

4<sup>th</sup> Polish Congress of Mechanics  
23<sup>rd</sup> International Conference on Computer  
Methods in Mechanics

Perspectives of a small spacecraft formation in a  
geostationary orbit for earth remote sensing

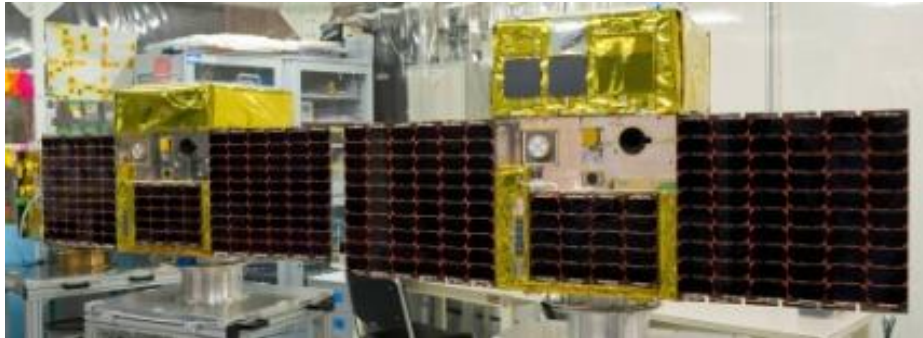
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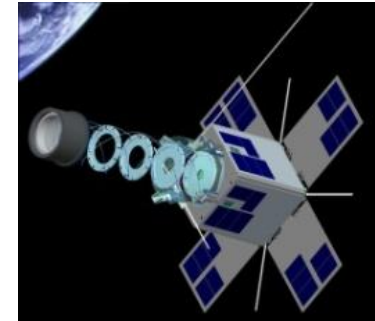
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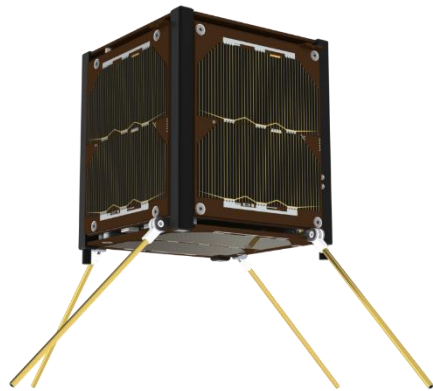
# Introduction: Small spacecraft – state of art



Micro-satellite: 20-100kg



Nano-satellite: 2-20kg



Pico-satellite: 0.5-2kg

Small satellite is a disruptive technology in space industries. Traditionally, space industries were dominated by satellites which have thousands of kilograms and are bulky and expensive. Small satellites denote a new generation of miniaturized satellites which, by taking advantages of modern technologies (e.g., integrated circuits, digital signal processing, MEMS, and additive manufacturing), can achieve a significant reduction in volume, mass, development time, and cost of satellites.

# Spacecraft formation types

**Trailing formations** are formed by multiple satellites orbiting on the same path. Each one follows the previous one separated by a specific time interval to either view a target at different times, or obtain varied viewing angles of the target. Trailing satellites are especially suited for meteorological and environmental applications such as viewing the progress of a fire, cloud formations, and making 3D views of hurricanes.

**Cluster formations** are formed by satellites in a dense (relatively tightly spaced) arrangement. These arrangements are best for high resolution interferometry and making maps of Earth.

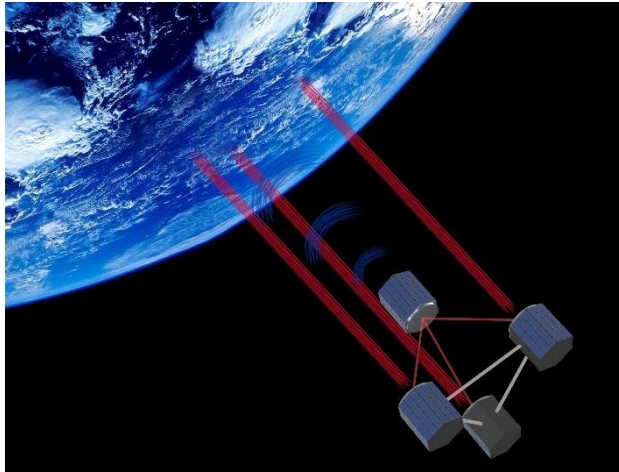
**Constellation formations** can be considered to be a number of satellites with coordinated ground coverage, operating together under shared control, synchronized so that they overlap well in coverage and complement rather than interfere with other satellites' important coverage.

## Geostationary Earth remote sensing

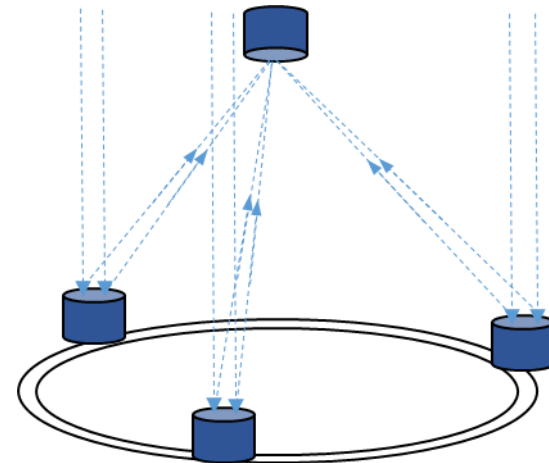
- LEO remote sensing satellites cannot monitor areas with high frequency.
- Geo-synchronous remote sensing satellite has 24 hour observability over  $\frac{1}{4}$  areas of the Earth, and data can be downlinked without time delay.
- High resolution requires larger aperture. Airbus studies a huge GEO satellite to get 6m GSD images.
- GEO remote sensing platform composed by many small satellites or deployed aperture is promising.

# Synthetic Aperture

It is planned to use the Fizeau type synthetic aperture space telescope for each microsatellite to reach high resolution imaging

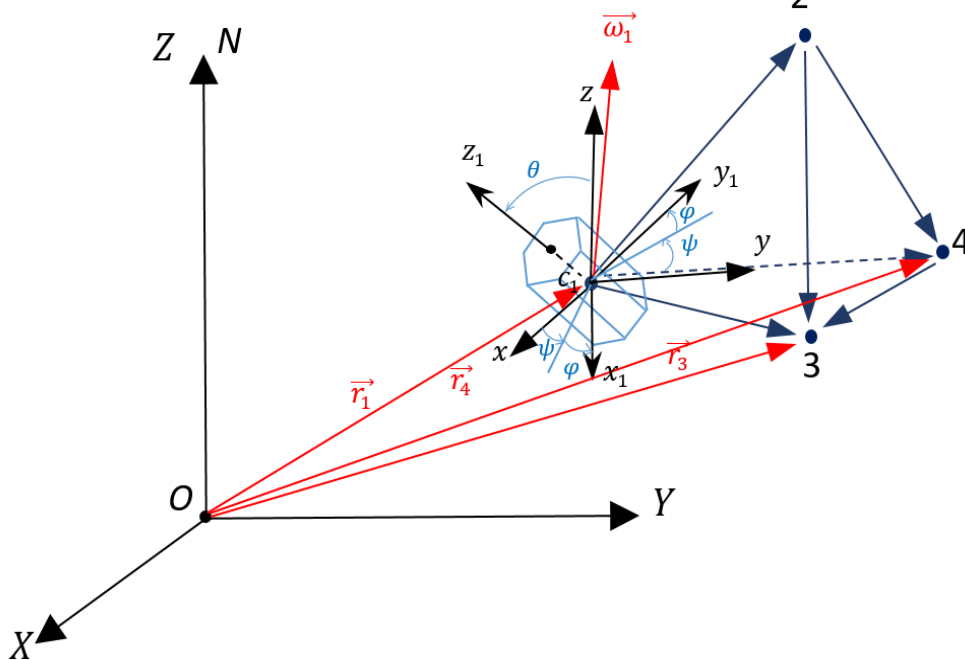


Satellite formation with aperture telescopes



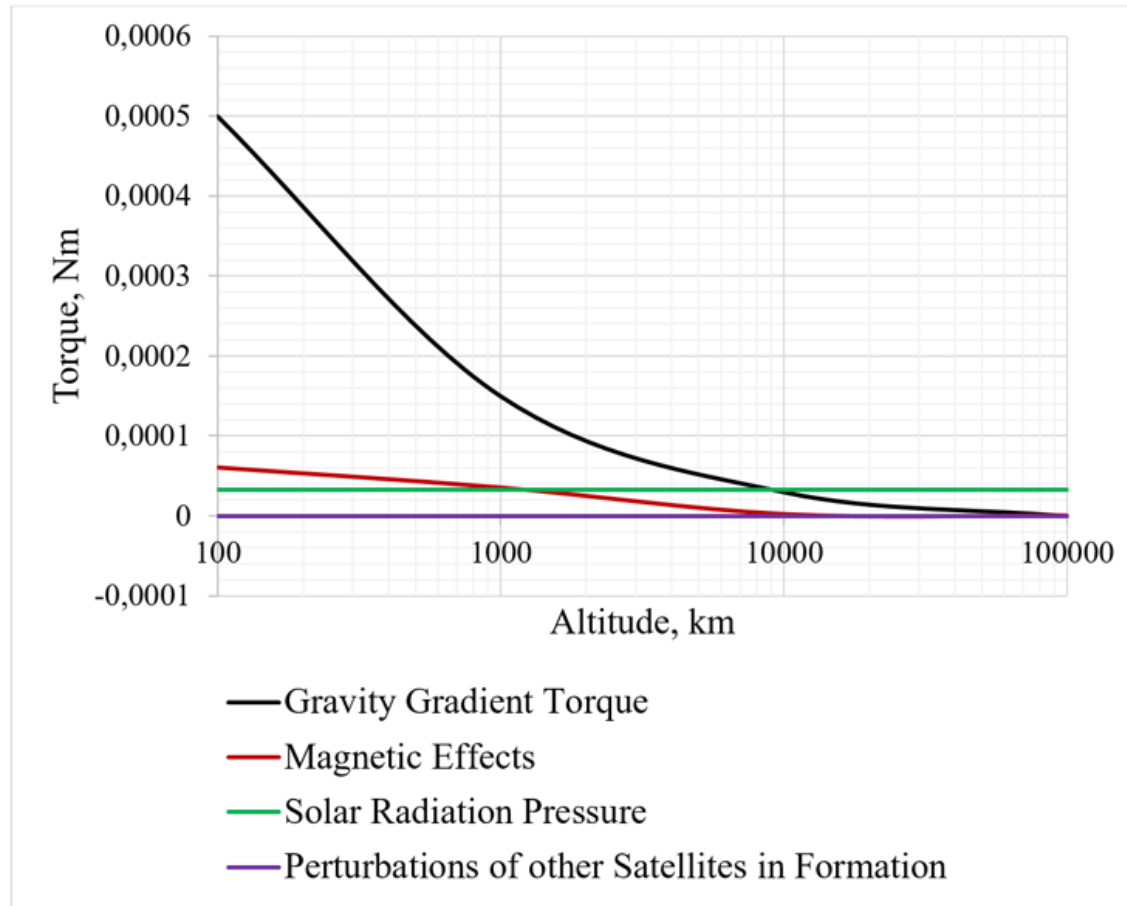
Imaging with multi-aperture optical telescopes  
and an application

# Mathematical model of a small spacecraft motion in a formation



$$\left\{ \begin{array}{l} \ddot{x}_1 = GM \frac{x_1}{r_1^3}, \quad \dot{\psi}_1 = \frac{\sin \varphi_1}{\sin \theta_1} p_1 + \frac{\cos \varphi_1}{\sin \theta_1} q_1 \\ \ddot{y}_1 = GM \frac{y_1}{r_1^3}, \quad \dot{\theta}_1 = p_1 \cos \varphi_1 - q_1 \sin \varphi_1 \\ \ddot{z}_1 = GM \frac{z_1}{r_1^3}, \\ \dot{\phi}_1 = r_1 - p_1 \sin \varphi_1 \operatorname{ctg} \theta_1 - q_1 \cos \varphi_1 \operatorname{ctg} \theta_1 \\ J_x \dot{p}_1 + (J_z - J_y) q_1 r_1 = M_{x_1}, \\ J_y \dot{q}_1 + (J_x - J_z) p_1 r_1 = M_{y_1}, \\ J_z \dot{r}_1 + (J_y - J_x) p_1 q_1 = M_{z_1}. \end{array} \right.$$

# Estimation of moments acting on small spacecrafts in the GEO



Environmental torques acting on the small spacecraft, depending on the height of the orbit



# Small spacecraft control system

$\overrightarrow{M_c}$  control moment is a function of coordinates characterizing the angular position and the angular velocity of the small spacecraft:

$$\overrightarrow{M_c} = \overrightarrow{M_c}(\overrightarrow{\omega_{bo}^b}, \overrightarrow{Q_{bo}}, K_\omega, K_Q)$$

where  $\overrightarrow{\omega_{bo}^b}$  - angular velocity of small spacecraft in body frame with respect to the orbital coordinate system,

$\overrightarrow{Q_{bo}}$  - quaternion defining the current angular position of the small spacecraft in the orbital coordinate system;

$K_\omega, K_Q$

As a result of the study, the values of the coefficients of the P-controller  $k_1, k_2, k_3$  were determined to stabilize the motion of the small spacecraft relative to the center of mass. In the calculations, the following data was taken: small spacecraft orbit – geostationary (36,000 km), moments of inertia of the spacecraft  $J = [0.04, 0.04, 0.01]$ , initial angular position and angular velocity are assumed to be equal

$K_\omega, K_Q$  – unknown control parameters.

The specific task of building a control system with a known form of the control law will be directed to determining unknown parameters of the control law (P-controller), based on the conditions of stability and quality of control processes.

$$\overrightarrow{\omega^b} = [1, 2, 3] \text{ rad/s}, \psi = \pi/3 \text{ rad}, \varphi = \pi/3 \text{ rad}, \theta = \pi/3 \text{ rad}.$$

# Simulation results

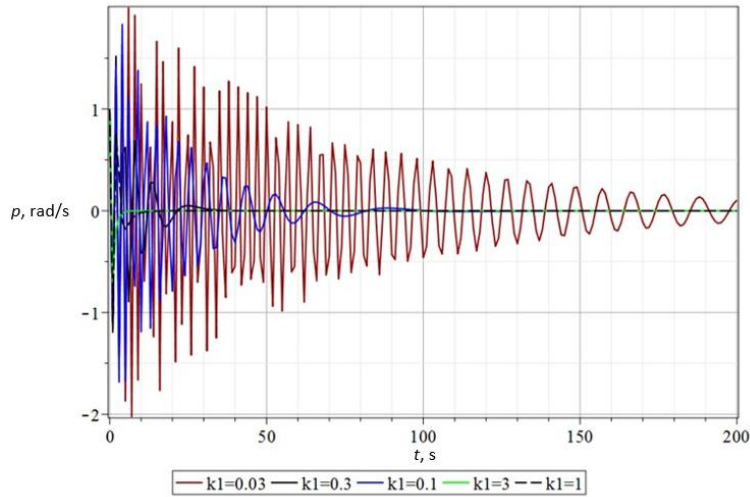


Figure 2 – Stabilization of the angular velocity component along the Ox axis

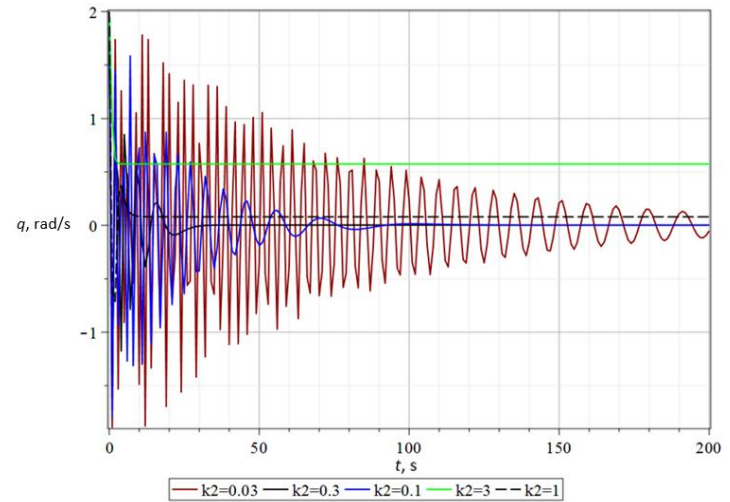


Figure 3 – Stabilization of the angular velocity component along the Oy axis

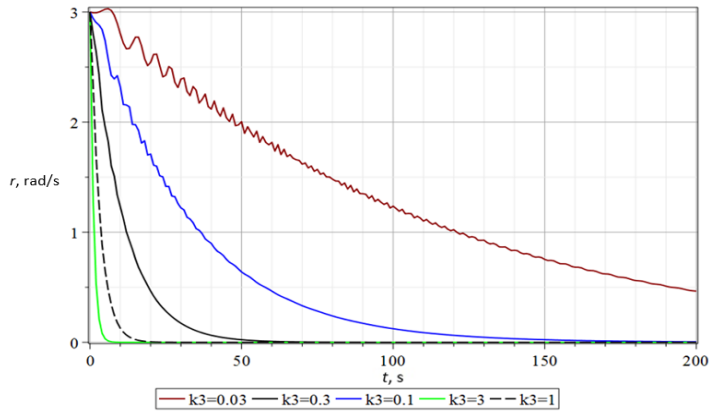


Figure 4 – Stabilization of the angular velocity component along the Oz axis

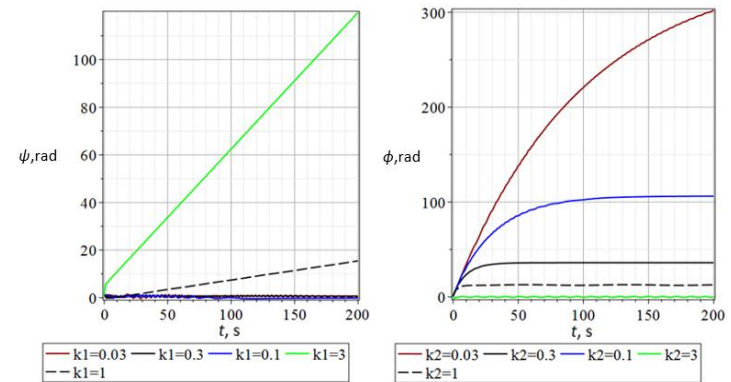


Figure 5 – Euler angles: precession, rotation

# Conclusion

This research discusses the small spacecraft motion control system, which will later be part of a group located in a geostationary orbit for the purpose of remote sensing of the Earth.

Based on the analysis of the effect of perturbations on an small spacecraft with a mass of 50 kg, it was determined that in geostationary orbit the moments of the SRP forces and the moments of gravitational forces prevail over the magnetic moment. Thus, it turned out that for the small spacecraft motion control system in the geostationary orbit, it is necessary to take into account the moments of the SRP forces and gravitational moments as the main acting factors.

This research also presents the results of the simulation of the small spacecraft motion control system in the geostationary orbit using the P-controller. As a result of the simulation, the values of the coefficients for P-controller  $k_1$ ,  $k_2$ ,  $k_3$  were determined for stabilizing the motion of the small spacecraft relative to the center of mass.

## Future plan

- Determine the volume of spacecraft formation configuration
- Develop the control of small spacecraft relative position in the formation with an accuracy of several  $\mu\text{m}$

# Thank you for your attention!

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