BUMP REDUCTION FOR THE SWITCHNG BETWEEN CONTROL MODES OF THE MULTIMISSION PLATFORM

Jairo Cavalcanti Amaral[1], Marcelo Lopes de Oliveira e Souza[2]

National Institute for Space Research -INPE
Course of Space Engineering and Technology/Space Mechanics and Control (ETE/CMC)
São José dos Campos, SP, 12227-010
[1]jairo_amaral@hotmail.com, [2]marcelo@dem.inpe.br

Abstract: *Many control systems switch between control modes according to necessity. That is often simpler than designing a full control to all situations. However, this creates new problems, as determining the composed system stability and the transient during switching. The latter, while temporary, may introduce overshooting that degrade performance and damage the plant. This is particularly true for the MultiMission Platform (MMP), a generic service module currently under design at INPE. Its control system can be switched among nine main Modes of Operation and other submodes, according to ground command or information coming from the control system, mainly alarms. It can acquire one and three axis stabilization in generic attitudes, with actuators including magnetotorquers, thrusters and reaction wheels. In this work, we will begin to analyze, design and simulate a reconfigurable control architecture with focus on reducing the bump on the switching between at least two modes of the MultiMission Platform, as part of a larger work in progress. It will be done by creating a virtual plant for the unused controls, which will keep their outputs close to the actual control, minimizing differences at the switching times. The tests are planned to be based in simulations with the MatrixX/SystemBuild software, from National Instruments, which support developers with tools to model, analyze and test a control system. They focused mainly on the worst cases that the satellite is supposed to endure in its mission, be it during modes or transitions between modes and submodes. Being able to withstand them, the control system is considered apt to other simpler situations.*

Keywords: bump reduction, switched modes, MultiMission Platform.

1 Introduction

Many control systems switch between control modes according to necessity. That is often simpler than designing a full control to all situations. This is the case of hybrid control systems. Figure 1 shows an example of such a control system, where a discrete switching signal σ selects which control block C will be used for the plant P.
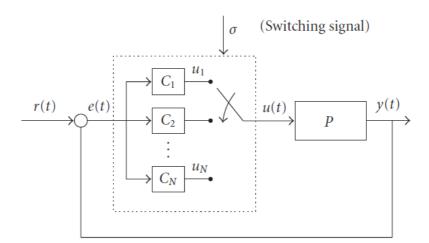

Figure 1 (Source: Yamé and Kinnaert, 2007).

Besides its obvious advantages, this also creates new problems, as determining the composed system stability (Liberzon and Morse, 1999) and the transient during switching (Graebe and Ahlén, 1996), (Yamé and Kinnaert 2007). The latter, while temporary, may degrade performance and damage the plant due to overshooting or discontinuities. It is often desirable to attenuate this, even at the expense of a slower transition.

In this paper, we will begin to analyze, design and simulate a reconfigurable control architecture with focus on reducing the bump on the switching between at least two modes of the MultiMission Platform, as part of a larger work in progress. While it is a relatively simple example, it is a real case, and we expect it to be a starting point for more complex works.

1.1 The MMP

This work presents the beginning of the analysis, design and simulation of the reconfigurable control architecture 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 command or information (mainly alarms) coming from the control system. The MMP can acquire 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; otherwise, it was designed. 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 panels, if it is not done yet; points them to the Sun using thrusters; 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 thrusters. As there is thruster control for only two axes, it will also wait for the best moment to make a maneuver.

1.2 Operation Modes

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 for 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 dessaturation with magnetic actuators also happens.
- Wheel Dessaturation Mode with Thrusters (WDM). In this mode the reaction wheel dessaturation 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 (COM). 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.
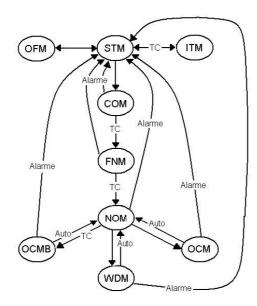
Figure 2. Transition logic of the operation modes of the MMP. INPE (2001).

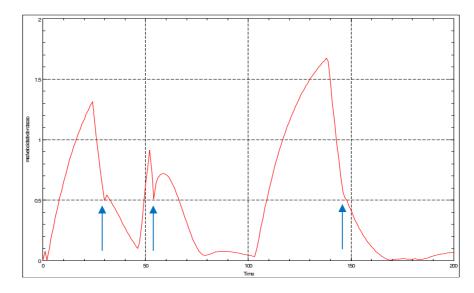## 2 The Bumpless Transfer Problem

There are strategies including input blending, output blending and state initiation, besides much older approaches for the wind up problem (Peng et al. 1998). The wind up phenomenon was one of the first problems related to transitions. It happens when the control loop is opened, as during an actuator saturation, and the integral component of a controller accumulates too much, causing an overshoot.

As we are dealing with relatively simple systems, we will attempt first to reduce the transient by treating the unused controller as a plant, and forcing it to track the output of the first controller; this is related to the problem of obtaining the inverse function of a system. Thus, both outputs will have not only close values, but also close derivatives. There are different methods in the literature to treat this, according to the complexity and requirements: from nonlinear plants with bidirectional switching during transients (Graebe and Ahlén, 1996), to linear systems at steady states (Yamé and Kinnaert 2007).

As an example of this problem, Figure 3 shows the module of the angular velocity during the Fine Navigation Mode of the MMP. Each peak is a rotation for a nominal attitude acquirement. The first two exhibit clear "bumps" (marked with blue arrows) during the switch from coarse to fine control.

Even if there is not an impact, the unnecessary oscillation of the module of the angular velocity means a slower acquirement. We will test different approaches to enhance the smoothness and even duration of the transition.

Figure 3. Module of the angular velocity during three consecutive rotations for nominal attitude acquirement during the Fine Navigation Mode. The first two exhibit clear "bumps" during the control law switch.

3 Tests

The tests are planned based in simulations with the MATRIXx/SystemBuild software, from National Instruments, which supports developers with tools to model, analyse and test a control system. They focused mainly on the worst cases that the satellite is supposed to endure in its mission, be it during modes or during transitions between modes and submodes. The plant includes simulators such as orbit propagation, air drag, and variations in inertia moment. They were taken from (Amaral 2008).

4 Expected Results

We expect to find the best approaches for reducing the bump phenomena during the transition between submodes of the MultiMission Platform. Focus will also be given not to use unnecessarily complex techniques. After that, we intend to apply them to faster dynamic systems, and to consider also the general stability problem.

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