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Information management in an Integrated Space Telerobot

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ABSTRACT

The in-orbit operations, like space structures inspection, servicing and repairing, is expected to be one of the most significant technological area for application and development of Robotics and Automation in Space Station environment.The Italian National Space Plan (PSN) has started up its strategic programme SPIDER (SPace Inspection Device for Extravehicular Repairs) in the early 1987, this program is now continued by the Italian Space Agency that in may 88 have take over the role of national agency for space activities.SPIDER programme is scheduled in three phases, with the final goal of performing docking and precision repairing in the Space Station environment.SPIDER system is an autonomous integrated space robot, using mature Artificial Intelligence tools and technics for its operational control.This paper describe the preliminary results of a joint study between ASI and IESI on the information architecture of the spacecraft.

I. INTRODUCTION

The main goals of SPIDER system are visual inspection in a fly-around mission and precision repairing activities on the space structures.
The main characteristics of SPIDER are the following:
- small dimension (~1 mc) and low weight (~ 400 kg.)
- "biological" evolution capability
- retrievable by a platform or spacecraft based robotic arm.

The SPIDER programme is scheduled in three main phases:.

-in the first phase, SPIDER will be a space vehicle for visual inspection around large and/or small space structures, by means of a flying-around approach. In this phase, SPIDER will be strictly teleoperated

-in the second phase, SPIDER capabilities of autonomous navigation will be extended limiting commands to very high level instructions. The human operator will act in this phase only as a supervisor

-in the third phase, SPIDER will be able to do docking and repairing, increasing its autonomy. The presence in this phase of two small cooperative arms (linear dimension - 1m) and a docking robotic arm will allow to operate precision repairing and micro-manipulation capability.

In the following, we describe mainly the SPIDER-I system.
SPIDER-I mission, around the space structures, will allow to:

- test SPIDER fly-around capability

- support visual inspection of external devices

- find damaged areas of space structures, increasing crew safety and reducing dangerous extravehicular human interventions.

In the SPIDER evolution through the different described phases will be followed by a similar modularity in the Robotics Intelligence Subsystems. In section II we give the requirements for the SPIDER -I design reference mission. In section III we give a general platform description, in section IV the Architecture of the control system is depicted. In section V the relevant aspects concerning the interaction of sensor and controls SPIDER subsystems are described .

II. SPIDER-I Design Reference Mission

In order to define the SPIDER-I system specifications, the following LEO external visual inspection scenario has been hypothesized:

- SPIDER should be deployed in LEO by a space transportation system (STS, HERMES,OTV...).

- Fly by the target structure (eg. MTFF, ISS).

- Demonstrate proximity operation capability flying at a fixed distance from the coorbiting structure at different relative velocities

- Report accurate image and other information about the external environment and the target

- Exploit passive docking capability

- Admit a mission duration of at least 1 h and a station keeping period of 24 h before a retrieval operation performed by other space transportation systems or orbiting permanent facilities.

The SPIDER system specifications has been defined on the basis of these mission requirements.

III. PLATFORM DESCRIPTION

The SPIDER is a small dimension free-flyng spacecraft. It's aspect is that of a cylinder with polygonal bases and with a design reference mass of 400 kg.
The SPIDER overall dimension are:

-Length 150 cm

-Diameter 90 cm

The Robotic Intelligence System (RIS) is located the forward of the spacecraft with a mass of about 170 kg. The spacecraft reaction control system (RCS) will permit medium-range and proximity operations. The cold gas will be used as propellant to prevent pollution of optical or other exposed surfaces during proximity operation. The use of low-impulse trhusters (e.g. electrical propulsion) will be considered for the SPIDER-III mission. The first prototype will be equipped with 2 x 12 high impulse (30 Nw) cold gas trhuster for rotation and/or coarse movements and 2 x 4 low-impulse cold gas trhusters for precision movements. Four tanks will assure a total impulse of 4000 Nw/s.
Two third of the spacecraft will be covered with solar cells arrays in order to provide 150 Wh for each orbital period. A set of rechargeable batteries will provide power during eclipse.

IV. ROBOTICS INTELLIGENCE SYSTEM

The RIS will support in the final SPIDER prototype all the main high level function of the spacecraft:

-On board data handling

-Guidance and Navigation

-Perception and Reaction

-Man Machine Interfacing

-Remote Manipulation

Also if in the first phase some of this function will be mainly controlled by the remote human operator, the SPIDER system will exploit an intelligent behavior in the area of guidance and navigation,man machine interface and mission planning. In the following the RIS architecture and information flow are described.

1. FUNCTIONAL ARCHITECTURE

In order to exploit this "intelligent" behavior the RIS provide a set of specialized modules for different tasks (Fig. 1). This solution permits:

- a concurrent processing of different tasks.

- a specialized Knowledge structures

- a substantially fail-safe design

The interaction between the processes is performed through a "blackboard" that shares common interest information. The coexistence of different priorities among different processes forces a substantially asynchronous access at the blackboard. So, we can refer to our system as a white-board architecture /1/.
In order to extend the module design flexibility and the system design modularity, the information shared in the blackboard must be, as far as possible, process independent, in the sense that any process can access it in the more easy way.

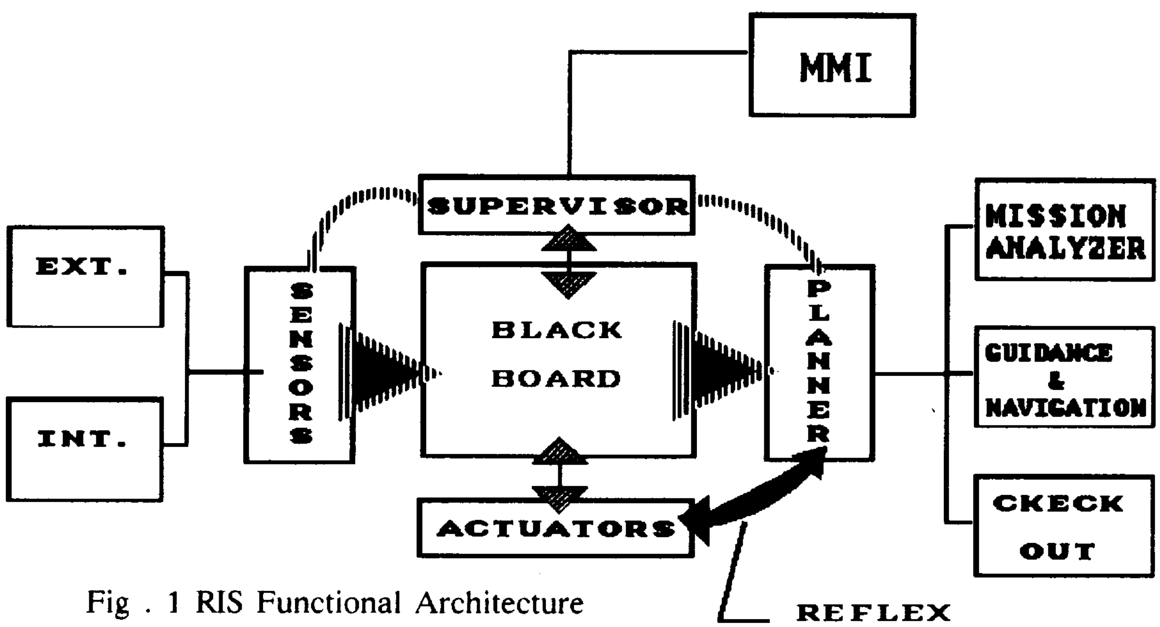

Fig . 1 RIS Functional Architecture

Supervisor

The white-board architecture claims for a Supervisor module that handles the specialized module priority, use of parameters, synchronization and so on. In addition, the role of such a module is of reporting all operator commands and triggering blackboard maintenance process.
This module is structured in Internal and External sensors. The Internal Sensor module provides to the Knowledge Base all information about spacecraft internal state, classical subsystems included. The External Sensor module handles all the information about the

outdoor space, such position and velocity of the spacecraft, target characteristics, etc. A deep difference exists between these two modules, because while the first interacts mainly with maintenance and internal monitoring process, the latter is involved both with main spacecraft task (inspection) and the guidance and navigation
subsystem. In order to perform these activities an extensive use of sensor information fusion is made. This goal is achieved using as interface among external sensor module and blackboard system a set of "virtual sensors" /1/,/2/.
These sensors are obtained using different specialized sensor information in order to obtain high level information (e.g. depth and color). The virtual sensor characterization is driven by the supervisor module using the requests made by the operator or by other modules. In tab.1 a set of the SPIDER
proposed external sensors is shown.

Absolute position sensors

- **Star Sensors**
- **GPS Receiver**

Relative position sensors

- **Continous wave laser**
- **Accelerometers**
- **CCD cameras**
- **Mw sounder**

Tab. 1

We have already mentioned the sensor fusion task; it must be noted that different purposes can be met by means of these definitions /3/:

Sensor cooperation - Use of mixed perceptual information

Sensor competition - Use different sensors for the same task with different accuracy

Sensor independence - No interaction between sensors

Anyway, the complete definition of the external sensor subsystem will be made after completion of a certain number of technological assessment studies expected for the end of the 1988.

Planning

The Planning system controls the system reasoning on the data acquired by the sensor information module, on the directive made by the module and drives self check procedure of the spacecraft. It also converts High Level directive in execution sequences, usable by SPIDER subsystems.

In order to perform these different tasks the Planning module is decomposed in three modules:

Mission Analysis

Guidance & Navigation

Check-Out

The first module is an aid to the human operator that permits a fast evaluation of the mission requirements, or of a subset of operation connected with a SPIDER mission. The Guidance and Navigation module implements the missions proposed by the Mission Analysis module and/or using information from the blackboard, implementing also collision avoidance maneuver.The Check-Out module is a diagnostic expert system, specialized to the SPIDER subsystem trouble shooting. It also maintains records of malfunctioning of spacecraft sections.It's important to point out that the planning system cannot directly implement its decisions, except that in the case of severe danger for the spacecraft or for others coorbiting objects, in that case the system will bypass human control implementing the reflexive behavior.

Man Machine Interfacing

This is one of the key subsystem of the SPIDER system. Infect, in a teleoperated system, the man machine interaction must permit an easy and high level dialogue between the operator and the spacecraft. In this area, all state-of-the-art tools will be used in order to argument the: scene rendering, situation simulation, alarm transmission. Also in this area specific studies are ongoing in order to select appropriate devices and software tools.

Actuators

This subsystem is the interface between the Robotic Intelligent System and the other spacecraft subsystems that implements the directive processed by the RIS or directly transmitted by the human control.Naturally it comprends the RCS, the thermal control, and the power subsystems. In the following, spacecraft evolution will comprend also the active docking mechanism and the manipulation arms and end-effectors.

Hardware Architecture

The hardware implementation of the described functional architecture will face with several problems mainly connected to the space qualification of terrestrial processors and software. Moreover, a lot of problems that do not yet even have a solution in ground based situation should be resolved. An other point susceptible of carefully evaluation is that of the bandwidth of the radio-link among the user station and spacecraft and the choice of the format of image supported information transfer. This problem will be obviously related with the space qualified hardware available and with the trade off in the distribution of computational charge among the spacecraft and the user station.
Also the opportunity of using a ground based workstation will be evaluated having in mind:

-redundancy

-signal propagation delay

-computational power

2. INFORMATION FLOW

The first SPIDER mission will be a demonstration flight that will show the capabilities of the system in the free fly and user supervised inspection. A generic SPIDER-I mission is brunched in the following Tasks:

A- Deployment by a space transportation system

B- Free-fly to the target

C- Target Inspection

D- Free-Fly Back to a Station Keeping Position

E- Retrieval

Phase A and E are for the SPIDER-I spacecraft quite passive task, i.e. the spacecraft will have only a passive docking interface that will be docked to the deployer. Phase B and D are substantially similar task with main difference in the start and end point. Task C is the core of the SPIDER-I mission in witch the external inspection capabilities of the spacecraft will be tested.At the purpose of demonstrate the compatibility of the described RIS functional architecture with these tasks, we have analyzed the structure of each task and pointed out their mutual relation and interaction with the spacecraft subsystem.The resulting representation is shown in Fig. 2.

1. Task A and E

As already shown the SPIDER during these phase will be totally passive. The only task that must be performed is the complete system Check-Out. A rule of the type:

IF Check-Out-Succes THEN Deploy

IF Check-Out-Succes THEN Retrieve

Will be the only condition-action pair that will control both the operations.

2. Task B and D

After the deployment the SPIDER will be in a Station-Keeping position. The problem is to implement the best trajectory to the target. In the problem definition, and without a loss of generality we have supposed that:

-There is no relative motion between SPIDER and the Target at the moment of deployment.

-And that the Spider trajectory to the Target is described by a plane curve.

The subtask of the free-flyng among two position are:

-Path Planning

-Check Out

-Guidance and Navigation

The Path Planning must compute a transfer orbit for SPIDER from the Start Point to the target proximity. Their input data must be :

-Spider State Vector at the Deploy

-Target State Vector

-Internal Subsystem State

-Known Obstacles on the Path (IF any)

-A Path Optimization Criteria

The Output of this process will be a Transfer orbit and a firing sequence for the RCS.The Check-Out will provide information of Spacecraft Faults, if any, a fault recovery analysis if possible. These process, active in all the Task of SPIDER, will change is focus of attention depending the actual system state and on the basis of the actual task goal.The guidance and navigation must pilot the spacecraft from the start to the end point implementing the strategy selected by the Planner. In practice his task is to compare external sensor readings with the data suggested by the planner, and if evidence of a divergence from the path is found send a request to the planner for a new plan. The G&N will also implement a collision avoidance strategy, if unknown obstacle are detected by the external sensors.

3. TASK C Target inspection

The target inspection, as described, will be one of the main goal of the SPIDER demonstration flight.

During this part of the mission the spacecraft should demonstrate it's capability in proximity flight, self-planning, and high-level command interpretation capability. Main sub-tasks of Target Inspection are:

-Proximity Flight
-External Sensor Data Handling
-Target State Vector

Proximity Flight

During proximity flight SPIDER will free-flight at a fixed distance around the target. At proper angle must zero is velocity respect to the target, and activate proper External Sensor. A tight interaction exist in this phase between:

-Planner
-Guidance and Navigation-
-External Sensor Data Handling.

In fact, in the actual system configuration, the external sensor are connected in a rigid way to the spacecraft

External Sensor Data Handling

This sub-task control all the data flow between external sensors and RIS. Implementing also the virtual sensor requested by different process (mainly by planner).
The ESDH send also request to the planner in order to force a stop of the spacecraft if requested by some sensors.
High level subtask of ESDH are:

-Stop and Zoom on operator Request
-Special Target part Recognition (thermal shields,solar arrays etc..)
-Supervised Inspection

Target State Vector Determination

This High Level Task determine the target center of mass motion parameters, in the SPIDER frame of reference, and target motion around its center of mass, to do that send request to the ESDH in order to activate proper Virtual Sensors connected to range finders and microwave sensors.
Data produced by this task are then used by the planner in order to correct the SPIDER orbit or implement user request.

V Conclusions

Actually the described architecture has been implemented using a commercial tool that offers knowledge representation facilities both in form of rules and frames. The explicit goal of this activity is to better understand the information flow and the knowledge

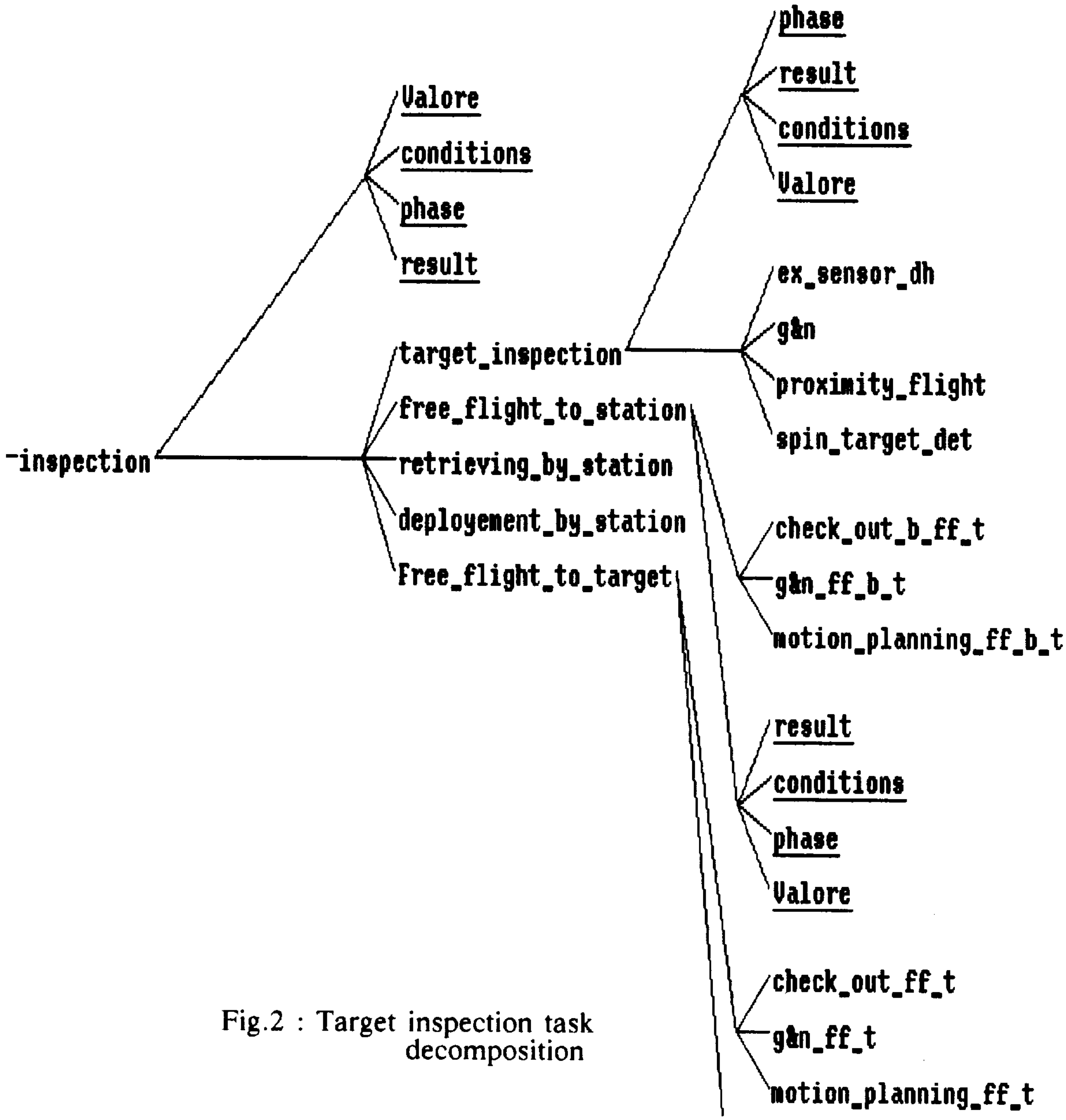

Fig.2 : Target inspection task decomposition

structure in order to define the final architecture design for the high level components of SPIDER robotic intelligence subsystem.

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