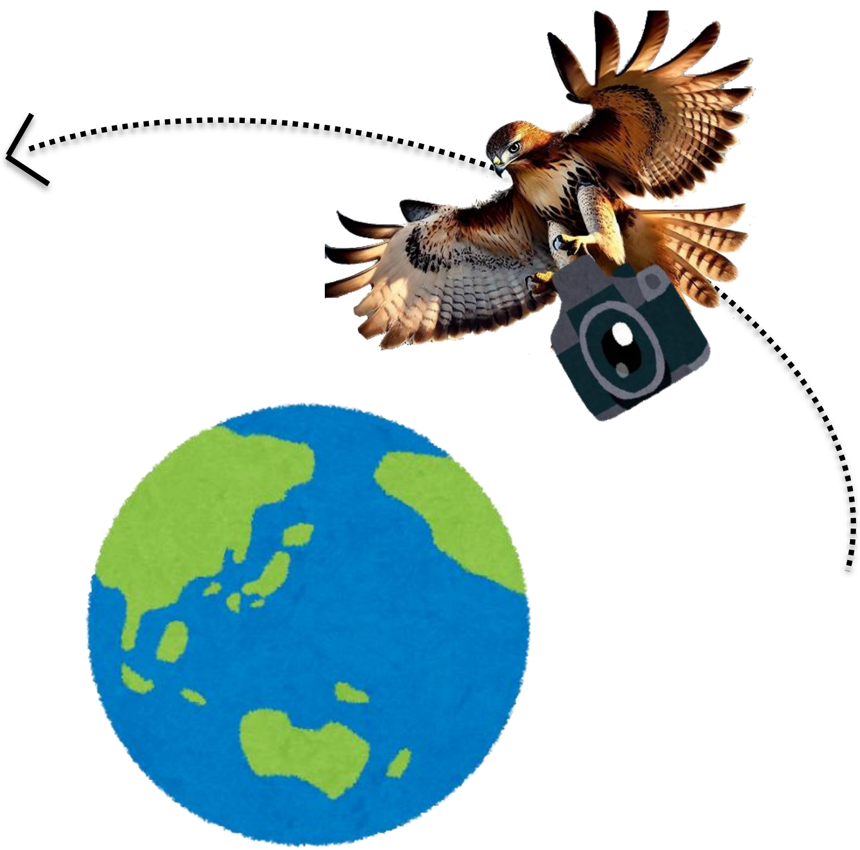
May 16th, 2025

Problem Description for the 12th Spacecraft Control System Design Contest

Remote Sensing Satellite Control System Design Contest Award



The applicant that achieves the highest score is awarded with extra prize.
The total prize money is ¥90,000.

Eagle Eye

Control the satellite attitude while considering angular momentum in very low Earth orbit, where aerodynamic torque is significant, to accurately capture more remote sensing images.

Outline of the Problem

The theme of this contest is to control the satellite attitude while considering angular momentum in very low Earth orbit (VLEO), where aerodynamic torque is significant, and to capture as many remote sensing images of specified regions as possible during the satellite's pass over Japan.

For simplicity, the following assumptions are made.

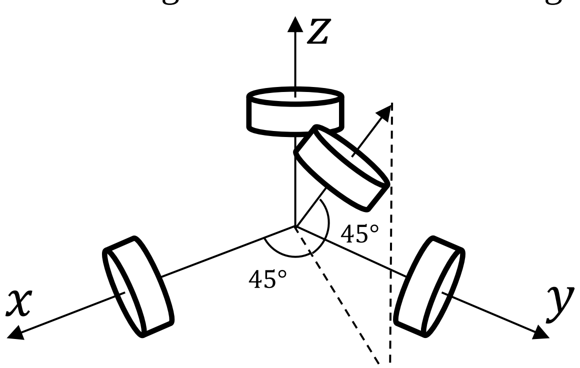
・The Earth's gravitational field is modeled as a central force field (simple inverse-square law).

・Orbital changes due to aerodynamic drag are not considered during imaging. Orbital control is also not taken into account, as it can be performed after imaging if necessary.

・The satellite is treated as a rigid body, and the only disturbance it receives is aerodynamic torque.

・Aerodynamic torque varies depending on the satellite's attitude. The torque is calculated based on a satellite shape model, using the projected area in the velocity direction.

・The satellite knows exactly its own position, velocity, attitude (quaternion), and body rate. It also has access to its reaction wheel angular momentum and the geomagnetic field.



The specifications of the satellite are as follows

・The satellite consists of a bus module and an optical system equipped with an area sensor. The bus module includes deployable solar array panels (SAP) and an attitude control system.

・Four reaction wheels can be arranged in XYZ-S (xyz-skewed wheels) configuration, with limits on torque and angular momentum.

・MTQs also have upper limits on their magnetic moment output

The operational scenario is as follows.

- A list of target imaging areas is provided to participants in advance (“set_Target.m”), including the latitude and longitude of the center and four corners of each area. All target areas are defined as rectangles aligned with lines of latitude and longitude.
- Since the first competition will be conducted using the provided list, but the list may change in subsequent competitions, software that can flexibly handle sudden updates is preferred.
- The satellite is initially at an altitude of 300 km, which may be changed to 200 km in the second problem at the contest venue.
- The initial position is set slightly before entering the first imaging area over Japan, allowing the time for attitude control to prepare for imaging.
- The satellite's angular velocity and the reaction wheel angular momentum are both initially set to zero.
- The simulation continues until none of the target areas can be imaged from the satellite's orbit.

Symbols

C_D :Drag Coefficient

$\boldsymbol{F}_{\mathrm{aero}}$: Aerodynamic drag force

h : Angular momentum stored in the wheel and its maximum allowable momentum

$\boldsymbol{I}$: Moment of inertia of the satellite

$\boldsymbol{M}$: Magnetic moment generated by MTQs.

m : Mass of the satellite

$\boldsymbol{q}$:Quaternion of the satellite

$\boldsymbol{r}$: Position vector of the satellite

$\boldsymbol{r}_{\mathrm{offset}}$: Offset vector between mass center and center of the projected area in the velocity vector

T_{aero} : Aerodynamic torque acting on the satellite

$\boldsymbol{T}_{\mathrm{rw}}$:Torque of the reaction wheels

$\boldsymbol{v}$: Velocity vector of the satellite

$\boldsymbol{\omega}$:Angular velocity of the satellite

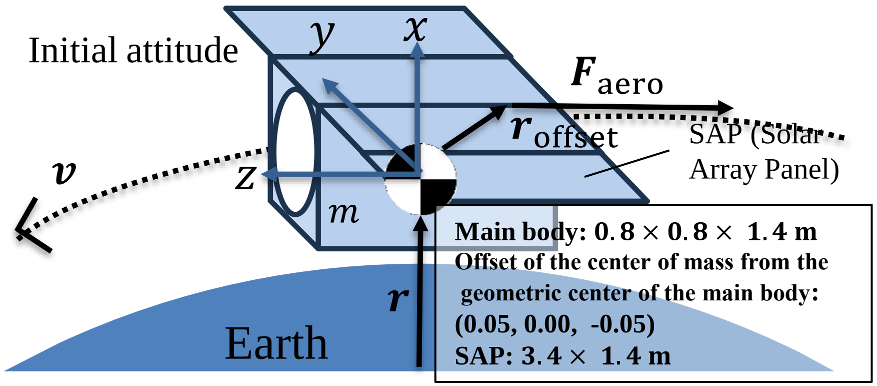
S : Projected area in the velocity vector of the satellite

μ :Gravitational parameter for the Earth

ρ :Air Density

Coordinates

Inertial coordinate system – Origin: Earth's center of mass; x, y, z axes: fixed in the inertial space.
Body coordinate system - Origin: satellite center of mass; z-axis: perpendicular to the SAP deployment panel,x-axis: the direction perpendicular to both the x- axis and z-axis, following the right-hand rule.
Earth centered Earth fixed coordinate system - All axes rotate with the Earth, so this frame is fixed relative to the Earth's surface.



The satellite's initial attitude aligns the optical axis with the velocity vector, while rotating around it to keep the solar array panels facing the Sun—minimizing drag and torque, and maximizing power generation.

The control system operates at a frequency of 10 Hz and performs attitude control suitable for imaging, accounting for aerodynamic torque and resulting angular momentum changes.

Dynamics & Kinematics

The orbit and attitude dynamics of the satellite are given as follows:

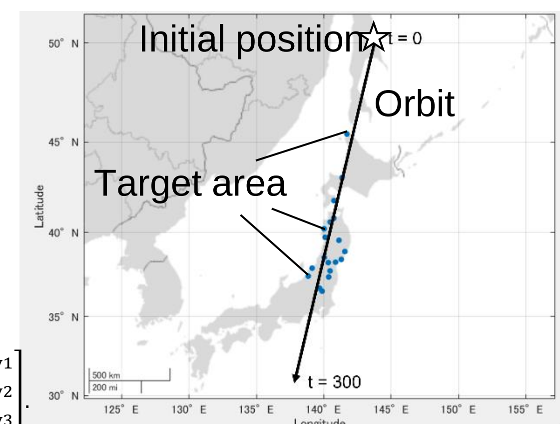
$$m\ddot{\boldsymbol{r}} = \boldsymbol{F}_{\mathrm{aero}} - \mu\frac{m}{r^3}\boldsymbol{r}, \boldsymbol{v} = \dot{\boldsymbol{r}}, \boldsymbol{F}_{\mathbf{aero}} = -\frac{1}{2}C_{\mathrm{D}}S\rho v\boldsymbol{v}\,.$$

$$\boldsymbol{I}\dot{\boldsymbol{\omega}} = -\boldsymbol{\omega}\times(\boldsymbol{I}\boldsymbol{\omega}+\boldsymbol{h}) - \boldsymbol{T}_{\mathrm{rw}} + \boldsymbol{T}_{\mathrm{aero}} + \boldsymbol{T}_{\mathrm{MTQ}}, \dot{\boldsymbol{q}} = \frac{1}{2}\begin{bmatrix} -[\times\,\boldsymbol{\omega}] & \boldsymbol{\omega} \\ -\boldsymbol{\omega}^T & 0 \end{bmatrix}\boldsymbol{q}.$$

$$\boldsymbol{T}_{\mathrm{rw}} = \dot{\boldsymbol{h}}, \boldsymbol{T}_{\mathrm{MTQ}} = \boldsymbol{M}\times\boldsymbol{B},\ \boldsymbol{T}_{\mathbf{aero}} = \boldsymbol{r}_{\mathrm{offset}}\times\boldsymbol{F}_{\mathrm{aero}}\ ,\ T_{\mathrm{rw}} = \begin{bmatrix} 1 & 0 & 0 & \cos\pi/4\cos\pi/4 \\ 0 & 1 & 0 & \sin\pi/4\cos\pi/4 \\ 0 & 0 & 1 & \sin\pi/4 \end{bmatrix}\begin{bmatrix} T_{\mathrm{rw1}} \\ T_{\mathrm{rw2}} \\ T_{\mathrm{rw3}} \\ T_{\mathrm{rw4}} \end{bmatrix}.$$

Observation and Evaluation

- For each given target area, a score is calculated based on the product of the area size and the coverage rate (the ratio of the actually imaged area to the required area). The total score is the sum of the scores from all areas.
- Each area has its own score weight. If the coverage rate does not meet a certain threshold, the score for that area is zero.
- The following conditions must be met during imaging:
  -The distance between the satellite and the target area must be below a specified threshold (based on GSD requirements; for simplicity, only distance is considered, not viewing angle).
  -The ground speed of the satellite's line-of-sight must be below a certain threshold (to satisfy constraints related to attitude motion and image blur during exposure, ensuring acceptable S/N and image quality)



What can an applicant do?

The applicant must implement a control algorithm in "**Control.m**" (MATLAB®, in the "user" folder). Optionally, a planning algorithm may be added in

The input variables to "Control.m" are as follows:

t: current time [s]
utc: current UTC [datetime]
r: position of satellite (3 x 1) [m]
v: velocity of satellite (3 x 1) [m/s]
q: quaternion of satellite (4 x 1, q(4) is scalar part) [-]
w: angular velocity of satellite (3 x 1) [rad/s]
hw: angular momentum of rws (4 x 1) [Nms]
mag: magnetic field vector in body coodinate (3 x 1) [T]

The output variables from "Control.m" are as follows:

T_rw: control torque of rws (4 x 1) [Nm],
M_mtq: output magnetic moment of mtqs (3 x 1) [Am^2]
is_observe: The flag enables automatic image capture when conditions are met. While not always optimal for scoring, toggling it between "true" and "false" allows users to target higher scores.

The input variables to "Plan.m" are as follows:

t: current time [s]
utc: current UTC [datetime]
r: initial position of satellite (3 x 1) [m]
v: initial velocity of satellite (3 x 1) [m/s]
q: initial quaternion of satellite (4 x 1, q(4) is scalar part) [-]
w: initial angular velocity of satellite (3 x 1) [rad/s]
hw: initial angular momentum of rws (4 x 1) [Nms]
targets: target list (n x 1, cell array).

The applicant can send torque and magnetic moment command to RWs and MTQs , respectively, via Control.m. The applied torque and magnetic moment are limited within [-trq_max, +trq_max] and [-mtq_max, + mtq _max], respectively. The stored momentum in the wheel is limited within [-hw_max, +hw_max]. Utility functions are provided for applicants, such as coordinate transformation and observation condition evaluation functions, all of which are organized in the "utility" folder. Please refer to the comments within each function for usage instructions.

To consider more efficient control strategies, the applicant may refer to the space environment models provided in the following files:

•**Magneticfield.m**: A dipole model that defines the Earth's magnetic field using the magnetic poles.

•**Airdensity.m**: A standard atmospheric model in which air density depends only on altitude.

The applicant can use a single global variable named "user". The applicant can use user-defined functions. Please store them in the "user" folder.

The applicant can ***NOT*** use MATLAB® toolbox functions.

A set of sample programs is provided by the contest organizer. Please run "main.m" for the simulation. It is tested under the Windows OS environment with MATLAB® version (latest R2024b and previous ones including R2024a, R2023b, R2023a, R2022b, R2022a, R2021b, R2021a, R2020b, R2020a, R2019b, R2019a, R2018b).

Sample settings

Constant and variables are sorted alphabetically.

	Symbol	Description	Value
Constant	conv_rw2body	torque and momentum distribution matrix from rw to body	Refer to "Dynamics" on page 4.
	dt_control	control cycle	0.10 s
	fov_corner_pxpy, fov_corner_mxpy, fov_corner_mxmy, fov_corner_pxmy	corner vectors of field of view in body coordinate	Refer to the source code#
	fov_x, fov_y	telescope field of view	1.2, 0.8 deg#
	hw_max	maximum momentum stored in each wheel	0.52 Nms#
	II	moment of inertia of satellite	[12.0, 0.10, 0.20; 0.10, 10.0, 0.15; 0.20, 0.15, 10.0] kgm2
	II_inv	inverse of II	inv(II)
	los	line of sight	[0; 0; 1]
	mass	mass of satellite	$1.0*10^2$ kg
	mtq_max	maximum applicable magnetic moment of each MTQ	5.0 Am^2
	mu	gravity constant of the Earth	3.986004e+14 m^3/s^2
	observarion_cover_min	Ratio of the imaged area to the total area of the target region required to earn a score.	70%
	observation_interval_min	minimum interval of observations	0.50s
	observation_los_speed_max	maximum allowable speed of the point where line of sight intersect the surface of earth when observation	$2.4*10^3$ m/s#

Note. The value that has sharp(#) may be changed at the contest site to excite the game.

Sample settings

Constant and variables are sorted alphabetically.

	Symbol	Description	Value
Constant	observation_offnadir_max	maximum allowable offnadir angle when observation	30 deg#
	panel_vertices_px, panel_vertices_mx, panel_vertices_py, panel_vertices_my, panel_vertices_pz, panel_vertices_mz	vertices of each panel in body coordinate	Refer to the source code
	r_earth	radius of the Earth	6378137 m
	trq_max	maximum applicable torque of each wheel	0.10 Nm#

	Symbol	Description	Value at t=0
Initial Value	hw	angular momentum of wheels	[0.0; 0.0; 0.0; 0.0] Nms
	q	quaternion of satellite	[0.826683; 0.358458; 0.413488; 0.130887]#
	r	position of satellite in ECI coordinate	[3956773.901; 1598570.956; 5136732.910] m#
	utc	coordinated universal time	datetime(2025, 5, 8, 0, 48, 0)
	v	velocity of satellite in ECI coordinate	[6006.637; 618.309; -4819.272] m/s#
	w	angular velocity of satellite	[0.0; 0.0; 0.0] rad/s

Note. The value that has sharp(#) may be changed at the contest site to excite the game.

Points of attention

As described in the following page,
https://ists.ne.jp/the35th/12th-spacecraft-control-system-design-contest/
those who wish to participate in this contest are required to submit the application, and please apply using the form below (NOT E-MAIL) by July 7th, 2025, apart from submitting your code: https://docs.google.com/forms/d/1IWVsGCo-a5lyOuzWb4NH1wNdGDWqFDGKHZV7rBi7x04/edit#responses

Participants must submit the following items to https://nuss.nagoya-u.ac.jp/s/C6m2aPGrQQfG9d8 without delay July 16th, 2025.

- ZIP-compressed "user" folder created by you including "Control.m“ and ”Plan.m”
- A Power Point presentation introducing your team or yourself and the control code you have created, including its features

The contest will take place on June 9 at the ISTS location. The room for on-site participants and the contest URL for on-line participants will be posted on the ISTS or the contest web pages as they become available, so please keep checking back for the latest information.

We are all looking forward to your amazing control based on your great ideas. Good luck!

Contest Organizers:
INAMORI, Takaya – Nagoya University
SAHARA, Hironori – Tokyo Metropolitan University
YOSHIKAWA, Shoji – Mitsubishi Electric Corporation
MATSUZAWA, Shinji – CANON ELECTRONICS INC.