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HIL Testing of the B-dot Attitude Control Law

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1. Introduction

1.1 Context

- This research was conducted in the Laboratory of Simulation and Control of Aerospace Systems of University of Brasilia, Brazil;
- In order to test attitude control algorithms in the laboratory a Hardware-In-the-Loop (HIL) simulator is used. The development of the simulator began in 2016, when an air bearing table and a Helmholtz cage were implemented;
- The simulator increases the reliability of space missions by allowing the performance analysis of Attitude Determination and Control Systems (ADCS) in the laboratory environment on the early stages of a satellite project.

1. Introduction

1.1 Context

- Perturbation torques on the deployment of CubeSats induces angular velocities that must be damped for proper operation of subsystems, such as those requiring pointing (e.g., camera, antenna, solar panel);
- Therefore, the satellite should be equipped with an effective detumbling hardware and software. This work focuses on the tests of the B-dot attitude control law for detumbling through the HIL simulator of University of Brasilia.

Deployment of the Brazilian SERPENS-1 CubeSat from the International Space Station in 2015 - Credits: NASA

1. Introduction

1.2 The B-dot Controller

- The B-dot magnetic attitude controller is a well-known method for detumbling;
- This control law requires active magnetic actuators responsible to generate magnetic dipole moments (**m**) whose interaction with the geomagnetic field (**B**) originates control torques (**T**) on the satellite body.

$$\vec{m} = -K\dot{\vec{B}}$$

$$\vec{m} = Magnetic\ Dipole\ Moment\ [Am^2]$$

$$\vec{B} = Magnetic\ Field\ [T]$$

$$K = Control\ Gain$$

$$\vec{T} = \vec{m} \times \vec{B}$$

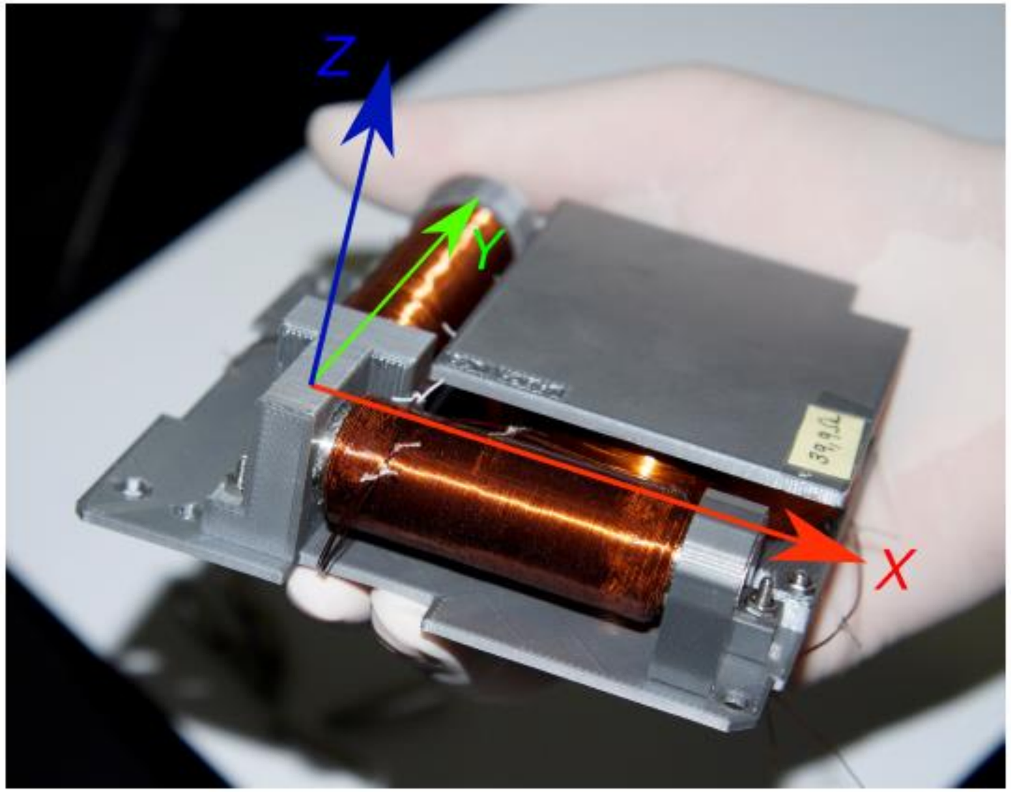
$$\vec{T} = Torque\ [Nm]$$

2. HIL Test Facility

2.1 Magnetic Actuator

- Two sets of 3-axis magnetic actuators are used in order to increase the resultant magnetic torque.
- The actuators were integrated in a 2U CubeSat mockup.

Coil Axis	Maximum m [Am^2]	Nominal Power
X	≈ 0.68	300 mW at 5 V
Y	≈ 0.68	
Z	≈ 0.19	

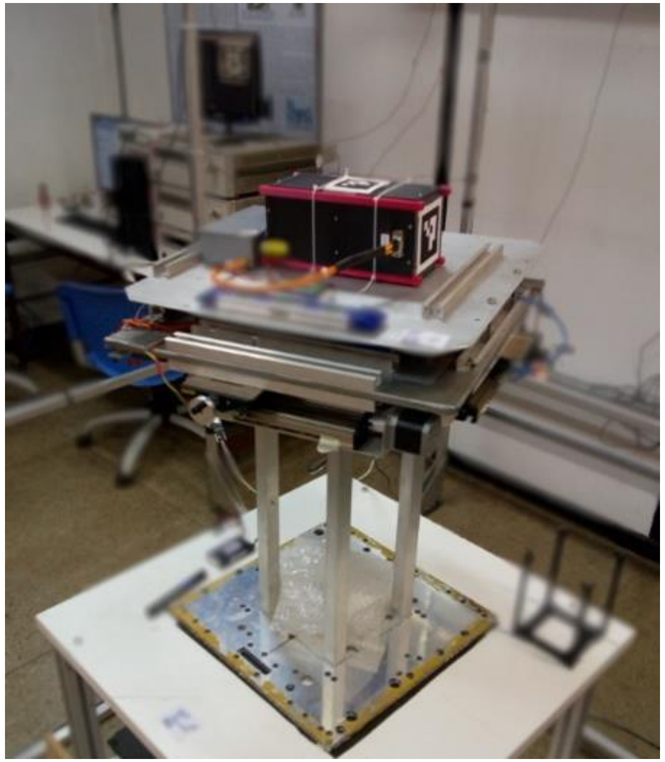


3-Axis Magnetic actuator developed in the laboratory

2. HIL Test Facility

2.2 Air Bearing Table

- The air bearing table with low friction excursion of 360^o in yaw (ψ) and $\pm$ 38^o in pitch (θ) and roll (φ) is used for reproducing the attitude kinematics;
- It is equipped with an IMU, a microcontroller and a radio for PC interface;
- The table allows the attachment of the satellite mockup, so that the set moves together during the experiment.



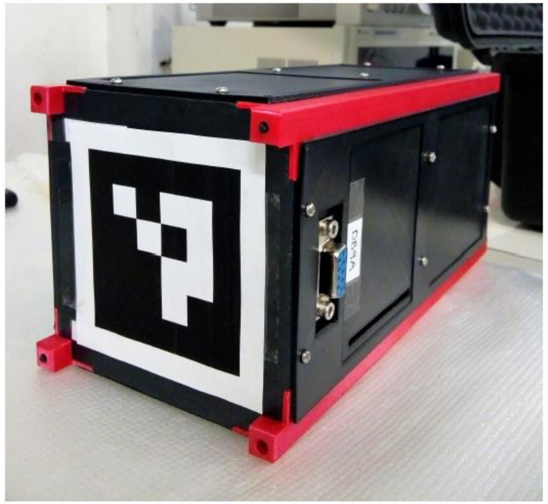
Air bearing table

2. HIL Test Facility

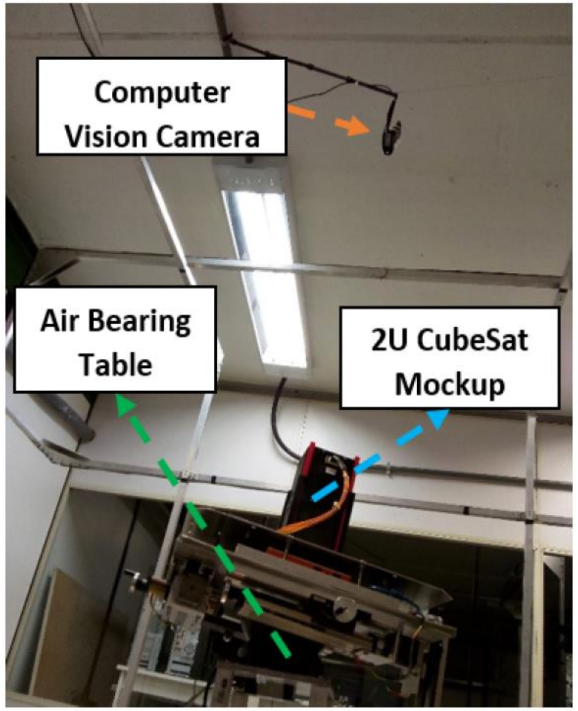
2.2 Air Bearing Table

The attitude is determined by two subsystems:

- An Inertial Measurement Unit (IMU) for acquisition of the pitch and roll angles;
- A computer vision system based on the usage of ArUco fiducial markers to obtain the yaw orientation.



Mockup CubeSat 2U assembled with the actuators

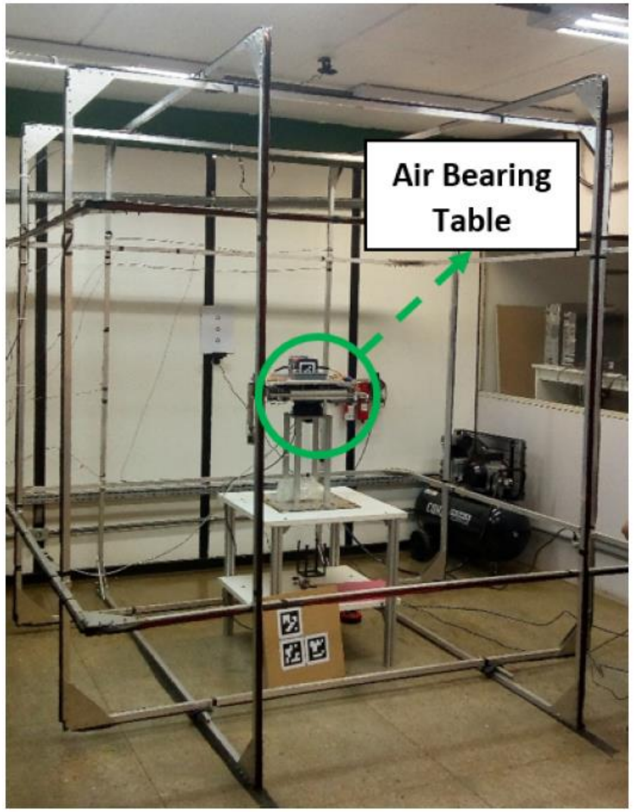


Camera vision system

2. HIL Test Facility

2.3 Helmholtz Cage & Orbit Propagation

- The Helmholtz Cage is used to reproduce the orbital geomagnetic field in the controlled environment of the laboratory;
- It allows the generation of magnetic fields with up to 180 μT of intensity in each axis;
- The coils of the cage are driven by DC power supplies with a PC interface, allowing the creation of a control mesh with a magnetometer;
- The orbit to be simulated is selected through the insertion of a Two-Line Element (TLE) set.

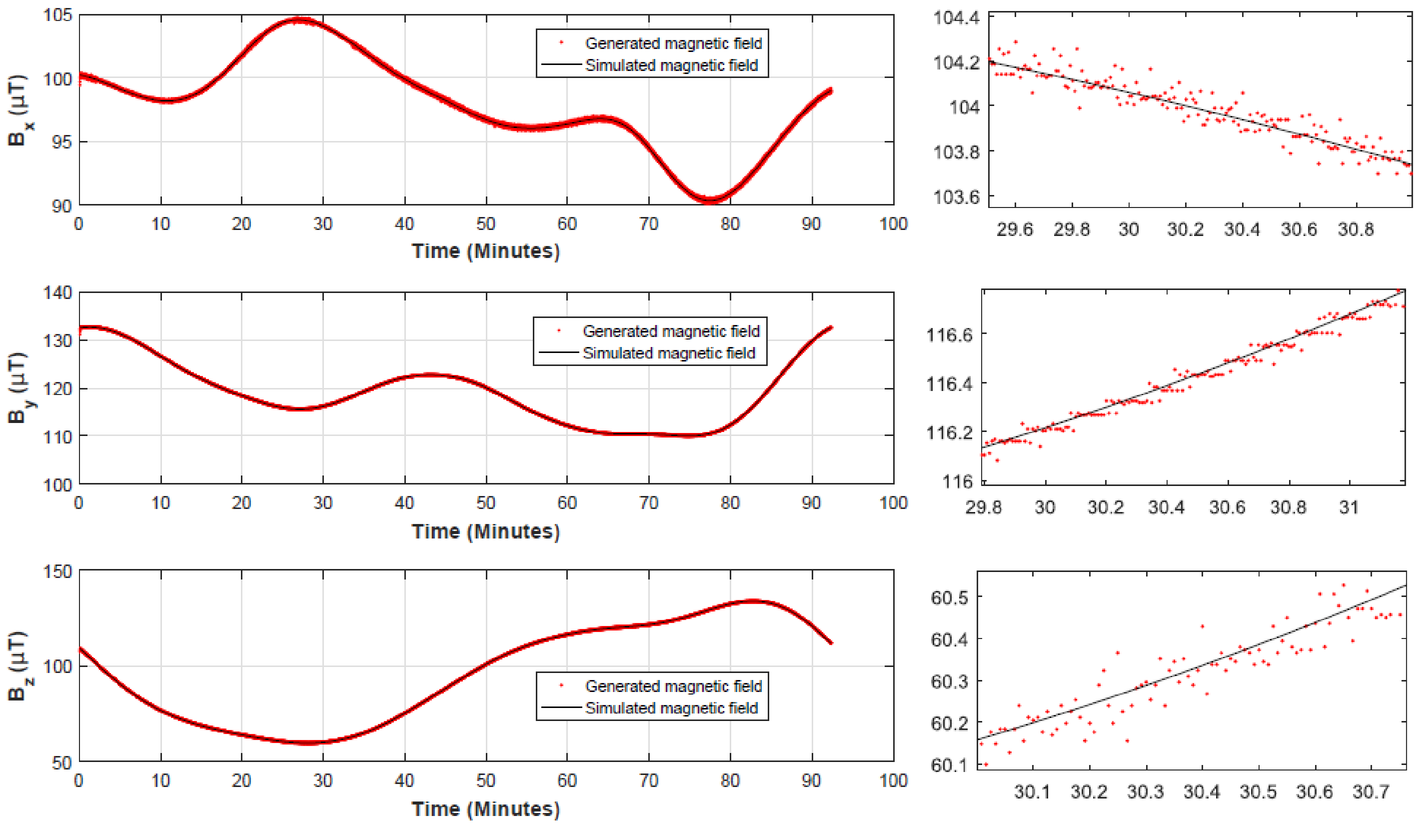


Helmholtz cage

3. Testing Procedures

3.1 Orbit Propagation

- The orbit is propagated and the magnetic field components for every point of the orbit are calculated using the WMM 2015;
- The calculated magnetic field components are used as reference to generate a controlled magnetic field through the Helmholtz Cage. An offset of 100 µT was added to this reference.



Magnetic field simulated through the Helmholtz cage

3. Testing Procedures

3.2 Setup of the Experiment

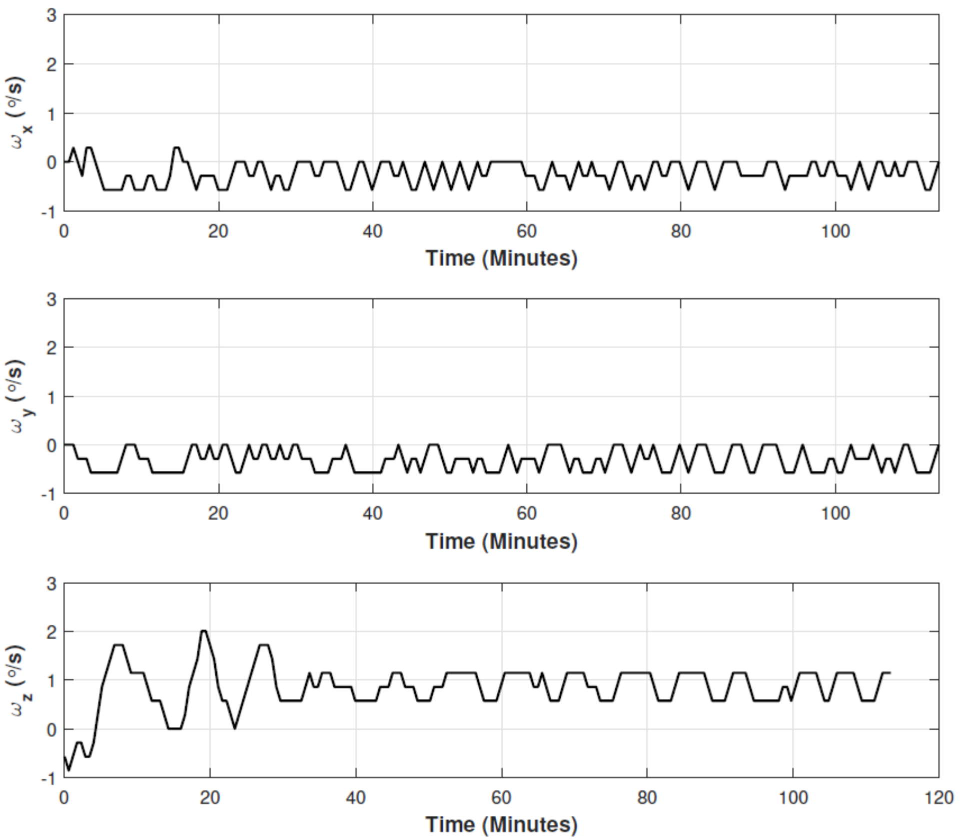
- A perturbation of approximately 1.77 º/s was applied to the vertical axis of the air bearing table (Z axis);
- The sampling time of the sensors is 0.5 s.

Setup of the Experiment	
Angular velocity about X axis	≈ 0 º/s
Angular velocity about Y axis	≈ 0 º/s
Angular velocity about Z axis	≈ 1.77 º/s
Sampling Time (Ts)	0.5 s
Simulation Interval	113 minutes

4. Results

4.1 Angular Velocity

- It can be seen that the quality of the angular velocity measures is poor. It happened due to the COTS IMU used as instrumentation;
- The readings concerning the X and Y axis are coherent with the presented setup, remaining near 0 º/s throughout the experiment;
- The damping of the angular velocity about the Z axis is confirmed through the attitude measurement.



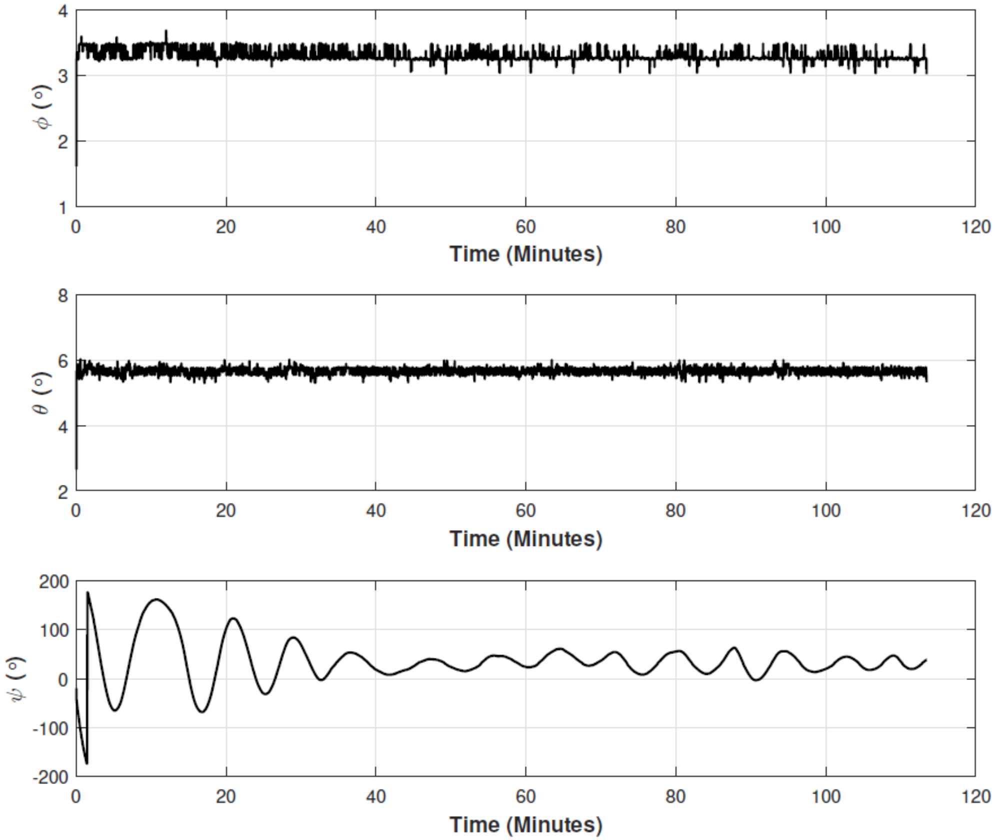
Angular velocities in the axis of the mockup

4. Results

4.2 Mockup Attitude

- The measurements showed the convergence of the mokcup yaw attitude to an arbitrary orientation;
- This behavior is coherent with the expected.

B-dot testing



Attitude of the mockup

5. Conclusion

- Despite the high inertia associated with the air bearing table and the limitations of the actuator to handle such high mass (≈ 15 kg), the B-dot controller was properly tested with the necessary adjustments to the overall test environment;
- Even with the low precision of the IMU, the obtained results were satisfactory and the damping on the angular velocity about the vertical (Z axis) could be analyzed;
- During the experiment the magnetometers suffered interference of the magnetorquers. To overcome this issue it is planned for future activities: the alternation between the reading of the magnetic field data with the magnetometer of the satellite and commanding the actuators and; the usage of an embedded filter to process the magnetometer data;
- The B-dot experiment allowed the functional validation of the HIL test facility on testing magnetic attitude control algorithms.

Thank you

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