Analysis, Design and Simulation of a Reconfigurable Control Architecture for the Contingency Mode of the Multimission Platform

Jairo C. Amaral[1], Marcelo L. de O. e Souza[1]

[1]Division of Space Mechanics and Control – National Institute for Space Resarch (INPE)
Av. dos Astronautas, 1.758 Jd. Granja – São José dos Campos – SP – Brazil
`jairo.amaral@dem.inpe.br, marcelo@dem.inpe.br`

Abstract*. Currently, Reconfigurable Control Systems (RCS) are becoming more and more widespread and studied in the aerospace community. This work presents the analysis, design and simulation of reconfigurable control architecture for the Contingency Mode of the Multimission Platform (MMP), a generic service module currently under design at INPE. Its* ***embedded real time control system*** *can be switched among nine main Modes of Operation, according to ground commands or information (mainly alarms) coming from the control system. The implementation follows the specifications when they were found; when specifications could not be found, they were designed ad hoc. The tests are based in simulations with the MATRIXx/SystemBuild software. They focus mainly on the worst cases that the satellite is supposed to endure in its mission; this can be during modes, or during transitions between modes and submodes.*

1. Introduction

Control systems of satellites, aircrafts, automobiles, traffic controls, etc., are becoming increasingly complex and/or highly integrated due to their use of computers networked via communication devices and protocols working in real time. In these systems, the reconfiguration of control modes and law are increasingly being used, to meet diverse phases of the mission or even faulty operations. This should happen smoothly, with fast and minimum transients and stable and precise steady states; otherwise the controls could enter strange modes, degrade performance and even reach instability.

This work presents the analysis, design and simulation of the reconfigurable control architecture for the Contingency Mode of the Multimission Platform (MMP). The MMP is a generic service module currently under design at INPE. Its **embedded real time control system** can be switched among nine main Modes of Operation and other submodes, according to ground commands or information (mainly alarms) coming from the control system. The MMP can aquire one and three axes stabilization in generic attitudes, with actuators including magnetotorquers, thrusters and reaction wheels.

The implementation followed the specifications when they were found; when specifications could not be found, they were designed ad hoc. The MMP enters in the Contingency Mode right after the launcher separation, or if there is an emergency, according to the following sequence: it stops any rotation using magnetotorquers; opens the solar pannels, if it is not done yet; points them to the Sun using propulsors; and acquires gyroscopic rigidity using reaction wheels. If the stopping with magnetotorquers is not achieved in a predetermined time, the MMP will enter in a submode for trying to achieve it with propulsors. As there is propulsor control for only two axes, it will also wait for the best moment to make a maneuver.

1.1 State of Art Comparison

Currently, Reconfigurable Control Systems (RCS) are becoming more and more widespread and studied in the aerospace community. Examples related to our work are:

The Oersted [Boegh and Blanke,1997] is a Dannish microsatellite of aproximatelly 60 kg launched in 1997. Its main objective is to collect measures of Earth`s magnetic field and high energy particles in this vicinity. Being small and low costing, it was not possible to deal with failures adding redundancies, so the integrity of the attitude control needed to be waranted by an automous supervising system. The Oersted`s architecture needed to accommodate the implementation of many functions, and they were implemented in a supervisory structure of three levels: an inferior with I/O of the control net, a second level with algorithms for detection and acocomodaton of faults, and a third level with supervisory logic. The many control modes are consideed separately, while the supervisory level needs to choose the correct mode for each situation.

The Open Control Plataform [Wills et al. 2000] is an open software architecture developed at Georgia Tech for distributed, reconfigurable, hierarchical control systems. Complex control systems for autonomous vehicles require components that are often supported on different types of hardware platforms and operating systems. They must often interact in a distributed environment, and at the same time, the configuration and integration must be flexible enough to allow rapid online adaptation to react to unpredictable events. The specifc drive of this project was to support the autonomous control of unmanned vehicles with capacity of vertical take off and landing (helicopter).

1.2 Operation Modes

Due to the diversity of conditions that the MMP will face during its entire life, there is a separation in many Operational Modes, where each mode is defined by the environment and conditions in which the satellite will be. Those modes are shown in Figure 1, and are divided in two major groups, defined by the environment where the satellite is:

Ground Modes:

- Off Mode (OFM). In this mode, all the equipments are shut off (with disconnected batteries). This mode is to storage and transport.
- Integration and Test Mode (ITM). This mode is used during the assembly and integration tests, or in the launch platform. During the assembly and integration, all the tests are done, while at the launch platform, only the tests of functional verification will be done.

Flight Modes:

- Start Mode (STM). This mode can be used on the ground, during the flight phase, and at any time during the useful life of the satellite.

- Contingency Mode (COM). The objective of this mode is to automatically take the satellite and its payload from STM to a safe mode after the launcher separation, or in case of an anomaly.
- Fine Navigation Mode (FNM). This mode is used to acquisition of attitude, position and time in a precise way to allow the transition from the COM to the nominal mode.
- Nominal Mode (NOM). This is the operational mode of the satellite, where the payload can perform its objectives. In this mode the wheel desaturation with magnetic actuators also happens.
- Wheel Desaturation Mode with Thrusters (WDM). In this mode the reaction wheel desaturation is done by the action of thrusters. This proceeding aims to reduce the angular speed of the wheels back to nominal levels of operation.
- Orbit Correction Mode (OCM). It is used to execute orbital maneuvers on the orbital plane, or from it.
- Orbit Correction Mode Backup (OCMB). If one of the thrusters fails, the orbital maneuvers will be executed with only two of the symmetric thrusters, to minimize the disturbing torques.

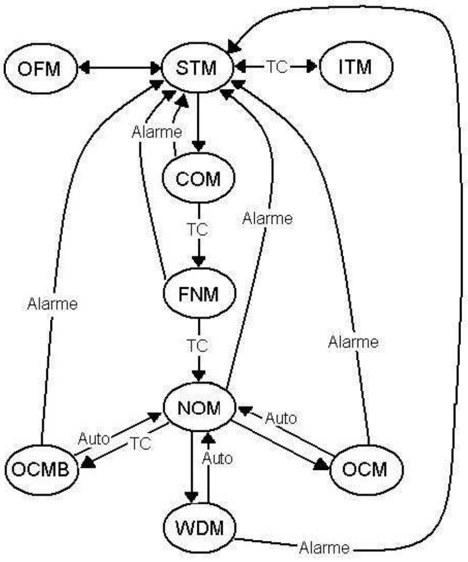

Figure 1. Transition logic of the operation modes of the MMP.

Source: INPE (2001).

2. Implementation

According to the specifications, the Contingency Mode is charged of executing a stop with magnetotorquers and the solar pointing in two axes. It may be accessed normally by the Start Mode, and by any other mode in case of an alarm.

We could not find in the available literature about the MMP a control law for the magnetotorquers in the Contingency Mode. Thus we choose a control law derived from the work of [Prudêncio, 2000] for the satellite SACI-1, which in its turn, is based in the work of [Shigehara, 1972] and is analogous to the same law used in the dessaturation. As there is no need of a specific pointing, all the magnetotorquers use a version of this control policy for reduction of rotation velocity. If the magnetotorquers cannot stop the satellite in a specified time, it enters in a submode for trying a stop with thrusters. In any case, when the satellite accquires an angular speed under 0.2 degrees/second, it will open its pannels and execute a fine stop with reaction wheels.

A law for the solar pointing was not found in the available literature about the MMP. Therefore, the law adopted was for two separated rotations: the first around the y-axis, and the second around the x-axis. Each one is a bang-bang control law.

The control signal is converted in polar coordinates, so that the poles would be in the y axis and the vector z would be between (0, π/2) rad. It activates the propulsors of the y axis so that the rotation of the satellite would be reduced to zero. The point where the torque direction is reversed is obtained by the Torricelli equation. As the Sun has a slow aparent movement, and the pointing does not need to be very precise, the signal which indicates the angular speed comes from the inertial unit in this model.

The transition between modes and submodes are controlled by a state machine, which enables different control laws accordingly. It is fed with sensors and outputs from other control blocks.

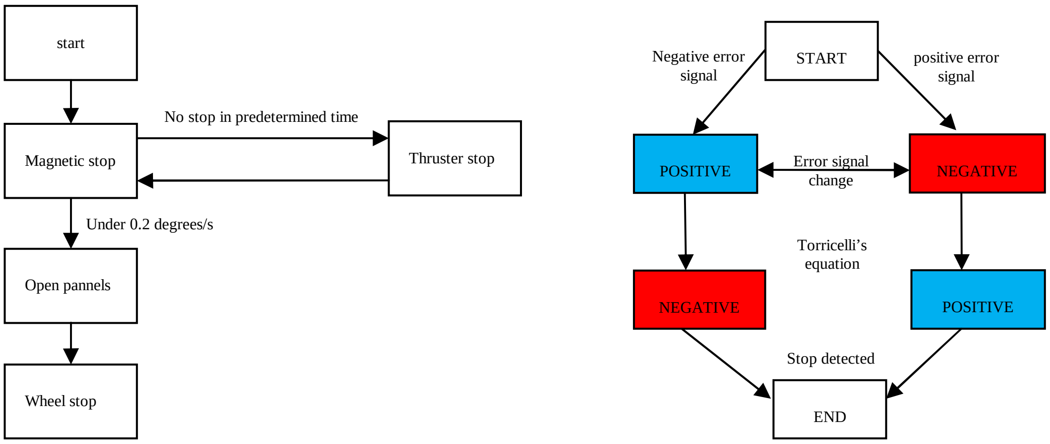

Figure 2. Block diagram of the detumbling (left); and block diagram of an axis alignment with thrusters (right).

3. Tests

The tests are based in simulations with the MATRIXx/SystemBuild software, from National Instruments, which supports developers with tools to model, analyse and test a control system. Their general objective is to check if the MMP satisfies the design requirements, but our main interest is to check the stability during the transition of control laws from modes and submodes.

Even if each mode of operation has a stable control law, this conclusion cannot be extended for the resulting system when the subsystems are not linear. This is known as the **Problem of Hyperstability**, and might turn the validation of reconfigurable control systems extremely difficult. There are analytical approaches for such, but their practical applications are limited. As an alternative, we focused in numerical simulations of the worst cases which the satellite is supposed to endure in its mission; it might be during modes of operation or during their transitions. If the results are satisfactory, it will be reasonable to conclude that they will do so in the other cases.

The plant includes simulations such as orbit propagation, air drag, and variations in inertia moment, and it was reused from [Amaral 2008]. We expect to show that the MMP is able to satisfy the official requirements found and the ad hoc requirements.

4. Results

The two example cases considered a circular orbit with 7000 km of radius and 45 degrees of inclination.

Figure 3 shows the module of the angular speed being reduced by the magnetotorquers from 1.7 degrees/s to under 0.2 degrees/s. This was achieved in aproximately 2 hours.

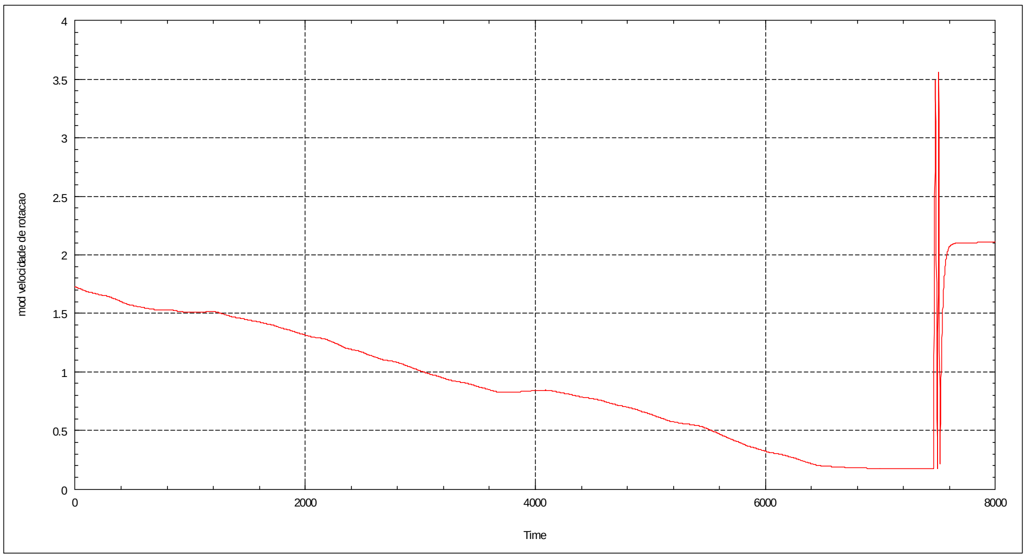

Figure 3. Module of angular speed during magnetic stop.

Figure 4 shows the same scenario, but focuses in the solar pointing stage. After the stop, the thrusters are activated, one axis at a time, for executing two rotations towards the Sun. Then the satellite acquires gyroscopic rigidity using a reaction wheel.

These two examples transit through all the submodes detailed in each diagram of Figure 2. Transits like the magnetic stop, pannels oppening and reaction wheel stop were not much noticeable in the angular speed in Figure 3 [6000 s – 7500 s]; but the inversion of thrusters' control signal are clearly seen as the two spikes in Figure 4 [7450 s -7550 s].

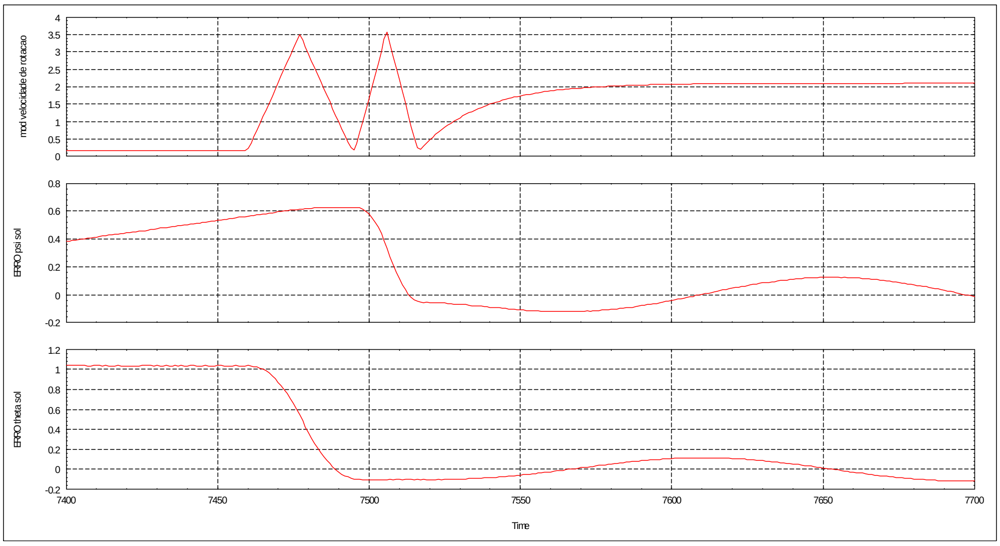

Figure 4. Module of angular speed and errors of solar pointing.

5. Conclusions and Future Objectives

The results until now show that the implementation satisfies the project requirements. For low inclinations of orbit, the detumbling with magnetotorquers loose effectivity and fails to stop in the predetermined time, but the submode with thrusters was able to force a stop. Besides, the solar pointing submode worked well even when the initial position was opposite to the Sun. We expect to estimate in what kind of orbits, and in what rotation axis, the magnetotorquers can stop the rotation in a given time. We also expect to identify what situations could delay or prevent a solar pointing after the stop. Later, we intend to investigate other transients in the control system caused by the switching between modes of operation.

References

AMARAL, J. C. Análise, Projeto e Simulação de uma Arquitetura de Controle Reconfigurável para a Plataforma MultiMissão. Dissertação (Mestrado em ETE/CMC) — Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2008.

BØGH, S. A., BLANKE, M. Fault-Tolerant Control — A Case Study of the Ørsted Satellite, Compenhagen, DEN, 1997.

INPE. A822000-DPK-01/D5a – Multimission Platform Data Package for System Requirements Review (SRR). 2001. São José dos Campos – SP.

PRUDENCIO, S. V. Simulação Digital em Tempo Real de um Sistema de Controle de Atitude Magnético Autônomo de um Satélite. Dissertação (Mestrado em ETE/CMC) — Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2000.

SHIGEHARA, M. Geomagnetic Attitude Control of an Axisymmetric Spinning Satellite. Journal of Spacecraft and Rockets, 9(6):391-398, 1972.

WILLS, L; SANDER, S; KANNAN, S; KAHN, A; PRASAD J V R; SCHRAGE, D. An Open Control Platform for Reconfigurable, Distribute, Hierarchical Control Systems. — Proceedings of the Digital Avionics Systems Conference, Philadelphia, PA, October 2000.