Development of a hardware-in-the-loop test platform for nanosatellites ADCS integrated with an UKF

João Victor Lopes de Loiola
Lucas Meneses Bandeira da Silva
Simone Battistini
Chantal Cappelletti
Renato Alves Borges

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LAICA’s Platform

- **Hardware**
  - Air bearing platform
  - Helmholtz cage
  - IMU Sensor
- **Actuators**
  - Reaction Wheels
  - Magnetorquer
- **Software**
  - Orbital propagator
  - UKF
  - Graphical visualization

*Figure*: General view of the LAICA’s platform.
Objective: the objective of this work is to develop a hardware-in-the-loop system to test nanosatellites actuation systems

- Frictionless condition.
- Use of three small reaction wheels.
- COTS gyro measurements.
- This work is a first attempt to close the control loop (ukf implemented in matlab and first control test of the wheels).
- Derivation of the wheels model.
Architecture of the Simulator

**The Problem**

**Architecture of the Simulator**

**Graphical View**

**Actuation System**

**UKF**

**UKF Results**

**PD Controller**

**PD Controller Results**

**Conclusions**

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**TLE**

**ORBITAL PARAMETERS**

\( a, e, i, \omega, \Omega, \nu \)

**SGP4 ORBIT PROPAGATOR**

\( \vec{r}_e, \vec{v}_e \)

**TRANSFORMATION MATRIX**

**ORBITAL REFERENCE FRAME**

**UKF**

\( \theta_{srr}, \phi_{srr}, \psi_{srr} \)

**ROTATIONAL MATRIX**

**ROTATIONAL BODY REFERENCE FRAME**

**ERROR EVALUATION**

**CONTROL**

**REACTION WHEELS**

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Graphical view of the software simulation which relates the body frame axes with to the orbital frame axes.
Reaction wheel’s model obtained from the step response:

\[
\frac{\Omega}{V_c} = \frac{51.42 s^4 + 2.004 \cdot 10^4 s^3 + 3.849 \cdot 10^5 s^2 + 9.916 \cdot 10^5}{s^4 + 93.47 s^3 + 552.5 s^2 + 2618 s + 7729}
\]  (1)
Due to the platform nonlinear model, it was implemented an Unscented Kalman Filter (UKF) algorithm. The estimated state vector is given by:

\[
x = \begin{bmatrix}
\phi \\
\theta \\
\psi
\end{bmatrix}
\]  

The system model is presented in Eq. 3.

\[
g(x_t, u_t, w_t) = x_t + \Lambda(x)u_t\Delta t + w_t ,
\]

Where,

\[
\Lambda(x) = \begin{bmatrix}
1 & \text{sen} \phi \text{tg} \theta & \cos \phi \text{tg} \theta \\
0 & \cos \phi & -\text{sen} \phi \\
0 & \text{sen} \phi \sec \theta & \cos \phi \sec \theta
\end{bmatrix}
\]
**Figure:** Unscented Kalman Filter output in black and measurement of the data in blue.
To test the hardware-in-the-loop system it was implemented a PD controller presented in Equation 5 in order to control the orientation of the satellite around the Z axis using the reference provided by the software. According to (A.Wu, 1999), the discrete PD control law is giving by:

$$PWM(k+1) = K_p * \text{error}(k) + \frac{K_p * T_d}{T} (\text{error}(k) - \text{error}(k-1)),$$

(5)

Where $\text{error}(k) = \psi(k)_{ref} - \psi(k)$
**PD Controller Results**

**Figure**: System output under actuation of the PD controller.

![Graph showing system output under PD controller](image-url)
Figure: Error variation with the time.
• In this work, the body’s orientation was reconstructed using an UKF, a control law was tested and a mathematical model from the reaction wheel was obtained.

• The UKF provided a tolerance to noise and package loses and improved the efficiency of the PD controller.

• The hardware-in-the-loop system was capable of simulate a tracking operation.

• In the future, the UKF will implemented on board computer.

• Other control strategies will be implemented. The PD presented here was just a preliminary test.
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Thank You!

victor@lara.unb.br
silva.ngc7293@gmail.com