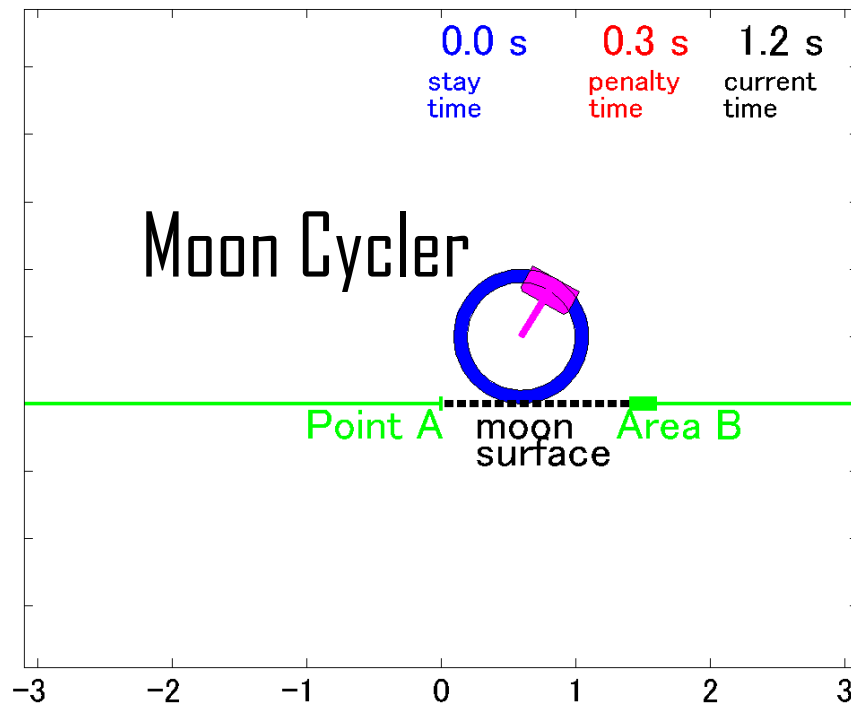


Problem Description for the 10th Spacecraft Control System Design Contest

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.

Outline of the Problem

The theme of the contest is to quickly transport a luggage from point A to area B using a unicycle-type trolley on the moon (“moon cycler”), i.e.

- to transport as soon as possible
- to lift and transport the luggage on the way

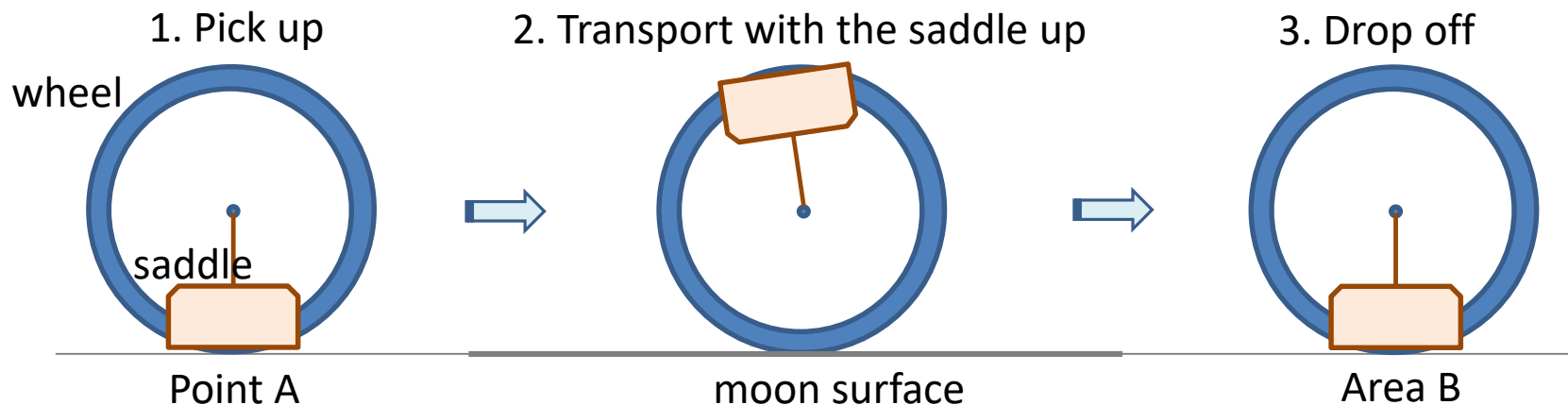
For simplicity, we take the following assumptions.

- The moon surface is flat.
- The trolley consists of the two rigid bodies, i.e. a wheel and a saddle and they are connected by a massless rigid rod.
- The wheel does not slip.
- Only the rotational motion of the wheel (pitch axis) is considered and the other rotational motions (roll and yaw axes) are ignored.

The specification of the moon cycler is as follows.

- The motor torque is applied to the wheel and its counter torque is applied to the saddle.
- The luggage is stored in the saddle.
- Both in the base A and base B, the saddle can be up or down. The saddle needs to be up outside the base (on the moon surface) so that the luggage is lifted up.
- Initially, the saddle is down and the cycler is at point A, the edge of the base A.
- After the contact point is kept within the area B with its saddle down, it is judged transport is finished.
- **The applicant that finishes the transport with minimum time wins the contest.** Note that the penalty time* is added to the recorded time.

*When the cycler is on the moon surface and the saddle is not up, then that time is added to penalty time.



Symbols

- d_B : distance of the area B from point A
- g : the gravity constant on the moon surface
- I_1 : the wheel inertia
- I_2 : the saddle inertia
- m_1 : the wheel mass
- m_2 : the saddle mass
- p_0, v_0 : the contact point position and velocity
- p_1, v_1 : the wheel c.m. position and velocity
- p_2, v_2 : the saddle c.m. position and velocity
- r_1 : the wheel radius
- r_2 : the rod length
- u : the wheel torque
- α : the saddle angle
- δ : the slope angle
- ψ : the wheel angle
- w_B : half width of area B

Kinematics and Dynamics

The position and velocity of the c.m. of the wheel and the c.m. of the saddle are given as follows.

$$p_0 = r_1 \psi \begin{pmatrix} \cos \delta \\ \sin \delta \end{pmatrix}, p_1 = p_0 + r_1 \begin{pmatrix} -\sin \delta \\ \cos \delta \end{pmatrix},$$

$$p_2 = p_1 + r_2 \begin{pmatrix} \sin \alpha \\ \cos \alpha \end{pmatrix}$$

$$v_0 = r_1 \dot{\psi} \begin{pmatrix} \cos \delta \\ \sin \delta \end{pmatrix}, v_1 = v_0, v_2 = v_1 + r_2 \dot{\alpha} \begin{pmatrix} \cos \alpha \\ -\sin \alpha \end{pmatrix}$$

The equations of motion of the moon cycler are given as follows.

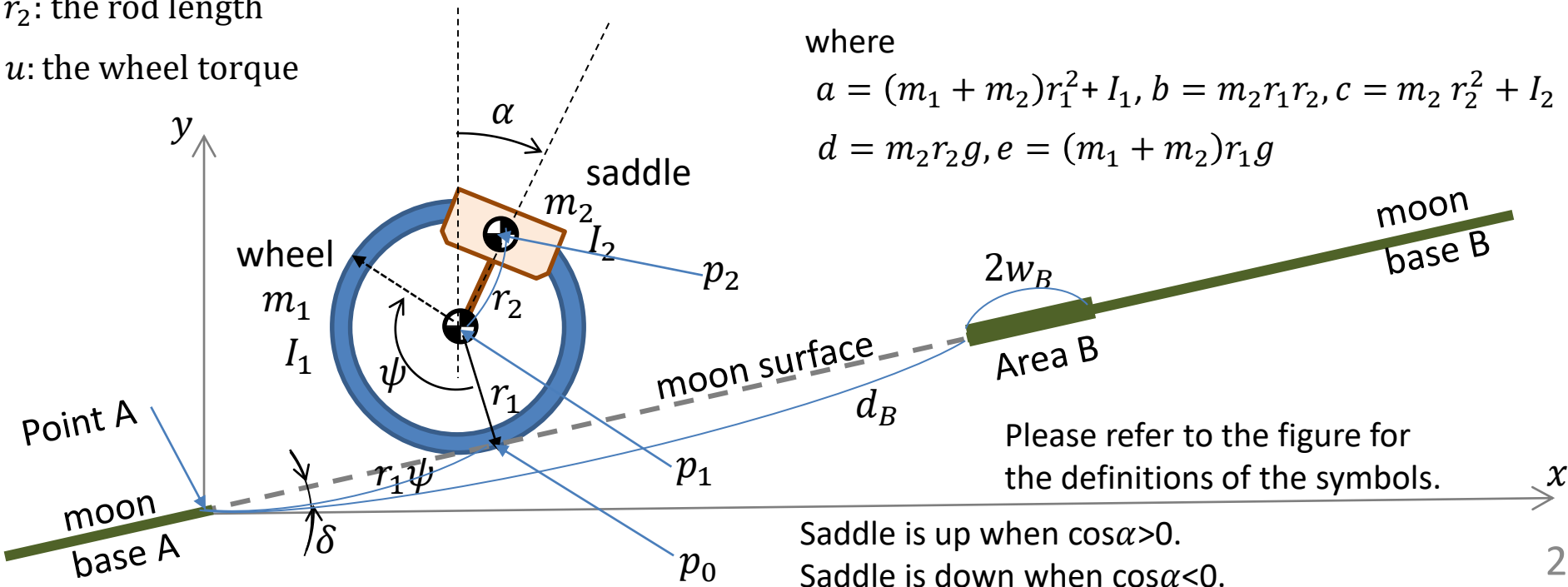
$$a\ddot{\psi} + b\cos(\alpha + \delta)\ddot{\alpha} - b\sin(\alpha + \delta)\dot{\alpha}^2 + c_1\dot{\psi} + e\sin\delta = u$$

$$c\ddot{\alpha} + b\cos(\alpha + \delta)\dot{\psi} + c_2\dot{\alpha} - d\sin\alpha = -u$$

where

$$a = (m_1 + m_2)r_1^2 + I_1, b = m_2r_1r_2, c = m_2r_2^2 + I_2$$

$$d = m_2r_2g, e = (m_1 + m_2)r_1g$$



Please refer to the figure for the definitions of the symbols.

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	: current time [s]
psi	: wheel angle [rad]
alp	: saddle angle [rad]
dpsi	: wheel angular velocity [rad/s]
dalp	: saddle angular velocity [rad/s]
B_goal	: goal position, range, and stay time [m],[m], [s]

The output variable from “Control.m” is as follows.

u	: commanded wheel torque [Nm]
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The torque applied to the wheel is limited within $[-trq_max, +trq_max]$, where trq_max is given by $2m_2r_2g$.

The applicant can use a single global variable named “user”.

The applicant can get values of constant listed in the table of slide “Sample Settings” via global variable “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 2011a, 2011b, 2012a, 2015b, 2016b, 2018a, 2019a, 2019b, 2020b, and 2021b.

Sample settings

	Symbol	Description	Value
Constant	c_1, c_2	the wheel and link viscous friction coefficient	0.3, 0.1 Nms*
	d_B	distance of the area B from point A	1.5 m*
	g	the gravity constant on the moon surface	9.81/6 m/s2*
	I_1	the wheel inertia	0.4e-1 kgm2
	I_2	the saddle inertia	0.4e-2 kgm2
	m_1	the wheel mass	2.0 kg*
	m_2	the saddle mass	2.0 kg*
	r_1	the wheel radius	0.5 m*
	r_2	the rod length	0.4 m*
	t_{s_min}	the minimum stay time within area B	5 s*
	w_B	half width of area B	0.10 m*
δ	the slope angle	0 deg*	
Variable	p_0, v_0	the contact point position and velocity	(0,0) m, (0,0) m/s (at t=0)
	u	the wheel torque	0 Nm (at t=0)
	α	the saddle angle	-180 deg (at t=0)
	ψ	the wheel angle	0 deg (at t=0)

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