N95- 23719

Autonomous Spacecraft Executive and Its Application to Rendezvous and Docking

Fuminobu Komura*, Masatoshi Furuya*, Toshiro Sasaki*
Robert L. Anderson, Roy K. Tsugawa****
*Systems Development Laboratory, Hitachi, Ltd.
1099 Ohzenji, Asao-ku, Kawasaki 215 Japan
Phone:+81-44-966-9111, Fax:+81-44-966-6823
**Civil and International Systems Division,
TRW Space and Electronics Group
One Space Park, Redondo Beach, CA 90278 USA
Phone:(310)812-2608, Fax:(310)812-7296

KEY WORDS AND PHRASES

autonomy, mission planning, rendezvous and docking

ABSTRACT

Autonomy is needed for future spacecraft to solve the problems of human operator overload and transmission delay. This paper describes the autonomous spacecraft executive for rendezvous and docking. It is an onboard expert system and has decision making capability for mission planning of nominal and contingency cases. The executive has been developed and verified using a hardware motion based simulator.

INTRODUCTION

Research activities have been done to develop autonomous space systems.[1] Spacecraft autonomy is needed to avoid the overload of human operators and to overcome the delay or loss of command link. Spacecraft rendezvous and docking is a typical mission which needs autonomous operations.[2][3]

Spacecraft autonomy is attained by realizing mission planning and contingency management functions in onboard computers. The product of mission planning or contingency management is a sequence of commands to the conventional control systems of the spacecraft.[3]

AUTONOMOUS SPACECRAFT EXECUTIVE

Fig. 1 shows the architecture of an autonomous spacecraft.[3] The Autonomous Spacecraft Executive is an expert system implemented on an onboard computer that makes decisions needed for the spacecraft mission. The Executive is interfaced to the GN&C (Guidance, Navigation & Control system) and the SM (System Manager), and receives state and status from the GN&C and SM, and generates control commands and sends them to the GN&C and SM.

This architecture has the following characteristics.
(1) It is a universal modular architecture and is applicable to any spacecraft.
(2) The modules that receive the control commands don't need to know whether the commands are sent from the Executive or from a ground controller.
(3) The Executive has a vehicle dynamics simulator as a mission planning tool.

EXECUTIVE FOR AUTONOMOUS RENDEZVOUS AND DOCKING

Requirements

We consider rendezvous and docking missions where the target vehicle is a cooperative passive vehicle which is holding its attitude in a LVLH (local vertical - local horizontal) frame and has a receiver for differential GPS and reflectors on the target for a docking sensor on the chaser vehicle. The active chaser vehicle has the architecture of Fig. 1.

To complete a rendezvous and docking mission

234

many decisions must be made. The most essential decision is to plan a flight path or a velocity profile to attain the mission goals under safety, timing and consumables constraints. The plans must be made for both nominal and contingency situations. They vary depending on the phases of flight, i.e., approach from a parking orbit, proximity, dock, separation, etc. To accomplish the rendezvous and docking mission autonomously the Executive is required to create these flight plans.[3][4]

For the final stage of proximity e.g. from 1000 ft to 0 ft, the requirements for the Executive will be as follows.

modes:
- nominal approach plan
- contingency: loss of GPS lock or loss of proximity sensor lock
    - replan and try again, or
    - abort the mission

constraints:
- safe velocity profile
- safe approach corridor
- time of arrival (for lighting control, crew schedule, communications availability, etc.)

Executive Functions

The Executive has the following functions to meet the above requirements.

(1) input
- mission goals from the ground controller
- spacecraft state and status from the GN&C and SM

(2) monitor
- status of sensors
- position and velocity of chaser relative to target:

determine whether within control volume and safety limits, and if mission requirements are attainable

(3) plan

Depending on the output of (1) and (2), either of the following plans is generated from the rules.
- nominal approach based on the time of arrival requirements
- contingency plan based on the spacecraft state and status
- abort

(4) output
- control commands to the GN&C and SM

Monitoring and Planning Rules

The Executive functions of monitoring and planning can be realized by a set of decision rules which are expressed in the following form.

```
IF
        (current_control_state)(relative_position)
        (vehicle_status)(mission_requirements)
THEN
        (create new plan
         or continue
         or create contingency plan
         or station keep
         or back away
         or abort)
```

The IF part represents the monitoring, and the THEN part represents the planning. By these rules the control state of the vehicle is determined. Fig.2 shows a state transition diagram for the proximity operation.

The generation of the nominal plan "create new plan" consists of the following processes.

1. Design velocity profile for each phase

The proximity operations consist of a number of phases separated by station keeping positions. For example, station keeping positions are set at -1000ft, -300 ft, -35 ft, and -20 ft. They are needed for changing the vehicle control modes and for adjusting the arrival time at the target. A transfer is usually used from -1000 ft to -300 ft to save fuel, and an LVLH approach is preferable within -300 ft for safety. The velocity profile is computed by using mission planning tools, e.g. a vehicle dynamics simulator.

2. Select the earliest possible docking window
3. Allocate duration for each station keeping position
4. Abort if no window is attainable

With these rules the Executive can make decisions needed for the nominal and contingency operations in the proximity stage. Other set of rules are used for the autonomous operations in other stages.

VERIFICATION TESTS USING A HARDWARE SIMULATOR

Simulator Configuration

The configuration of the verification test facility is shown in Fig. 3. The Executive was implemented on a PC and it was connected via an RS422 link to the 6 DOF (Degree of Freedom) dynamics simulator and the GN&C system installed on a VAX at the NASA Marshall Space Flight Center astrionics laboratory. The mockup of a chaser vehicle with the actual VGS (Video Guidance Sensor) was mounted on the floor and the VGS was connected to the 6 DOF simulator. The GPS was simulated in the 6 DOF simulator. The DOTS (Dynamic Overhead Target Simulator) on a VAX moves a crane arm based on the output state of the 6 DOF simulator. The mockup of a target vehicle is attached on the arm end. The reflectors for the VGS are attached to the back face of the target vehicle.

With this configuration the motion of the target vehicle relative to the chaser vehicle can be simulated. The range of simulated flight covers the final approach from 50 ft to 0 ft station keeping position where the three point docking mechanism can be activated to complete the docking.

In addition to the simulations using the above setup, the software simulations were done using only the Executive on the PC and the VAX simulator. The range of flight in these software simulations are from 1000 ft to 0 ft.

Test Results

Test runs of the chaser approach were made both in hardware simulations and software simulations by changing the initial conditions and the docking windows. The contingencies were brought about by either physically disabling the VGS hardware or simulating the loss of GPS lock at an arbitrary time during approach. In all of the cases it was verified that the Executive can start the mission replanning and generate a new approach or abort profile based on ground supplied mission rules.

Fig. 4 shows an example test result of a case where VGS lock was lost and regained during the final approach. While station keeping at x = -35 ft, the Executive generated a flight plan, PLAN1, for the nominal approach. The plan drives the chaser first to the next station keeping point at x = -20 ft, and the vehicle stays for the period needed to check the vehicle status, and the vehicle resumes the approach to x = 0 ft to meet the docking window #2. But during the approach the VGS lock was lost at t = 190 sec. When the Executive detected the loss it generated the contingency plan, PLAN2. The plan forces the vehicle to back up to the safe station keeping position at x = -35 ft, and let it wait until sensor lock is regained. Because the lock is regained during this back up, the Executive generated a new plan, PLAN3, similar to PLAN1, to resume a nominal approach, but this time the earliest window available is window #3. Tables 1. and 2. show the control commands for PLAN1 and PLAN2.

CONCLUSIONS

The autonomous spacecraft executive has been developed for autonomous on board mission planning for rendezvous and docking. Its decision making capability for nominal and contingency cases has been verified by simulations.

The executive is also applicable to other spacecraft missions which need autonomous onboard decision making.

REFERENCES

[1] M.L. Montemerlo, The AI Programs at the National Aeronautics & Space Administration, *AI Magazine*, Winter 1992.

[2] H. Nakamura, et al., Study of Autonomous Rendezvous and Docking, *J. Space Technology and Science*, vol.4, No. 2, 1989.

[3] R.L. Anderson, et al., Demonstration of Automated Proximity and Docking Technology, In *Proceedings of AIAA Space Programs and Technologies Conference*, March 1992, Huntsville, AL.

[4] M. Furuya, et al., A Study on High Level Decision Making Function in Onboard Computer System for Rendezvous and Docking, In *Proceedings of the 37th Space Sciences and Technology Conference*, October 1993, Kita-Kyushu, Japan.

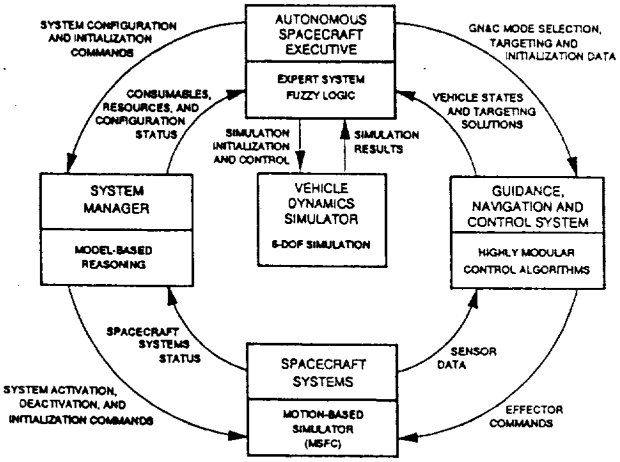

Fig. 1 Architecture of Autonomous Spacecraft

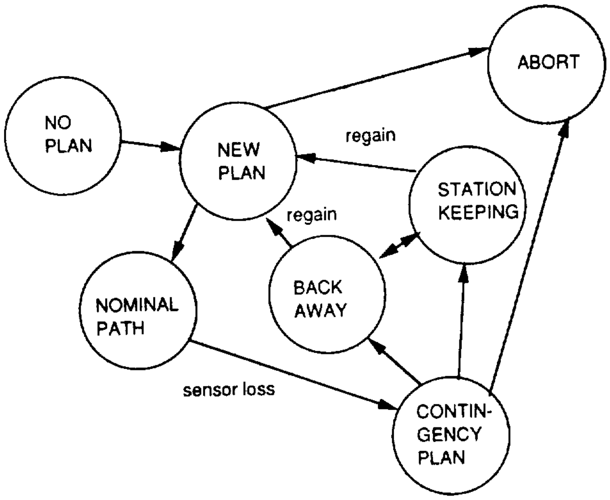

Fig. 2 State Transition Diagram for Proximity

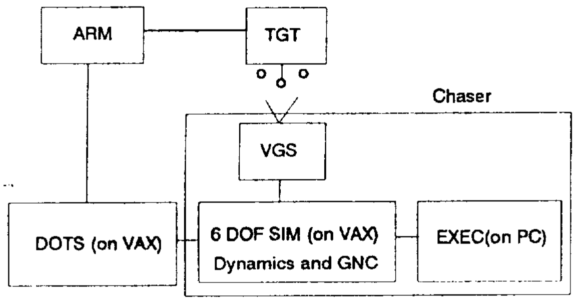

Fig. 3 Configuration of Verification Test Facility

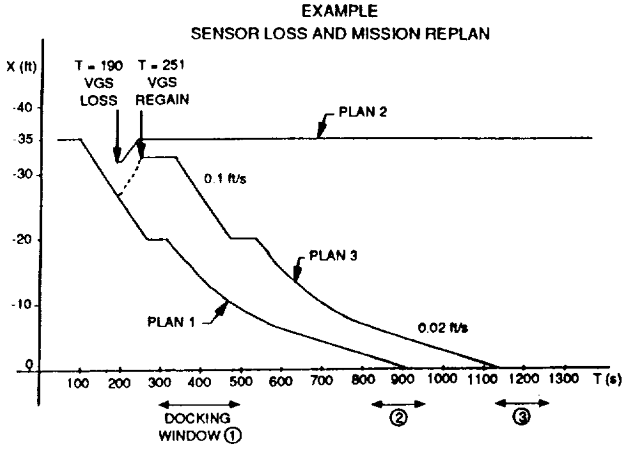

Fig. 4 Sample Test Result

Table 1. Control Commands for PLAN1

T(sec)	X(ft)	EVENT
0	-35	SET LVLH FRAME
0	-35	SET TARGET POINTING
0	-35	START STATION KEEPING
97.3	-35	START APPROACH
263.0	-20	START STATION KEEPING
273.0	-20	START TARGET BODY FRAME
273.0	-20	START ATTITUDE HOLD
313.0	-20	START APPROACH
919.1	0	START STATION KEEPING

Table 2. Control Commands for PLAN2

T(sec)	X(ft)	EVENT
191.0	-31.8	START STATION KEEPING
191.6	-31.8	SET LVLH FRAME
191.6	-31.8	SET TARGET POINTING
199.1	-31.8	START SEPARATION
240.8	-35	START STATION KEEPING