APPLICATION OF METHODS FOR TRANSIENT REDUCTION BETWEEN THE CONTROL MODES OF THE MULTIMISSION PLATFORM

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Abstract: *The Multimission Platform (MMP) is a generic service module currently in Project at INPE. In the 2001 version, its control system can be switched between nine main Operation Modes and other submodes. The Nominal Mode stabilizes the MMP in three axes and takes it to a nominal attitude, using three reaction wheels. Each wheel has coarse and fine acquisition submodes. The use of multiple Modes of Control for specific situations frequently is simpler than projecting a single controller for all cases. However, besides being harder to warrant its general stability, the mere switching between these submodes generates bumps, which can reduce the performance and even damage the actuator or plant. In this work, we present an application of diverse methods to smooth the transition between control submodes of the Nominal Mode of the MMP. In this work in progress, we will use techniques including, but not limited to, anti-windup and crossfading to compare and identify the combinations which produce the more satisfactory results. The tests are based in simulations with the software MatrixX/Systembuild. The tests focus on the worst cases the satellite may face. Being able to withstand these worst cases, the control system is considered apt to simpler situations. The tests show that many of the adopted strategies could smooth the transition and improve the performance of the system, and it was possible to identify advantages and disadvantages of each one.*

Keywords: *Multimission Platform, Transient Stability, Bumpless Transfer, Control Mode*

1 Introduction

The concept of reconfigurability is being applied for long in many areas, especially in aerospace, automotive, process control, etc. Applied to hardware, it consists in making the possible components of a ship standardized and independent (modularity) in the planning/developing phase, so that they can be coupled and/or switched in many ways without loss of time and resources in new developments, tests and validations for each possible configuration. Examples of this the satellite series PROTEUS and MYRIADE from the CNES, the RSAT (Remote Sensing Advanced Technology Satellite) from NASA, the satellite OERSTED from Denmark, the AOCS Framework Project from the University of Constance/ESA, the MMP (Multi Mission Platform) from INPE. Besides this, such concept has already started to be extended to the flight/operational phase.

Applied to software, the reconfigurability can be subdivided in the planning/developing phase or in the flight/operational phase. The first is analogous to the case with hardware, allowing software reuse and modification without the habitual penalties in tests and validation. An examples of this are the AOCSs from RSAT and MMP. The second phase allows a change in the control laws during mission phases, such as launcher separation, attitude acquiring, etc. There is also the possibility of failure detection and correction (of hardware, software, sensors, actuators, dynamics, etc.), with reconfiguration from Earth or autonomous, as was the case with the satellite OERSTED, and was the case of the AOCS Framework Project from the University of Constance/ESA.

A reconfigurable architecture, besides validating many operation modes, demands that the transitions between them be validated. If the different architectures are not linear, the fact of them being individually stable does not warrant that their transitions will keep the whole stable too. This is the problem of the Hyper-Stability that begun with the problem of Absolute Stability, conjectured first by Aiserman [1] in 1947, then by Kalman [2] in 1953. It was studied exhaustively by Popov [3] in 1957, and by others thereafter. This problem makes the essential point of reconfiguration, but it will be investigated in this work in an applied form, using the method of making simulations in the worst conditions and cases, and particularizing to the MMP.

Nowadays, there are many reconfigurable architectures in development and tests, for posterior standardization and adoption in the aerospace, automotive, process control, etc. Among them, we highlight the "Integrated Modular Avionics – IMA", which consists in a net distributed in real time on board of an airplane, with computational modules and communication nets capable of supporting multiple applications with different security levels, task assignments, monitoring the health of the conjunct, detection/diagnostics and reconfiguration on face of failures, overloads, etc.

2 MMP Description

According to INPE (2001) [4], the Multi-Mission Platform was conceived to be a modular platform able to serve as a base for many missions of science, communication and Earth observation from low Earth orbits. The MMP is constituted of basic subsystems that provide the essentials for the satellite functioning, and a support for the integration of a payload, which will be chosen according to the mission that the satellite will perform.

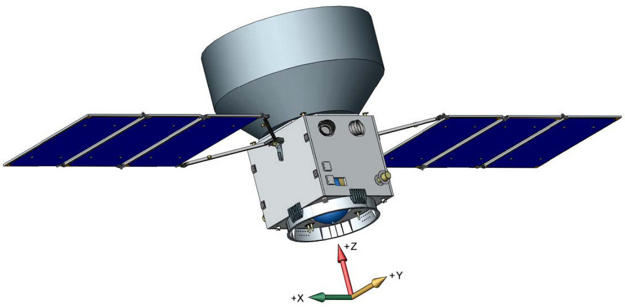

Figure 1. The MultiMission Platform with open panels and payload space. INPE [5].

Due to the diversity of conditions that a satellite 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 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.

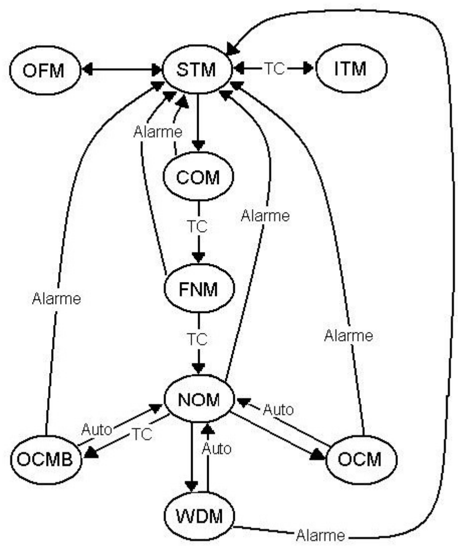

Figure 2. Transitional Logic among the Operational Modes of the MMP. INPE [4].

The transitional logic among the operational modes can be seen in Figure 2. The transitions can be done automatically (Auto), via telecommand (TC), or due to some anomaly in the satellite (Alarm).

COORDINATE SYSTEM – The system Local Vertical Local Horizon was used. In this system, the z axis is directed toward Earth's nadir, the y axis is directed toward the negative normal to the orbital plane, and the x axis is perpendicular to the other two, forming a dextrogyre system. The x axis coincides with the orbit speed vector in the case of a circular orbit. [6].

3 Implementation

ACTUATORS – The model for the reaction wheels was the same used by Moreira (2006) [7], with constants T_v = 20 s and K_v = 0.06 *N.m/V*.

ROTATION SEQUENCE – This work deals with the Fine Navigation Mode and its transition to Nominal Mode. The satellite enters this mode with null angular speed to an inertial reference. The panels will be pointed towards the Sun, though this is not relevant here; we can assume a generic initial attitude.

The Fine Navigation Mode is entrusted to take the MMP precisely to its nominal attitude – in this case, Earth. As there was not found specifications in the available literature, it was chosen that such a maneuver will be divided in up to three rotations, so that each considered variable be conveniently uncoupled from the others. Each rotation can, in the worst case, take the pointing to a point diametrically opposite, i.e., of π radians.

As the Earth has a considerable apparent movement in relation to the velocities that the reaction wheels can apply to the MMP, it was chosen that the two first rotations shall align the y axis of the MMP with the normal of the orbit plane. As this plane can be considered inertially fixed, there is not the inconvenience of the reference changing during the alignment of each axis.

The vector normal to the orbit plane can be found through the vector product between the vector direction of Earth and the vector orbital velocity. The direction of the vector normal to the plane of orbit is represented in polar coordinates, with the poles in $\pm$z. Up to two rotations are done according to the polar latitude and longitude, so that the face -y of the MMP be pointed towards this vector. As the last rotation is done in the orbital plane, there is no risk of the orbit movement taking the reference beyond reach.

SWITCHING OF CONTROL LAWS – The control law of each rotation can be divided in two phases. The first is the coarse one, which puts 90% of the maximum control tension on the corresponding reaction wheel, so that the satellite rotate on the direction that will reduce the error signal. When the absolute error signal ε is under a chosen value, the sign of the control is reversed so that the rotation speed will be reduced to near the desired attitude. When the absolute variation of the error signal is under a chosen value ζ, the control is switched to a finer PID, which will capture and maintain the desired attitude. The PID values were the same used by Moreira (2006) [7].

When both error and variation of error signal are under chosen values, the next rotation is started. And when the three possible rotations are done (if necessary), the system enters the Nominal Mode. Figure 3 shows the diagram of the transitional logic of a single rotation.

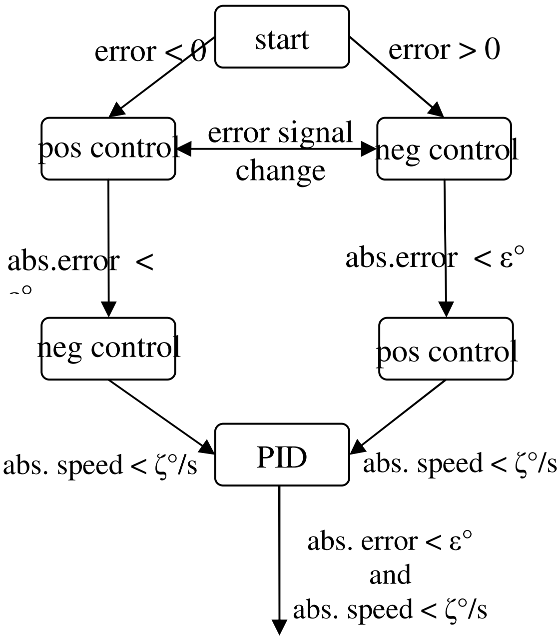

Figure 3. Transitional Logic of the Submodes of a single rotation, with example values.

BUMP REDUCTION BETWEEN CONTROL LAWS – Three methods of reducing the transient instability were applied: anti-windup, cross-fading and output tracking.,

ANTI WIND-UP - The anti-windup problem happens when there is a saturation that opens the control loop and causes the integral component to overshoot. The implementation to counter it consists in measuring the difference between the PID controller and the respective actuator, and then integrate and subtract this difference signal from the PID control signal, so that it cancel the integral component that would otherwise be growing (Figure 4).

To prevent the integrator from saturating, the tracking time constant must be chosen small. Too small values however decrease the controller performance. As a rule of thumb Åström [2006] suggested to choose the tracking time constant Td <= Ta <= Ti.

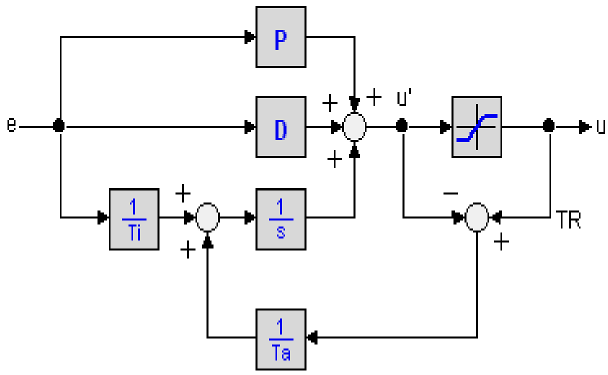

Figure 4: Implementation of the anti-windup scheme on the PID controller.

CROSS-FADING - The cross-fading method consists of using both control signals during a transition phase. Originally the control signals are multiplexed to select which one will be used by the plant. The resulting signal u is defined by the function $u = u_1a(t) + u_2[1\text{-}a(t)]$, where a(t) is a variable that transits from 0 to 1 in a pre-determined, smooth manner. The a(t) is obtained by dampening the original step signal that would cause the control transition in a multiplexer.

OUTPUT TRACKING - The output tracking method consists of forcing the unused control block to follow the output of the used control block. For this, the PID is treated like a plant, receives its own control block, an integrator, and is put on a feedback latch using the output of the primary control as reference. This ensures that both control blocks have the same output during the transition (Figure 5).

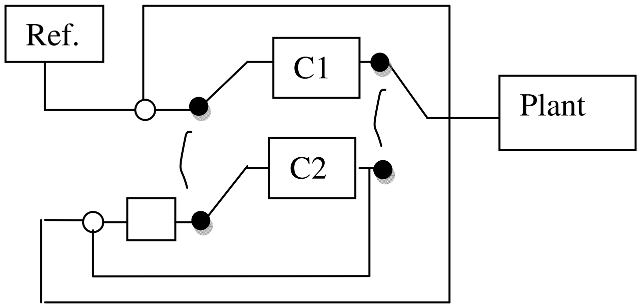

Figure 5: Implementation of the output tracking method before the control switch.

4 Methodology

Like Moreira (2006)[7], our simulations were done with the environment MATRIXx/SystemBuild, which makes it possible the development of the project in visual form, in block diagram. The block diagrams allow a systemic view of the project, at the same time that they store inside the blocks all the detailed and specified characteristics of each subsystem belonging to the project. This way, it is possible to interchange easily between two types of vision, detailed and systemic.

During the sub-blocks confection, they can be tested before being interconnected to other blocks. Independently of already being interconnected to other blocks or not, those sub-blocks can be modified again and/or tested, helping the development of the project.

This project referring to the MMP was based in a previous development made in MATRIXx/SystemBuild for the satellite SACI, and described in (Prudêncio, 2000) [8]. The model of the space environment, with the orbit propagator was reused entirely, with the addition of the characteristics necessary to the Orbit Correction Mode, not featured in this article.

The plant model, described by the dynamic and attitude kinematics equations, in quaternions, was partially reused. The modifications increased the influence of the reaction wheels on the dynamics, the orbital velocity over the plant kinematics, and the angular moment conservation during variations of the inertia moment (during the deployment of solar panels). Specific parameters of the MMP also had to be adopted, such as moments of inertia.

The reuse of a previous work was most important so that the present work could reach other levels of development. This reuse accelerated the modeling process and project simulation.

The simulations were done with a polar orbit with 7,000 km of mean radius and eccentricity 0.

For performance testing, there were used different initial, static attitudes, and different combinations of methods for transient instability reduction.

The simulations attempted to demonstrate the fulfilling of the project requirements. The worst possible cases of initial attitude errors that could be found in the proposed mission were simulated as examples of application of this work.

The general case focus on 90 degrees turns to align the satellite with the desired reference system in a given axis. When only one rotation is done, we chose the y axis of the satellite. However, there were also executed tests with smaller angles to check if the method is less effective or unnecessary on other cases.

5 Results

Figures 6 and 7 show that there is saturation of the control signal during the switching phase in a 180 and 30 degrees turn, respectively, when there is no strategy applied. They are able to switch to the Nominal Mode in less than 100 and 80 seconds, respectively.

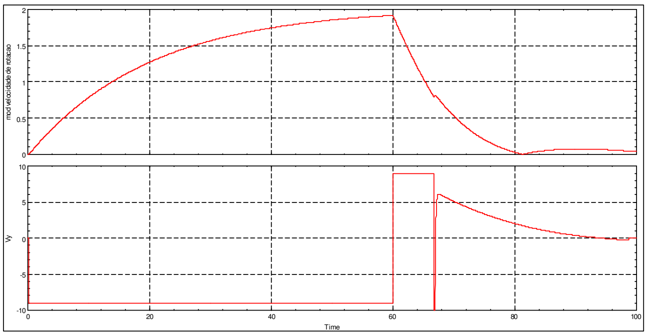

Figure 06: module of angular speed and control signal of the y axis.

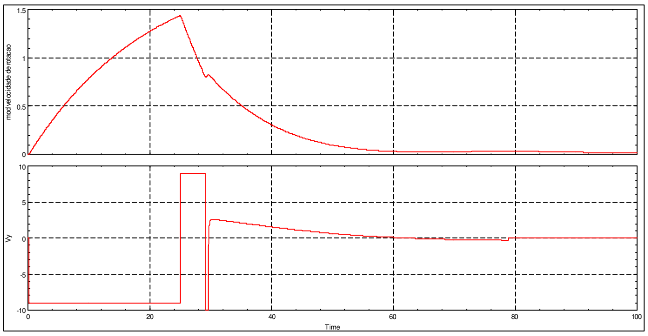

Figure 07: module of angular speed and control signal of the y axis.

Figure 8 shows the three rotations from a starting attitude of 30º, 30º, 30º to the referential, with no strategy employed. It takes less than 200 seconds to enter nominal mode.

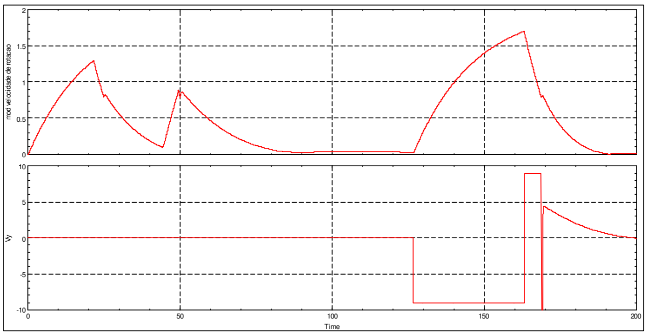

Figure 8: module of total angular speed and control signal of the y axis.

Figure 9 shows that applying the anti-windup strategy in a situation of small rotations in many angles (30°, 30°, 30°) does not avoid the saturation of the control signal, but improves the time of execution of the three rotations and transition to the next mode.

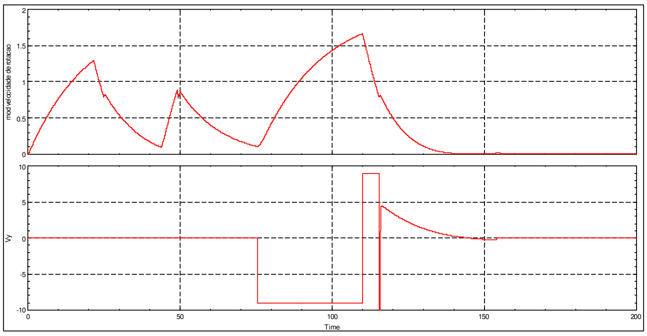

Figure 9: module of total angular speed and control signal of the y axis.

Figures 10 and 11 show that the use of cross fading avoids the saturation of the control signal.

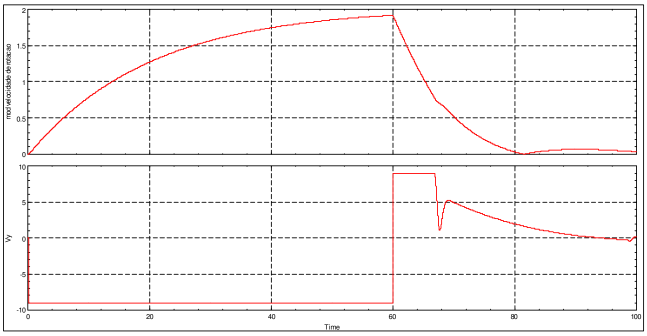

Figure 10: module of the angular speed in degrees per second, and the control signal in Volts.

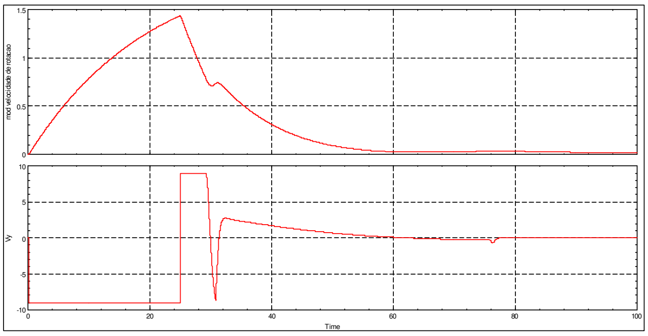

Figure 1 : module of the angular speed in degrees per second, and the control signal in Volts.

6 Conclusions

It was possible to improve the performance of the Fine Navigation Mode with the anti windup and the cross fading methods, in different situations.

The anti-windup implementation was able to reduce the time of rotations with smaller angles, but it could not eliminate the saturation.

The cross fading implementation was able to reduce the saturation, with little impact on the rotation time. However, it was more relevant with greater angles.

Later, we intend to implement and apply the output tracking method.

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