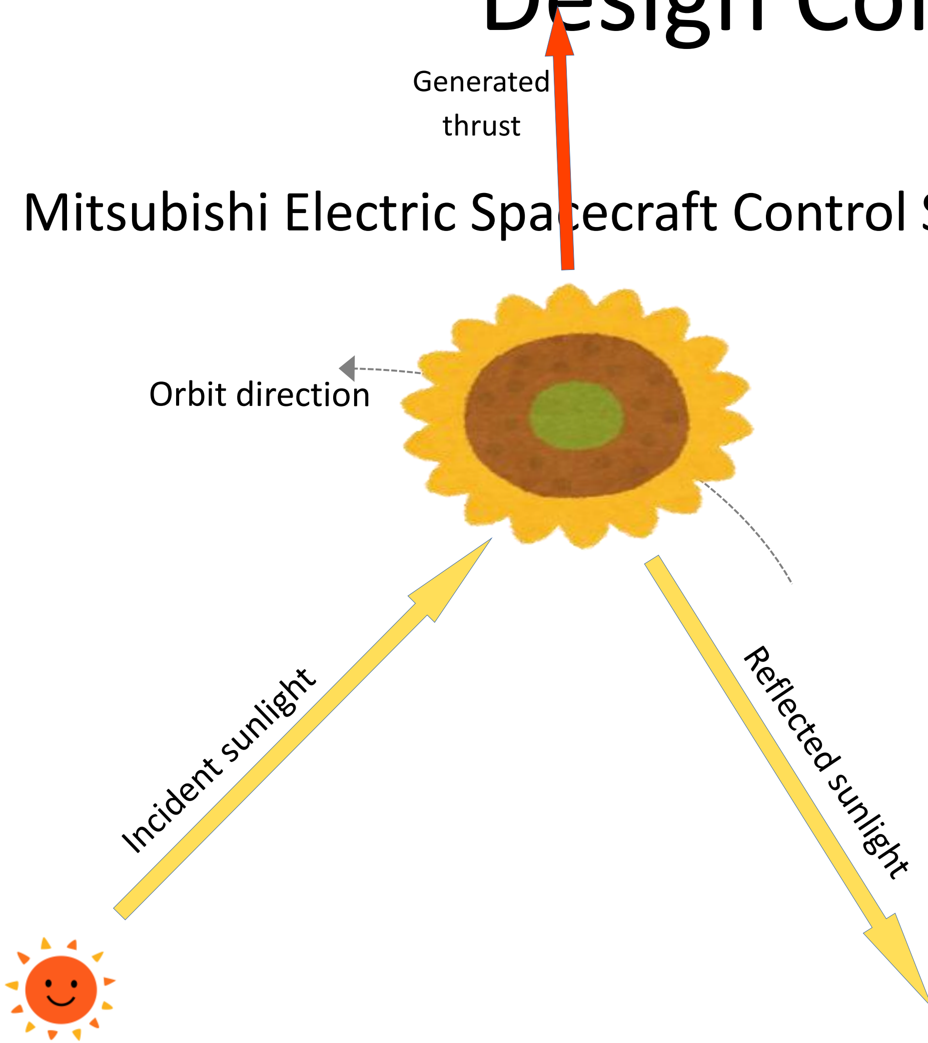
Rev.A

Problem Description for the 12th Spacecraft Control System Design Contest

Mitsubishi Electric Spacecraft Control System Design Contest Award



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

Sunflower

Outline of the Problem

The theme of this contest is to get a continuous orbit control force from the sun by keeping the one-sided sail oriented in a specified direction. To achieve this, the spacecraft (s/c) must meet the following conflicting requirements:

- Maintain the orientation of the sail while experiencing disturbance torques
- Save propellant consumed to maintain the orientation of the sail

For simplicity, we make the following assumptions:

- The orbital motion of the s/c is ignored (the sun direction seen from the c.m. of s/c does not change in inertial space).
- The only natural disturbance acting on the s/c is solar radiation pressure (SRP).
- The SRP can be represented by one acting on the large sail.
- The s/c is considered a rigid body.
- Changes in the satellite's moment of inertia due to fuel consumption are ignored.

The contest will be conducted under two initial conditions.

#1 trial: are identical to those of the sample program distributed in advance.

#2 trial: will be revealed at the venue.

The specifications of the s/c are as follows:

- The s/c can generate three-axis torque by thruster pairs.
- The torque generated by thruster pairs has an upper limit.
- The s/c has two reaction wheels (RWs) for y- and z- axes.
- The angular momentum storable in the RWs has an upper limit.
- The torque generated by RWs has an upper limit.
- Solar cells are attached to one side of the sail. They generate power only when that side is facing the sun.
- Power is constantly consumed even when the RWs and thrusters are not being driven. Power consumption increases in proportion to the torque of the RWs and the thruster pairs.

The operational scenario is as follows:

- The initial rotation speed of the s/c and the RWs is zero.
- Initially, the fuel tank is full and battery is fully charged.
- Change the s/c attitude to orient the sail in a specified direction and maintain that attitude.

The contest evaluation criteria are as follows:

- The participant with the highest total score will be the winner. **The score is multiplication of the amount of remaining fuel by the total time while the sail is oriented within the allowable angle in the specified direction.** The total score is the sum of scores for the #1 and #2 trials.
- If the battery becomes empty, it will be considered that the s/c has been lost, and the score obtained up to that point will be used for evaluation.

Symbols

$\boldsymbol{F}_{srp}$: solar radiation pressure (SRP) force
$\boldsymbol{h}_w$: angular momentum stored in the wheels
$\boldsymbol{I}_B$: moment of inertia of the s/c around its c.m.
$\boldsymbol{i}_g$: specified direction so that by aligning the normal vector of the sail surface, the desired orbit control force can be continuously obtained from the SRP force
$\boldsymbol{n}$: the normal vector of the sail surface ($=\boldsymbol{b}_z$ by definition)
$\boldsymbol{q}_I^B$: quaternion to express s/c attitude in the inertial frame
$\boldsymbol{r}_B$: vector of the center of solar radiation pressure (SRP) force from the c.m. of the s/c
$\boldsymbol{s}$: the sun direction ($=\boldsymbol{i}_z$ by definition)
$\boldsymbol{\tau}_{thr}$: torque generated by the pair of thrusters
$\boldsymbol{\omega}$: the body rate of the s/c

Coordinates

(I) inertial frame – origin: the c.m. of the s/c, x axis($\boldsymbol{i}_x$): set so that the left-handed system is established, y-axis($\boldsymbol{i}_y$): opposite direction to the orbital angular momentum and z axes($\boldsymbol{i}_z$): the sun direction
(B) s/c body frame – origin: the c.m. of the s/c, x axis($\boldsymbol{b}_x$): set so that the left-handed system is established, y-axis($\boldsymbol{b}_y$): sail extension direction, z axis($\boldsymbol{b}_z$): normal to the sail surface

Kinematics

When the attitude of the s/c is expressed by the quaternion $\boldsymbol{q}_I^B$, its time derivative is given as follows.

$$\dot{\boldsymbol{q}}_I^B = \frac{1}{2}\boldsymbol{Q}\boldsymbol{\omega} \qquad \boldsymbol{Q} = \begin{bmatrix} q_4 & -q_3 & q_2 \\ q_3 & q_4 & -q_1 \\ -q_2 & q_1 & q_4 \\ -q_1 & -q_2 & -q_3 \end{bmatrix}$$

$$\boldsymbol{q}_I^B = [q_1 \quad q_2 \quad q_3 \quad q_4]^T$$

Dynamics

The Euler's rotation equations describes the rotation of the s/c as follows.

$$\boldsymbol{I}_B\dot{\boldsymbol{\omega}} + \dot{\boldsymbol{h}}_w + \boldsymbol{\omega} \times (\boldsymbol{I}_B\boldsymbol{\omega} + \boldsymbol{h}_w) = \boldsymbol{r}_B \times \boldsymbol{F}_{srp} + \boldsymbol{\tau}_{thr}$$

The s/c has two wheels along $\boldsymbol{b}_y$ and $\boldsymbol{b}_z$ axis. The angular momentum stored in the wheels are expressed as

$$\boldsymbol{h}_w = [0 \quad h_y \quad h_z]^T$$

$$|h_y| \le h_{wmax_y}, \ |h_z| \le h_{wmax\_z}, \ |\dot{h}_y|, |\dot{h}_z| \le \dot{h}_{wmax}$$

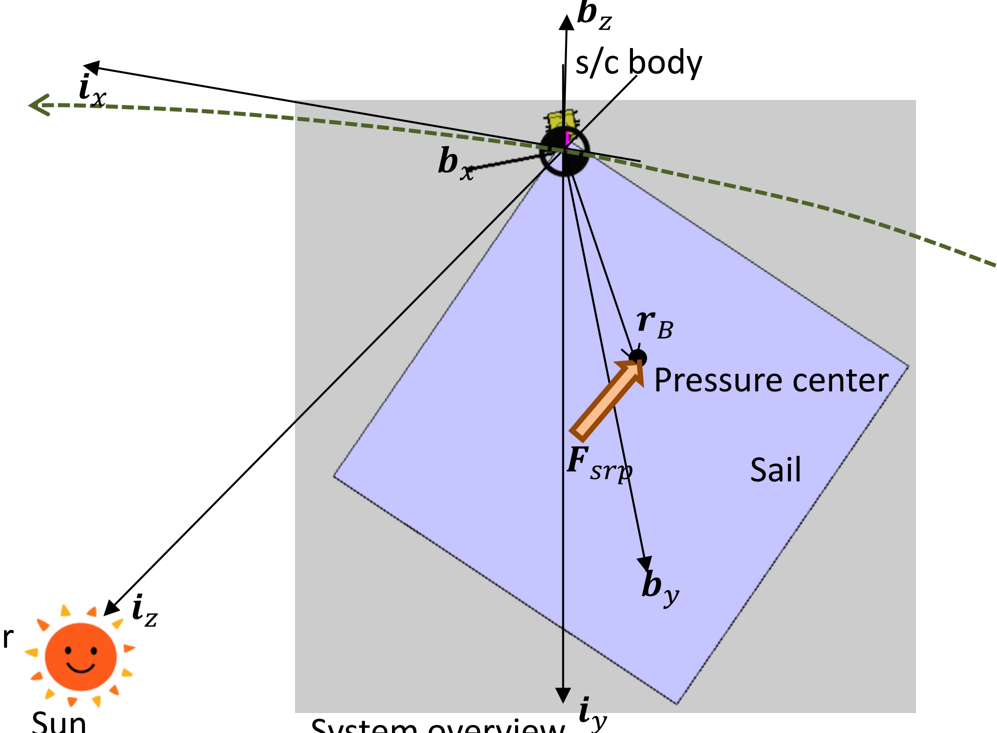
The s/c has 6 pairs of thrusters so that they generate pure torques around $\boldsymbol{b}_x$, $\boldsymbol{b}_y$ and $\boldsymbol{b}_z$ axes (expressed as $\boldsymbol{\tau}_{thr}$).

$$\boldsymbol{\tau}_{thr} = [\tau_x \quad \tau_y \quad \tau_z]^T \qquad |\tau_x|, |\tau_y|, |\tau_z| \le \tau_{max}$$

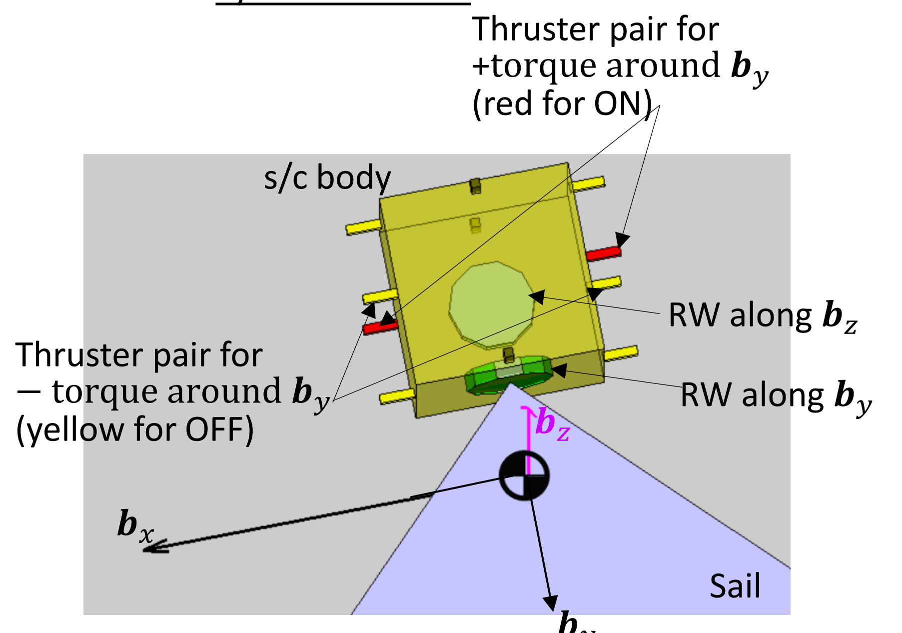
The solar radiation pressure force is modeled as follows.

$$\boldsymbol{F}_{srp} = -\frac{S_0 A}{c}(\boldsymbol{n}\cdot\boldsymbol{s})\left[\{2\rho_s(\boldsymbol{n}\cdot\boldsymbol{s}) + B_f\rho_d\}\boldsymbol{n} + (\rho_d + \rho_a)\boldsymbol{s}\right]$$

S_0: the solar constant (1366 W/m2)
A: the surface area of the sail
c: speed of light
B_f: Lambertian constant (2/3)
ρ_s: the specular constant of the sail surface
ρ_d: the diffusion constant of the sail surface
ρ_a: the absorption constant of the sail surface



System overview



Enlarged view of the spacecraft

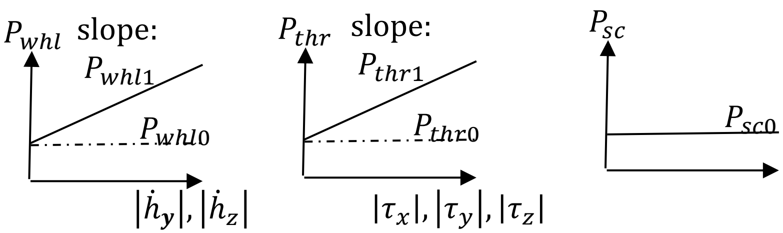
Power and fuel consumption

Power generation by the solar cells on the sail is proportional to the cross-section area toward the sun, where η is the conversion efficiency.

$$P_{gnrt} = \eta S_0 A(\boldsymbol{n} \cdot \boldsymbol{s})$$

Power consumption is modeled as follows.

$$P_{cnsm} = P_{whl} + P_{thr} + P_{sc}$$



The battery is charged/discharged according to the power balance. The battery can not be charged more than its full capacity. If the battery gets empty, the spacecraft is lost.

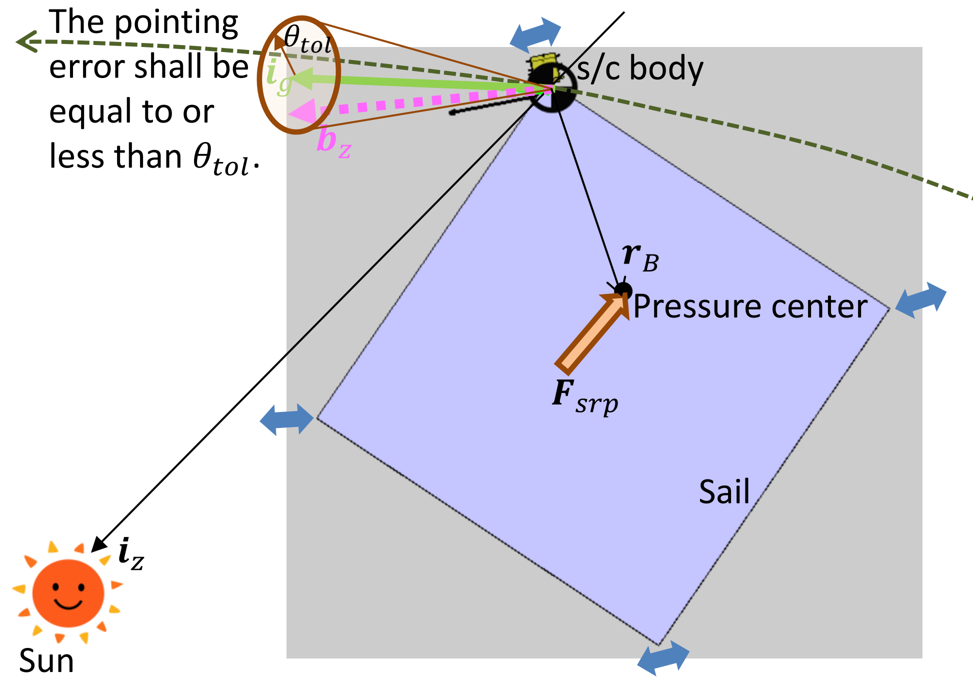
$$\frac{d}{dt}(\text{battery}) = P_{gnrt} - P_{cnsm}$$

The fuel consumption is modeled as

$$\frac{d}{dt}(\text{fuel}) = \frac{1}{g I_{sp}}\left(|\tau_x| + |\tau_y| + |\tau_z|\right)$$

Operation

The sail shall be kept pointed in a specified direction ($\boldsymbol{i}_g$) so that the desired propulsive force can be continuously obtained from the SRP force.



Operation image

What can an applicant do?

The applicant can design his or her control algorithm and implement it as a Matlab® program named "Control.m" stored in the folder "user".

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

t_in : current time [s]
x_in : state variables (13x1 vector)

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

u : thruster torque (x,y,z) [Nm] and
wheel torque (y,z) [Nm] (5x1 vector)
user_message : string of letters to be displayed in the real time monitor

The applicant can send thruster torque command. The applied torque is limited within [-thr_max*thr_arm, + thr_max*thr_arm]. The applicant can also send RW torque command. The applied torque is limited within [-trq_max, +trq_max]. The stored momentum in the wheel around y-axis and z-axis are limited within [-hw_max_y, +hw_max_y] and [-hw_max_z, +hw_max_z], respectively. Please note that only y-axis and z-axis RW torques are valid.

The applicant can get values of state variables in the table of slide "Index" from "x_in" using global index. For example, the s/c body rate "omg" is given as x_in(N_omg).

The applicant can get values of constant listed in the table of slide "Sample Settings" from global variable "user" whose field name corresponds to the constant name. For example, the allowable angle in the specified direction "angle_tol" is given as user.angle_tol.

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 R2022b update 1 and R2011b).

Sample settings

Constant and variables are sorted alphabetically.

	Symbol	Description	Value
Constant	A	area of the sail plane	81 m^2
	angle_tol	goal angle tolerance	3.0*%pi/180 rad#
	Bf	Lambertian constant	(2/3)
	bttry_full	battery full level	45000 Ws#
	c	speed of light	3.0e8 m/s
	cnv_eff	conversion efficiency	0.20
	fuel_full	tank full level	1.0 kg#
	g	standard gravity of the earth	9.80665
	g_I	goal direction vector in inertial frame	[sin(π/6);0;cos(π/6)]#
	hw_max_y	maximum momentum storable in the wheel (y-axis)	1.0 Nms
	hw_max_z	maximum momentum storable in the wheel (z-axis)	0.1 Nms
	I_B	moment of inertia of the s/c	diag([109;6.90;116]) kmg2
	Isp	specific impulse	40 s
	n_B	normal vector of the sail surface in body fixed frame	[0;0;1]
	Pwr_sc	consumed power by the s/c (stationary)	25 W
	Pwr_thr0	consumed power by a pair of thrusters (stand by)	3 W
	Pwr_thr1	consumed power by a pair of thrusters (actuated)	75 W/Nm

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	Pwr_whl0	consumed power by one wheel (stand by)	5 W
	Pwr_whl1	consumed power by one wheel (actuated)	640 W/Nm
	r_B	the vector from center of mass to the center of SRP in body fixed frame	[0.030;5.170;-0.050] m
	rho_a	the absorption constant	0.053
	rho_d	the diffusion constant	0.065
	rho_s	the specular constant	0.882
	S0	Power input from the sun	1366 W/m^2
	thr_arm	thruster arm length (distance of the thruster pair)	0.5 m
	thr_max	maximum thruster force	0.4 N
	trq_max	maximum allowable wheel torque	0.01 Nm

	Symbol	Description	Value at t=0
Variable	h_B	momentum stored in each wheel (3x1)	[0;0;0] Nms
	omg	body rate of the s/c (3x1)	[0;0;0] rad/s
	q	quaternion of the s/c (4x1)	[0;0;0;1]#

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

Index to state variables and stored variables

	Symbol	Description
State variables	N_q	quaternion of the s/c (4x1)
	N_omg	body rate of the s/c (3x1)
	N_h_B	momentum stored in each wheel (3x1)
	N_bttry	battery level (1x1)
	N_fuel	remaining fuel (1x1)
	N_pointing	accumulated pointing time (1x1)
	N_xo	state variable (13x1)
Stored variables	N_L_I	total angular momentum in the inertial frame (3x1)
	N_Fsrp_B	solar radiation pressure in the body frame (3x1)
	N_u_cmd	realized torques in the dynamics (6x1)
	N_u_user	thruster torque and wheel torque commanded by the user (5x1)
	N_pwr	consumed power (1x1)

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.