Mechatronic Design, Dynamic Modeling and Results of a Satellite Flight Simulator for Experimental Validation of Satellite Attitude Determination and Control Schemes in 3-Axis

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ABSTRACT
This paper describes the integration and implementation of a satellite flight simulator based on an air bearing system, which was designed and instrumented in our laboratory to evaluate and to perform research in the field of Attitude Determination and Control Systems for satellites, using the hardware-in-the-loop technique. The satellite flight simulator considers two main blocks: an instrumented mobile platform and an external computer executing costume-made Matlab® software. The first block is an air bearing system containing an FPGA based on-board computer with capabilities to integrate digital architectures for data acquisition from inertial navigation sensors, control of actuators and communications data handling. The second block is an external personal computer, which runs in parallel Matlab® based algorithms for attitude determination and control. Both blocks are linked by means of radio modems. The paper also presents the analysis of the satellite flight simulator dynamics in order to obtain its movement equation which allows a better understanding of the satellite flight simulator behavior. In addition, the paper shows experimental results about the automated tracking of the satellite flight simulator based a virtual reality model developed in Matlab®. It also depicts two different versions of FPGA based on-board computers developed in-house to integrate embedded and polymorphic digital architectures for spacecrafts applications. Finally, the paper shows successful experimental results for an attitude control test using the satellite flight simulator based on a linear control law.

Keywords: ADCS, test bed, dynamic model, FPGA, hardware-in-the-loop, air bearing system, satellite simulator.

RESUMEN
En este artículo se describe la integración e implementación de un simulador de vuelo satelital basado en un sistema de cojinete de aire, el cual fue diseñado e instrumentado en nuestro laboratorio para realizar investigación en el campo de sistemas de control de actitud de satélites, utilizando la técnica hardware-in-the-loop. El simulador de vuelo satelital cuenta con dos bloques principales: una plataforma móvil y una computadora externa donde se ejecuta software desarrollado en Matlab®. El primer bloque, integrado en una plataforma móvil suspendida en aire, contiene una computadora abordo basada en un dispositivo FPGA con capacidad de integrar arquitecturas digitales para adquisición de datos de sensores de navegación inercial, control de actuadores y manejo de datos. El segundo bloque es una computadora personal, donde en paralelo se ejecutan algoritmos basados en funciones desarrolladas en Matlab® para la determinación y el control de actitud. Ambos bloques están unidos inalámbricamente. En este artículo se presenta también el análisis de la dinámica de simulador de vuelo satelital para obtener su ecuación de movimiento, que permite una mejor comprensión del comportamiento del simulador. Además, se muestran los resultados experimentales de seguimiento automatizado del simulador de vuelo satelital basado en un modelo de realidad virtual. Se describe también el desarrollo de dos versiones de computadoras abordo basadas en FPGA para integrar arquitecturas digitales embebidas para aplicaciones en vehículos espaciales. Por último, el artículo muestra resultados experimentales de pruebas de control de actitud utilizando el simulador de vuelo satelital basada en una ley de control lineal.

1. Introduction

The Attitude Determination and Control System (ADCS) is a core module of a satellite platform, whose main function is to ensure the spacecraft will be pointing towards required targets either in earth or in space. When a satellite is placed in space orbit, and depending on its orbital altitude, it is subject to a number of environmental perturbations which deflect it from the desired orientation. In the case of Low Earth Orbit, located within 1000 km altitude, some of these disturbances are: atmospheric drag, the interaction with the Earth's gravitational field or nearby bodies in space, pressure due to solar radiation, among others [1].

An ADCS has all necessary hardware and software resources to compensate the deviations caused by such disruptive forces by applying control torques to the spacecraft, as well as with the execution of correction maneuvers based on data obtained from inertial navigation sensors. In this way, the satellite will point toward required targets [2]. The process of design and implementation of a satellite ADCS, involves the selection and sizing of equipment and components for the ADCS (navigation sensors, computing platform and actuators), as well as the definition of algorithms for attitude determination and control [2].

This approach also allows the development of simulators for validation of attitude control schemes [3], [4], [5], [25] which in our case are employed as test bench for physical validation of ADCS for spacecrafts in laboratory. Accordingly, the approach considers the attitude hardware selection processes (navigation sensors, actuators and on-board computer) and the definition of attitude control algorithms (determination, estimation and control laws). In this way, the research work presented in this paper allowed the experimentation and development of different components of the system. The approach has prompted the creation of a simulator not only for use in the definition stage of ADCS components (hardware and software), but also in the integration of an experimental test bed platform to conduct applied research in the field of spacecrafts attitude control. In addition, has allowed the formation of human resources in our laboratory in the referred field.

Moreover, this paper describes the integration and development of a Satellite Flight Simulator (SFS) developed at the Aerospace Development Laboratory at the Instituto de Ingeniería, UNAM (IINGEN-UNAM). Details about dynamic modeling, experimental results, testing and real-time monitoring of the SFS are also presented. The latter derived from the implementation of a particular case of control based on a linear sketch, using a hardware-in-the-loop (HIL) co-simulation scheme to accelerate the development process to obtain experimental results. From compact and modularized architecture, the SFS allowed to develop University technology and research in the area of attitude control, for satellites as well as for training purposes in areas such as: control, instrumentation, software development, electronics, telecommunications, and mechanical design.

2. Implementation Overview of the SFS simulation platform

The SFS was fully developed and instrumented at IINGEN-UNAM. It employs air flows generated with a compressor to levitate an instrumented platform that emulates the frictionless environment from space. On the platform side was installed the same scheme of implementation corresponding to a real satellite ADCS, thus, integrating inertial navigation sensors, flight computer, active actuators based on inertial wheels, communications, power and other electronic components of support, figure 1.

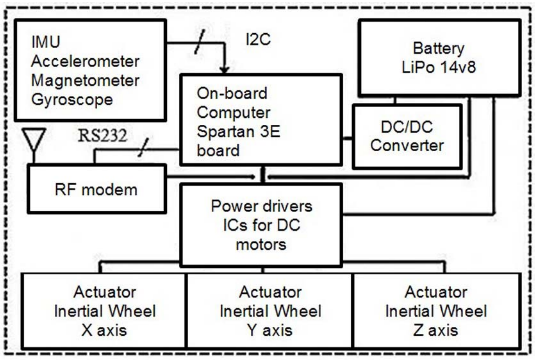

Figure 1. Instrumentation description for the SFS platform.