Saving mission yet to be launched: tight schedule for an unexpected project

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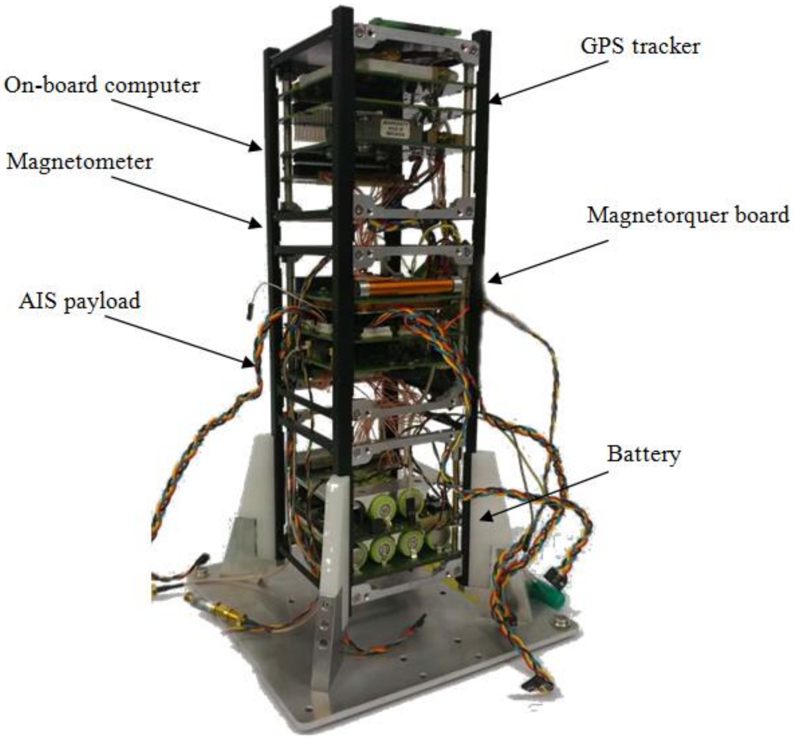
Outline

- Satellite description and main problems
- Attitude control solution
- Unexpected dynamical outcome
- Experimental results

The satellite

- 3U CubeSat for sea vessels monitoring
- Iridium and UHF transmitters
- Magnetorquers and magnetometer ADCS

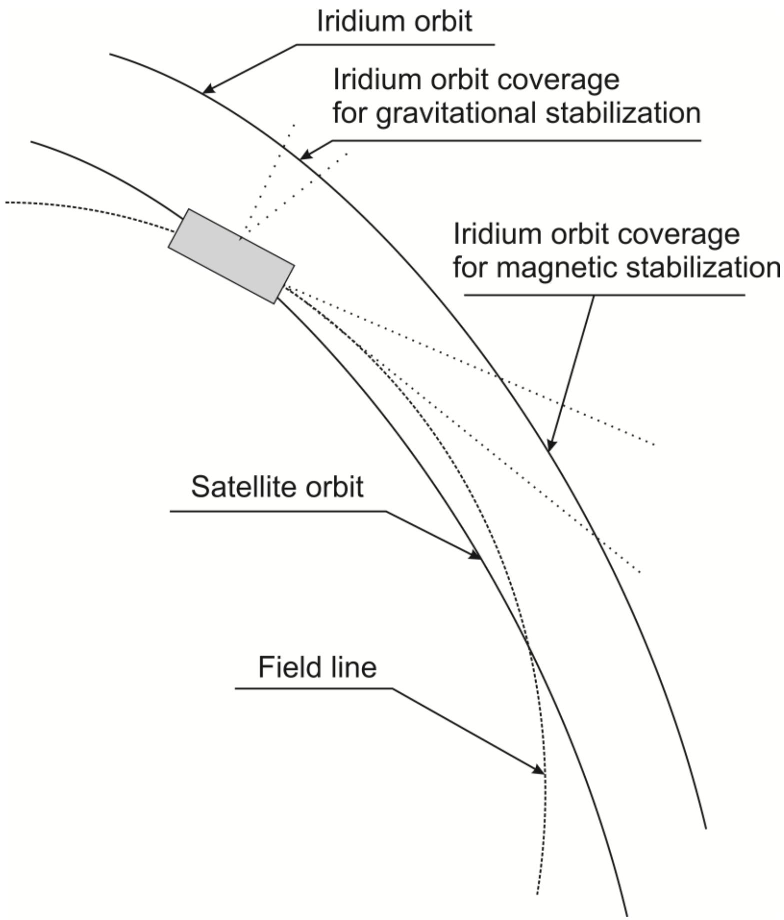


Problems

- About one month for the satellite preparation
- No one left from previous project team
- Onboard computer is faulty
- ADCS hardware lacks documentation
- UHF antenna very sensitive to temperature
- Iridium antenna with very narrow FOV
- Orbit altitude is only a bit lower than Iridium

Attitude decision

- Iridium transmitter is directed along the induction vector
- Optimistic Iridium orbits coverage
- Constant magnet should be added for power saving and B-dot used for detumbling



Interesting dynamical feedback

- Preliminary numerical simulation was carried out:
  - Axisymmetrical satellite
  - No disturbances
  - “Ideal” damping $\mathbf{m} = k\boldsymbol{\omega} \times \mathbf{B}$ and magnet $\mathbf{m}_2 = m_0(0,0,1)$
  - Simplified dipole geomagnetic field
- Attitude along the induction field is anticipated
- However, precession is in place

Motion representation

- Angular velocity in the inertial space:
  – Rotation around the axis of symmetry present
  – Simple dynamical equations with absolute velocity
- Attitude angles w.r.t. to the geomagnetic field
  – Nutation angle represents the attitude accuracy
  – Simple kinematics with the relative velocity
- Dynamics and kinematics should utilize the same velocity

Equations of motion

$$\dot{\Omega}_1 = \Omega_2\left(-\lambda\Omega_3 + \operatorname{ctg}\theta\Omega_2\right) - \varepsilon_1\Omega_1 - \varepsilon_2\sin\theta - \Omega_2\dot{\varphi}_m,$$

$$\dot{\Omega}_2 = \Omega_1\left(\lambda\Omega_3 - \operatorname{ctg}\theta\Omega_2\right) + \varepsilon_1\cos\theta\left(\Omega_3\sin\theta - \Omega_2\cos\theta\right) + \Omega_1\dot{\varphi}_m,$$

$$\dot{\Omega}_3 = -\varepsilon_1\sin\theta\left(\Omega_3\sin\theta - \Omega_2\cos\theta\right),$$

$$\dot{\varphi} = \frac{1}{\sin\theta}\left(\Omega_3\sin\theta - \Omega_2\cos\theta\right) + \dot{\varphi}_m,$$

$$\dot{\psi} = \frac{1}{\sin\theta}\left(\Omega_2 - \omega_{m3}\sin\theta\right) - \cos\theta\dot{\varphi}_m,$$

$$\dot{\theta} = \Omega_1 - \omega_{m1}\cos\psi - \omega_{m2}\sin\psi,$$

$$\dot{\varphi}_m = \frac{1}{\sin\theta}\left(\omega_{m2}\cos\psi - \omega_{m1}\sin\psi\right).$$

where $\lambda = C/A,\ \varepsilon_1 = kB_0^2/A\omega_0,\ \varepsilon_2 = m_0B_0/A\omega_0^2$

Precession

- Obvious conditions are $\Omega_3 = const,\ \theta = const$
- This leads to

$$\Omega_2 = \Omega_3 \tan\theta = const, \qquad \dot{\varphi} = \omega_\varphi = \Omega_3\left(1-\lambda\right) = const,$$

$$\Omega_1 = -\varepsilon_2/\varepsilon_1 \cdot \sin\theta = const, \qquad \sin\psi = -\varepsilon_2/\varepsilon_1\omega_{m2} \cdot \sin\theta = const.$$

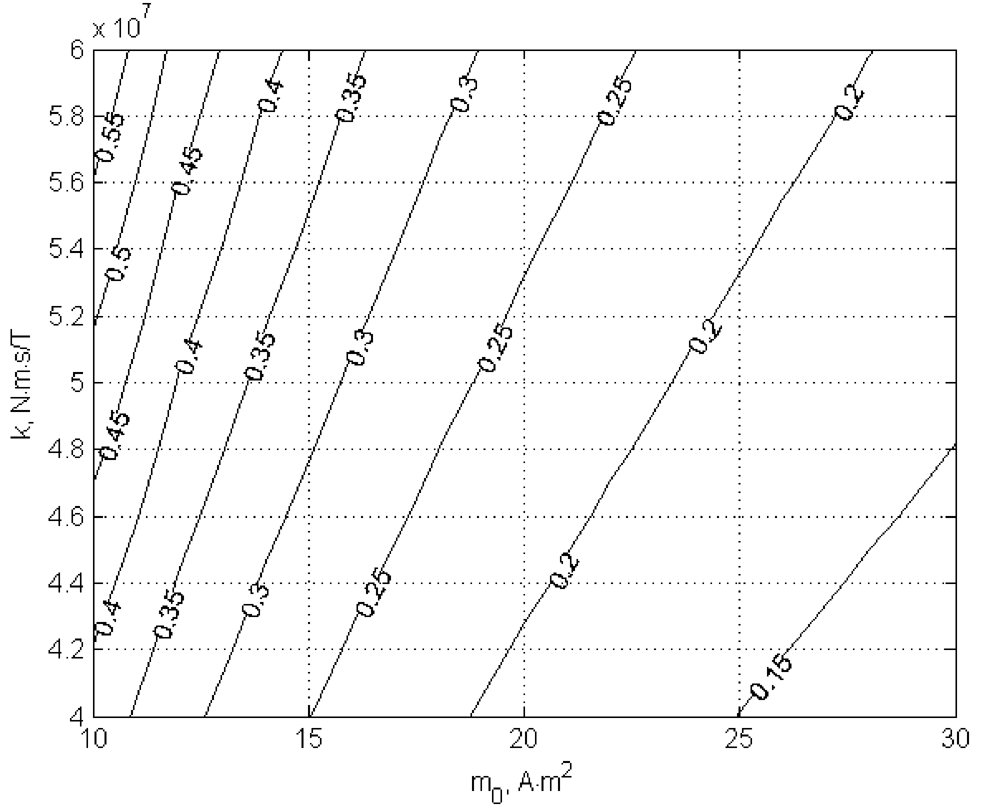
- Main parameters are given with equations

$$0 = \Omega_3 \tan\theta - \omega_{m3}\sin\theta - \omega_{m2}\cos\theta f\left(\theta\right),$$

$$0 = \Omega_3\left(\lambda - 1\right) + \omega_{m2}\frac{1}{\sin\theta} f\left(\theta\right),$$

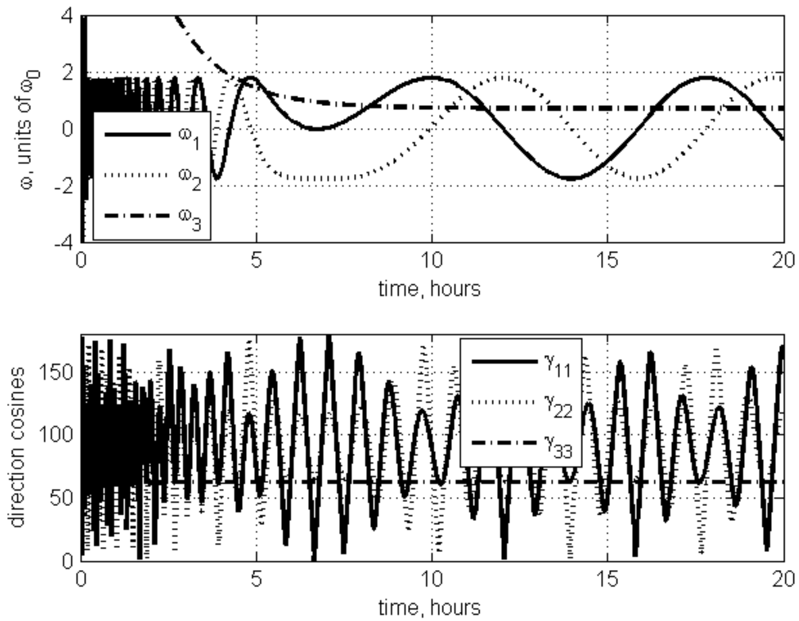
$$\cos\psi = f\left(\theta\right).$$

Precession stability depending on the control authority

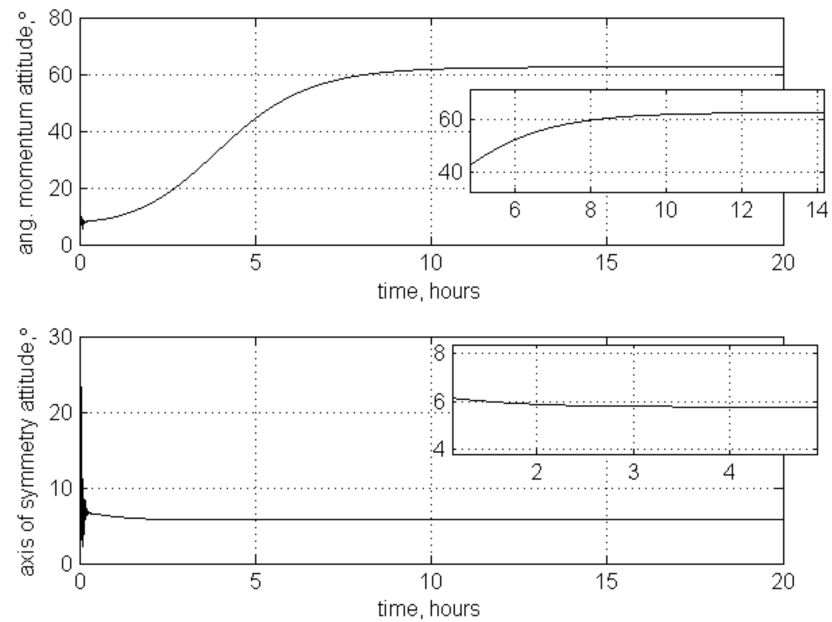


Numerical simulation
Simplified dipole model

Attitude angles and velocity

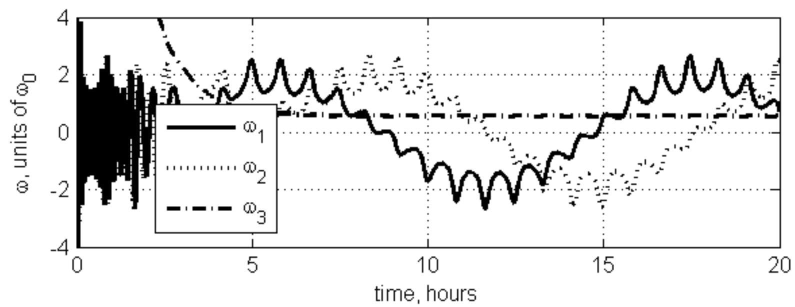


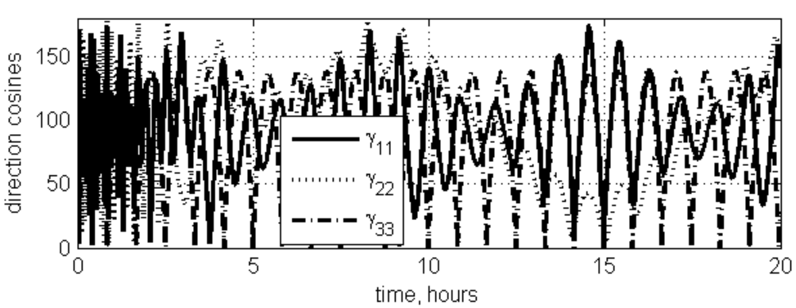
Axis of symmetry and angular momentum deviation from the induction vector



Numerical simulation
Direct dipole model

Attitude angles and velocity





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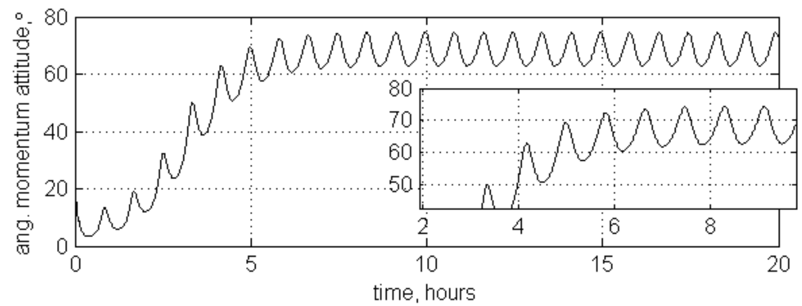
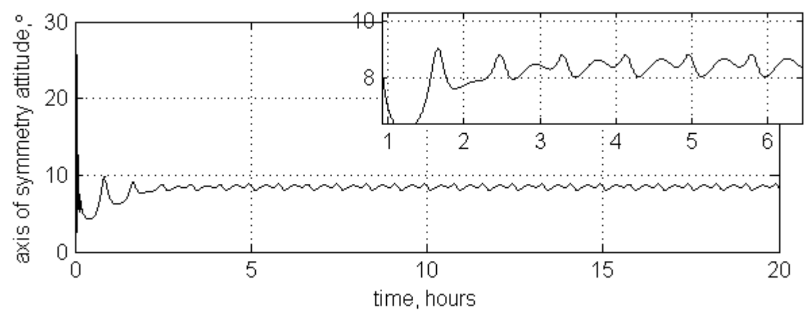
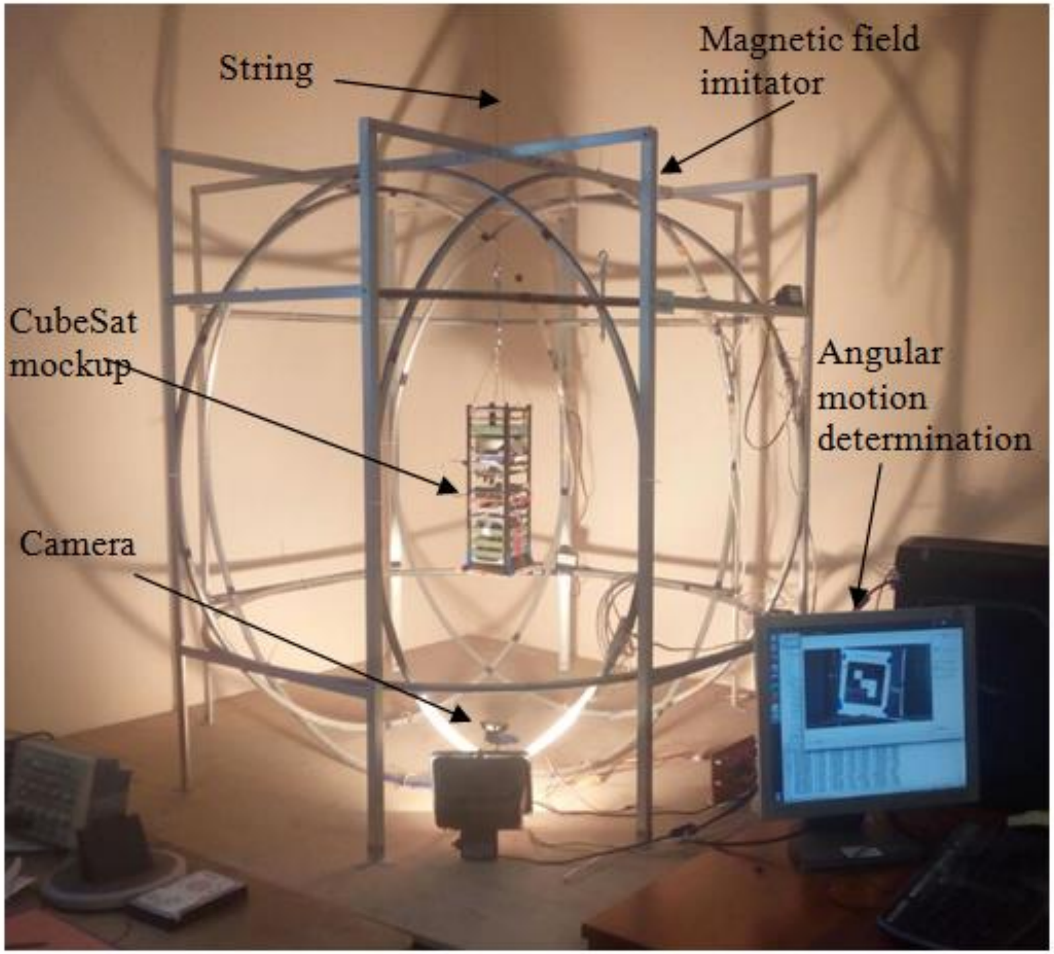




Laboratory facility

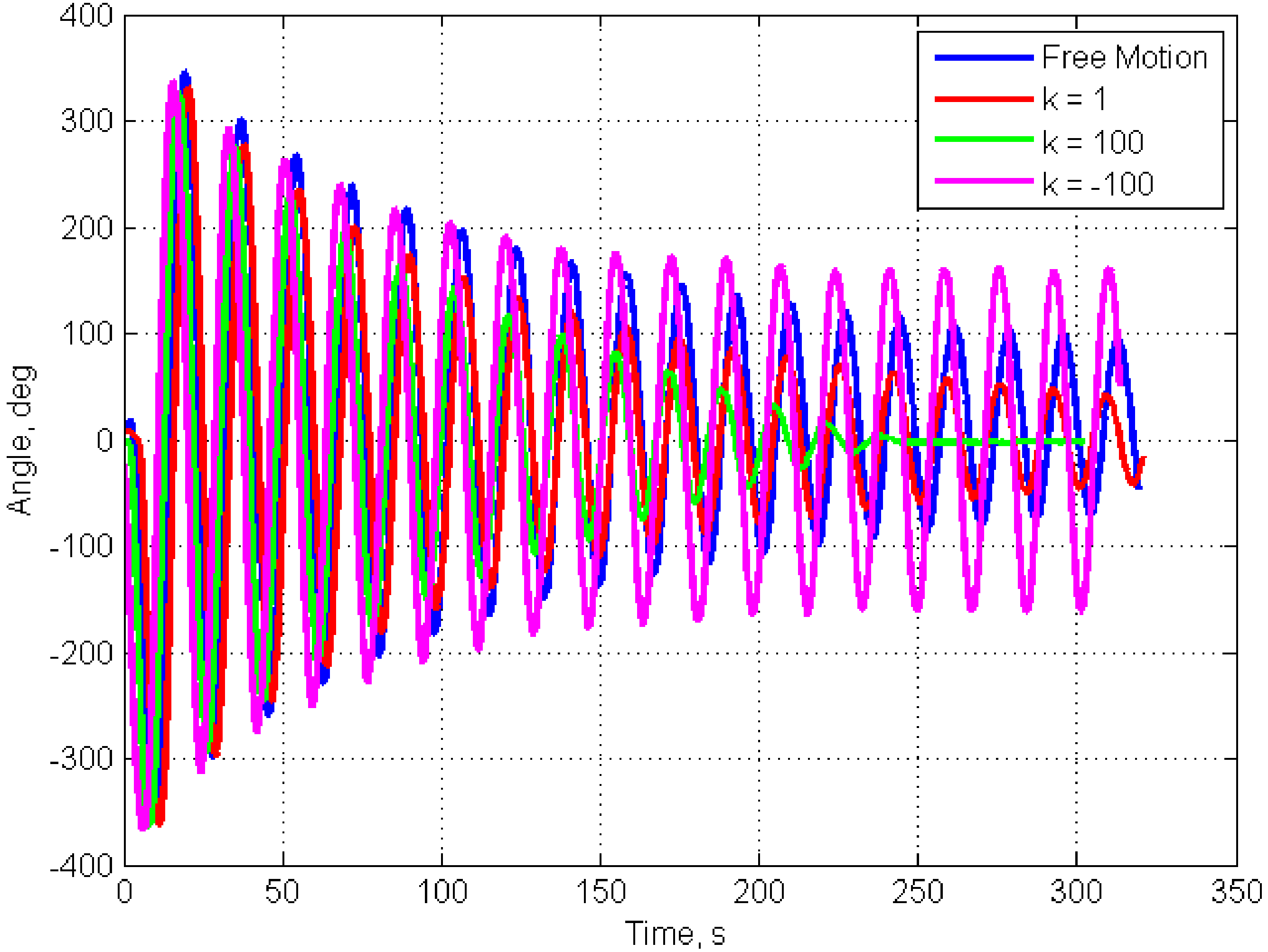
- Obsolete Helmholtz coils with constant field
- String suspension
- ADCS mockup
  - ADCS unit
  - Onboard computer
  - Bluetooth
  - Camera and mark attached to mockup



Experiments

- Magnetorquers calibration (0.3 and 0.52 $A\cdot m^2$)
- B-dot with 0.2 s measurements, 0.6 s control. Control gains:
  - 0 (free motion)
  - 1 (common damping, should provide better convergence)
  - 100 (damping with saturation, should show even better convergence in planar motion)
  - -100 (spinning with the worst convergence)

Experimental results



Results

- Simple attitude decision for the Iridium communication is provided
- Precession around the necessary attitude is preliminary investigated
- Experiments ensuring proper functioning of the magnetic control system, onboard computer and control algorithm are carried out on the simple test facility

Acknowledgements

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