foresees the in orbit demonstration of the SVMS capabilities to perform monitoring and visual inspections of the EUROPA facility on ISS (International Space Station) Express Pallet for a short (roughly one year) operation duration. The Shuttle will be considered as launch vehicle. As a minimum, the following operations will be performed:

- position and attitude measurement of typical EUROPA objects/element;
- tracking of typical moving objects (e.g. the arm end/effector), image acquisition for visual inspection and monitoring.

The development approach will emphasise the application flexibility aspects, considering further possible scenarios, including other ISS facilities, to perform operations such as: inspection/monitoring, object capture, locating and docking aid in RVD operations of space devices and structures.

Furthermore, the critical aspects for the SVMS implementation with respect to the following additional space scenarios will be considered:

- <u>Rover navigation</u>, for working out the Digital Elevation Map (DEM) of the soil in front of the rover. Such DEM can be useful for the telecontrol from Earth of both Moon and Planetary rover (i.e. in a scenario with communication delay in the order of tens of seconds to several minutes), in order to built up a geometric model of the surrounding environment for path planning and /or graphic reconstruction of the remote work scene;

- <u>Construction job</u> carried out by manipulators installed on landers and/or rovers, for accurately locating the parts to be installed/mounted in order to control the manipulator arm motion in a supervisory control mode;

- <u>Soil mapping</u> during landing (e.g. probes), for building up a DEM in the final approach phases, when the probe navigation control system must decide the actual landing location.

4 SYSTEM DESCRIPTION

4.1 Block diagram

The system block diagram is reported in Fig. 7.

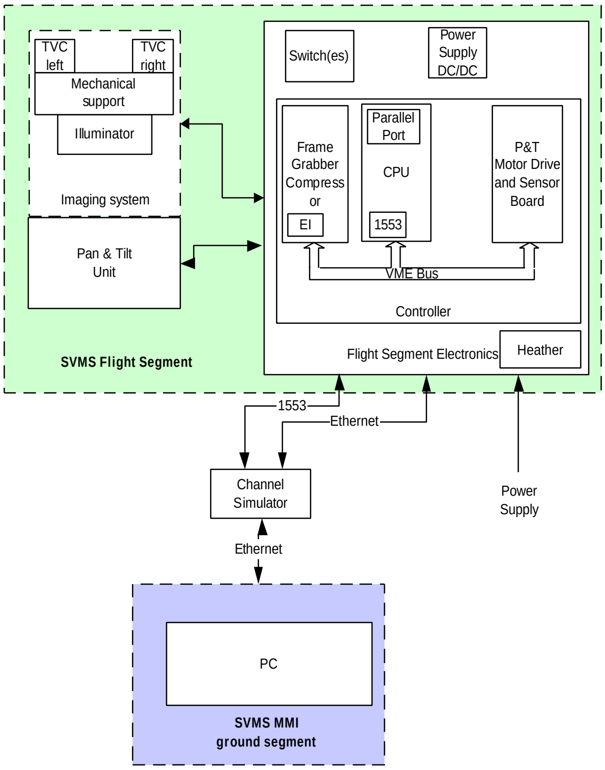

Fig. 7 SVMS general block diagram

The flight segment is composed of:

- A calibrated stereo pair of TV cameras
- Illuminator
- Accurate Pan&Tilt unit to vary pointing direction
- Electronics, including controller, power supply and ancillary equipment.

The controller will be comprised of a radiation tolerant VME computer, fitted with suitable interfaces to acquire video signals, to take control of the pan & tilt unit (PTU), and to interface with the ISS.

Fig. 8 shows the concept for the imaging system. It will include two similar angular joints, comprising the following items:

- Actuator: stepper motors
- Reduction gears: harmonic drive
- Sensor: resolvers

The precise measurement of current PTU angles is required. As a matter of fact the 3D coordinate measurements performed with reference to the TV cameras must be transformed in terms of robot body reference frame.

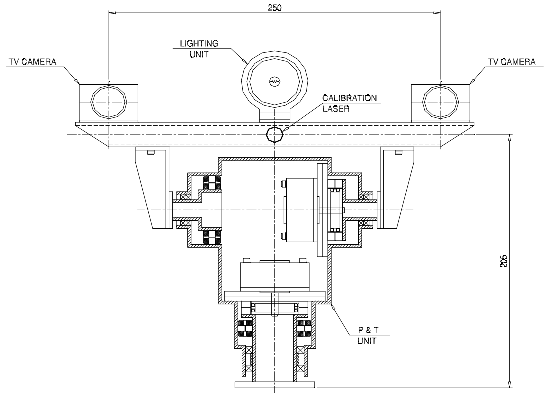

Fig. 8 Conceptual design of the imaging system, including illuminator and PTU

The system MMI will be constituted of a PC fitted with a suitable SW package, and it can be placed inside the ISS or on ground.
For testing purposes, a communication channel simulator will be used.

4.2 System functions

The MMI will permit the complete control of the system, in terms of function selection, status monitoring, alarms, reading of measurements, PTU commands and angles, etc. All the system functions will be available through menus and soft-keys on the MMI.
The MMI will include also the display of the image taken from the remote TV cameras (either left or right). The frame rate and resolution of this picture will be limited by the available data rate of the communication channel between flight segment and ground segment. JPEG compression algorithm will be used to get the maximum rate.
Finally, the MMI will include the graphic rendering of the environment geometric model, as measured by the system. The ISS MMI will be a simplified version without graphic rendering.

The system will be capable of performing specific tracking and measurement tasks on scene points, imaged by the calibrated stereo pair of TV cameras, and designated by the operator, through a cursor on the above MMI picture.
The SVMS is capable of working either in stereoscopic mode or in single view (monoscopic) mode. In the latter a single TV camera will be used and only a subset of the overall function set will be obtainable.
All the available system functions will be arranged in "operating modes", where the transition from one mode to another will be commanded by the operator.
The main operating modes will be as follows:

- Stereo mode, live picture. The picture is continuously updated and the measurements are carried out on the currently available image.
  - Single point measurement. 3D co-ordinates of a user-selected point are automatically measured by stereoscopy.

- Contemporary tracking/measurement of 1 up to 6 points. The user selects the points to be tracked, by clicking on them.
- Pose tracking, on the basis of 3D coordintes of the tracked points, the relative pose of a frame fixed with the points, i.e. with the object selected by the operator, is evaluated with respect to a frame fixed with the robot body.

- Stereo mode, still picture
  - Distance measurement between two points
  - Area mapping, the system automatically performs 3D coordinate measurements of a user-selectable area in the picture.

- Single view, live picture
  - Contemporary tracking/measurement of 1 up to 6 points
  - Pose tracking, on the basis of 3D coordintes of the tracked points, the relative pose of a frame fixed with the object is evaluated.

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Baseline	250 mm
HFOV	40°
Stereovision Total error	6 mm @ 2m 3 mm @ 1m
Repeatability	3 mm @ 2 m 0.8 mm @ 1 m
Single view	10 mm @ 2 m
Tracking/measurement rate	4 Hz
Illumination conditions	From full daylight, to eclipse conditions (with illuminator)

Tab. 1 Target performances

The lens support will allow to replace lenses with other focal lengths, before launch, to adapt the imaging system features to different scenarios.

5 CONCLUSIONS

The need for integrating a computer vision system in the sensor subsystem of a space telerobot is evident. Main advantages include the capability of implementing the following:

- High level supervisory control: the computer vision system allows to measure actual position of objects to manipulate;
- Object capture, through video tracking;
- Close navigation and docking, measuring the relative pose between robotic vehicle and environment;
- Geometric measure of the target objects during visual inspection;
- Soil mapping in front a rover for local path planning.

In the area of computer vision ASI considered appealing the possibility of transferring in space methodologies developed for other hostile environments.
The present paper has reported the background, in terms of previous studies and demo carried out for ASI and ESA, the requirements and the technical approach that will be used to develop a space qualified prototype of a stereovision system. The system will be able to perform automatically the following main functions:

- position/attitude measurements of objects, through stereovision and single view
- video tracking of objects
- metric survey (e.g. sizing of objects, geometric inspections, etc.)

The system will be fitted with a remote MMI, and a precision pan & tilt device, allowing to change aiming direction of TV cameras.
As far as possible, the development will make use of COTS components and subassemblies whose FM version is already available. When this is not available, a full development and qualification process will take place. The planned overall project duration is 36 months.
The reference demo scenario for this system will be the "Europa" mission, which will include telerobotic experiments on an Express Pallet of the ISS.

6 REFERENCES

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