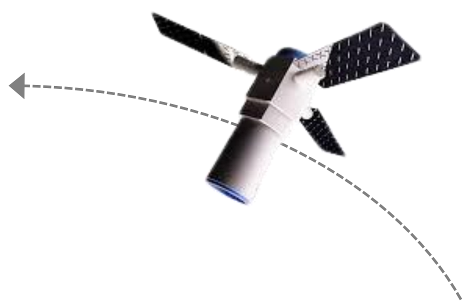
April 1st, 2023

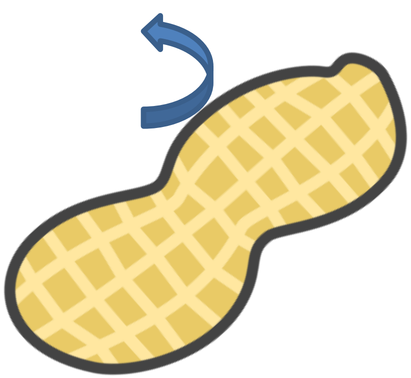
Last updated on April 26th, 2023

Problem Description for the 11th 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.



Spinning Peanut

Outline of the Problem

The theme of this contest is to take close-up pictures of a rotating peanut-shaped asteroid, "**Spinning Peanut**." To that end, the orbiter has the following conflicting tasks:

- Get close to the asteroid and take pictures
- Don't get too close to the asteroid and hit it

For simplicity, the following assumptions are made.

- The center of mass (c.m.) of the asteroid is stationary in inertial space.
- The gravitational field of the asteroid is modeled as a "dumbbell type" in which two point masses are rotating at a constant angular velocity around the c.m. of the asteroid.
- The orbital motion of the orbiter is planar motion around the spin axis of the asteroid.
- Rotational motion of the orbiter is around an axis parallel to the spin axis of the asteroid.
- The orbiter knows exactly its own position, velocity, attitude, and body rate.
- The only disturbance that the orbiter receives is the force caused by the gravity of the asteroid.

The specifications of the orbiter are as follows.

- The orbiter consists of a bus section and a telescope.
- The orbiter uses a thruster to control its trajectory.
- The thrust of the thruster is constant.
- There is an upper limit to the total delta-V.
- The orbiter uses a wheel to control its attitude.
- There is an upper limit to the magnitude of wheel torque.
- There is an upper limit to the accumulated angular momentum in the wheel.

The operational scenario is as follows.

- Initially, the orbiter is in orbit around the asteroid.
- If the thruster is not fired, the orbiter will not collide with the asteroid until the simulation end time.
- The upper limit of the total delta-V is equal to the magnitude of the orbiter's initial velocity.
- The initial rotation speeds of the orbiter and the wheel are 0.
- The shape of the asteroid is two circles connected by a rod.
- The target points to be taken pictures of are specified in advance on the surface of the asteroid.

The evaluation criteria for the contest are as follows.

- For each target point, it is judged that a picture has been taken when it is continuously within the field of view of the telescope for a predetermined time or longer, and a score is given according to the distance. When the same target point is shot multiple times, the highest score among the multiple shots is recorded.
- The participant with the highest total score at the end of the simulation wins.
- If the c.m. of the orbiter touches the surface of the asteroid, it will be judged as having collided with the asteroid, and the score obtained up to that point will be evaluated.

Symbols

d_{12} : distance between the edge of dumbell model parts 1 and 2
$dot(\boldsymbol{a}, \boldsymbol{b})$: inner product of vectors $\boldsymbol{a}$ and $\boldsymbol{b}$
f : thrust force
FOV : telescope field of view
h, h_{max} : momentum stored in the wheel and its maximum allowable value
m_s, i_s : mass and moment of inertia of the orbiter
$\boldsymbol{n}_c$: telescope boresight direction
$\boldsymbol{n}_t$: thruster nozzle direction
$\boldsymbol{p}_s$, $\boldsymbol{v}_s$: position and velocity of the center of mass (c.m.) of the orbiter
$\boldsymbol{p}_{a1}$, $\boldsymbol{p}_{a2}$: center of mass (c.m.) position of the dumbell model parts 1 and 2
$\boldsymbol{p}_i$: i-th target point position for the orbiter to take pictures of ($i = 1 \dots 7$)
r_1, r_2 : radius of the dumbell model parts 1 and 2
T_{photo} : minimum continuous time period to take pictures of the target point on the asteroid
θ_a : spin angle of the asteroid
θ_s : attitude angle of the orbiter
τ : wheel torque
O_{spin} : spin rate of the asteroid

Coordinates

(I) **inertial frame** – origin: the c.m. of the asteroid, x,y and z axes: coincide with those of the asteroid fixed frame at time t=0
(A) **asteroid fixed frame** – origin: the c.m. of the asteroid, x axis: the direction from the c.m. of the asteroid to the c.m. of the part 1, y axis: set so that the left hand system is established, z axis: spin axis
(B) **orbiter body fixed frame** – origin: the c.m. of the orbiter, x axis: set so that the left hand system is established, y-axis: telescope boresight direction, z axis: coincides with the asteroid spin axis

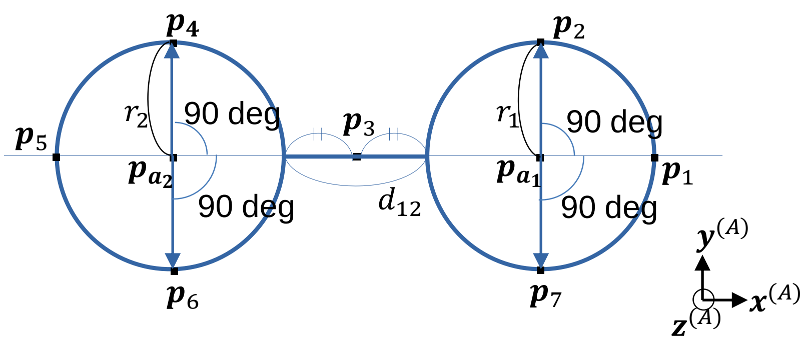
Kinematics

The c.m. position of the dumbell model parts 1 and 2 in the asteroid fixed frame is given as follows.

$$\boldsymbol{p}_{a1}^{(A)} = \frac{m_2}{m_1 + m_2}\begin{pmatrix} r_1 + r_2 + \dfrac{d_{12}}{2} \\ 0 \end{pmatrix}$$

$$\boldsymbol{p}_{a2}^{(A)} = -\frac{m_1}{m_1 + m_2}\begin{pmatrix} r_1 + r_2 + \dfrac{d_{12}}{2} \\ 0 \end{pmatrix}$$

The target points for the orbiter to take pictures of are evenly distributed over the asteroid surface as follows.



Dynamics

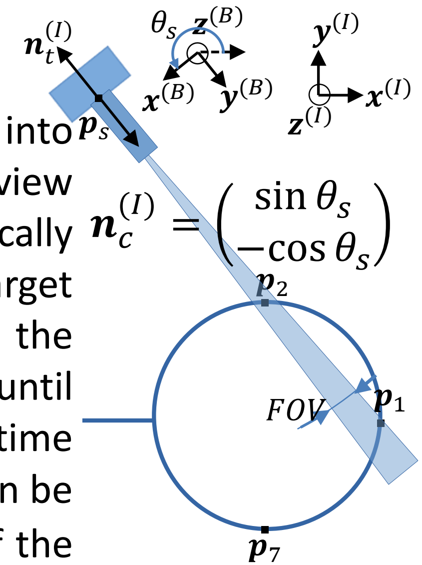
The translational and rotational equations of motion of the orbiter are given as follows.

$$m_s \ddot{\boldsymbol{p}}_s = -\frac{m_s \mu_1}{|\boldsymbol{r}_{1s}|^3}\boldsymbol{r}_{1s} - \frac{m_s \mu_2}{|\boldsymbol{r}_{2s}|^3}\boldsymbol{r}_{2s} + f\boldsymbol{n}_t$$

$$\boldsymbol{r}_{1s} = \boldsymbol{p}_s - \boldsymbol{p}_{a1},\ \boldsymbol{r}_{2s} = \boldsymbol{p}_s - \boldsymbol{p}_{a2},\ \boldsymbol{n}_t^{(I)} = \begin{pmatrix} -\sin\theta_s \\ \cos\theta_s \end{pmatrix}$$

$$i_s\,\ddot{\theta}_s = \tau, \qquad \dot{h} = -\tau$$

Observation



$$\boldsymbol{n}_c^{(I)} = \begin{pmatrix} \sin\theta_s \\ -\cos\theta_s \end{pmatrix}$$

When the target point comes into the instantaneous field of view (iFOV), imaging automatically starts. Then, when the target point continues to be within the iFOV without interruption until the predetermined imaging time T_{photo} elapses, the score S can be obtained as the total value of the instantaneous scores iS.

If the target point is out of the iFOV before T_{photo} elapses, imaging is canceled. If the target point continues to be within the iFOV beyond T_{photo}, the first imaging completes when T_{photo} elapses and the second imaging starts immediately. The score S has an upper limit S_{max}. When the same target point is imaged multiple times, the highest score is the score for that target point. In this example, because $\boldsymbol{p}_1$ is obstructed by the asteroid part 1, $\boldsymbol{p}_1$ is considered invisible. If the following inequality holds, the target point is judged being within the iFOV.

$$dot(\boldsymbol{r}_{si}, \boldsymbol{n}_c) \geqq |\boldsymbol{r}_{si}|\cos(FOV/2) \qquad \boldsymbol{r}_{si} = \boldsymbol{p}_i - \boldsymbol{p}_s$$

The corresponding instantaneous score iS is given as the inverse of the distance between the target point and the orbiter expressed in the unit of kilometer.

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 (9x1 vector)
photoL1	: 1st row of the photo table (1x7 vector)

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

u	: force (1:ON, otherwise:OFF) and torque [Nm]
user_message	: string of letters to be displayed in the real time monitor

The applicant can choose either 1 (ON) or otherwise (OFF) to set the thruster ON or OFF. The thruster force is constant. The total delta V has an upper limit. Note. When the thruster is ON, the orbiter gets thrust in the opposite direction to the thruster nozzle direction.

The applicant can send torque command. The applied torque is limited within [-trq_max, +trq_max]. The stored momentum in the wheel is limited within [-hw_max, +hw_max].

The applicant receives the current score for each target point from "photoL1". For example, 2nd target point has a score photoL1(2).

The applicant can get values of state variables in the table of slide "Index" from "x_in" using global index. For example, the orbiter's position "ps" is given as x_in(N_ps).

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, distance between the edge of dumbell model parts 1 and 2 "d12" is given as user.d12.

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 R2023a and previous ones including R2022b, R2022a, R2021a, R2019a, R2018a, R2016b, R2015b, R2012a and R2011b).

Sample settings

Constant and variables are sorted alphabetically.

	Symbol	Description	Value
Constant	d12	distance between the edge of dumbell model parts 1 and 2	30 m
	dV_max	maximum total delta V	norm of initial orbit velocity#
	FOV	telescope field of view	10 deg#
	hw_max	maximum momentum storable in the wheel	0.0175 Nms#
	ms, is	mass and moment of inertia of the orbiter	1 kg, 1 kgm2
	pa1_A, pa2_A	center of mass (c.m.) position of the dumbell model parts 1 and 2	Refer to Kinematics
	piL_A	target point position for the orbiter to take photos of	Refer to Kinematics
	r1, r2	radius of the dumbell model parts 1 and 2	300, 300 m
	socre_max	maximum score for each target point	999
	thrust	constant thrust force	0.01 N
	Tphoto	minimum continuous time period to take pictures of the target point on the asteroid	5 sec
	trq_max	maximum applicable torque	0.01 Nm
	Tspin	spin period of the asteroid	1,600 hour#
	muG1,muG2	gravity constant of asteroid parts 1 and 2	12.08, 12.08 m3/s2

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 at t=0
Variable	Ca2i	direction cosine matrix from asteroid fixed frame to inertial frame	[1, 0;0, 1]
	f	thrust force	0 N
	h	momentum stored in the wheel	0 Nms
	nc	telescope boresight direction	Refer to Observation
	nt	thruster nozzle direction	Refer to Dynamics
	ps,vs	position and velocity of the center of mass (c.m.) of the orbiter	(650, 0) m#, (0, 0.2458) m/s#
	the_a	spin angle of the asteroid	0 deg
	the_s, dthe_s	attitude angle and body rate of the orbiter	0 deg, 0 deg/s
	tau	wheel torque	0 Nm

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_xs	x-component of ps
	N_ys	y-component of ps
	N_ps	position of the c.m. of the orbiter
	N_dxs	x-component of vs
	N_dys	y-component of vs
	N_vs	velocity of the c.m. of the orbiter
	N_the_s	attitude angle of the orbiter
	N_dthe_s	body rate of the orbiter
	N_the_a	spin angle of the asteroid
	N_dV	total delta V
	N_hw	momentum stored in the wheel
	N_xo	state variable
Stored variables	N_u_cmd	force and torque realized in the dynamics
	N_u_user	force and torque commanded by the user
	N_ps_A	position of the c.m. of the orbiter in the asteroid fixed frame
	N_photoL	score for each target point

Points of attention

As described in the following page,

https://ists.ne.jp/program/11th-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 the end of **May**, 2023, apart from submitting your code: https://forms.gle/Zfvap1Yguv3EXfC17

The application deadline has been changed.

Participants must submit the following items to sahara@tmu.ac.jp BY E-MAIL without delay by the end of May, 2023.

- ZIP-compressed "user" folder created by you including "Control.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:

SAHARA, Hironori – Tokyo Metropolitan University

YOSHIKAWA, Shoji – Mitsubishi Electric Corporation

INAMORI, Takaya – Nagoya University