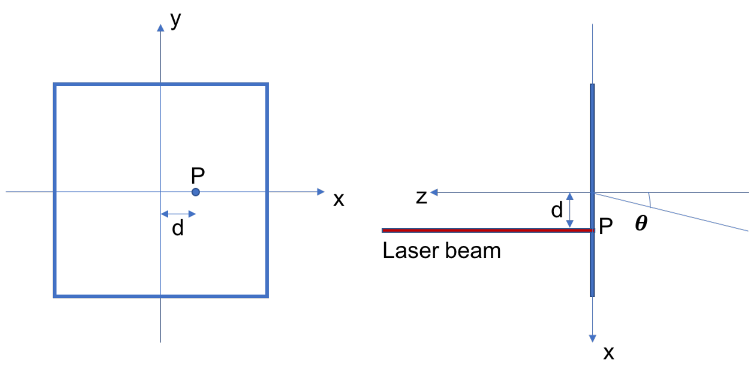
Space Missions and Systems

Homework#2 2017 – ATTITUDE CONTROL (of a science fiction system)

It has been proposed to use a powerful laser system to accelerate a spacecraft to relativistic velocities. In order to work, the laser beam should have a power of 300 TW and ideally hit a perfectly reflecting panel exactly at the center (assuming that the center of mass and the center of the panel lay on the axis of the laser beam). In general, the shaped laser beam will be slightly off-pointed, so that the center of pressure (*P*) will not coincide with the center of the panel. Hence a torque will be generated. Assume that the laser beam can be modeled as an infinitely thin pencil beam hitting the panel in *P*.



The spacecraft control system is made up by three reaction wheels (RW) aligned to the spacecraft body axes. The RWs have null initial angular velocity, moment of inertia I_W = 0.5 kg-m^2, angular momentum storage capacity ± 5236 N-m-s at 10000 rpm, and gross reaction torque ± 5.4 N-m. The maximum power available to the RW system is 120 W. The electric equations of the RW are:

$$i_W = \frac{T_c}{K_M}$$

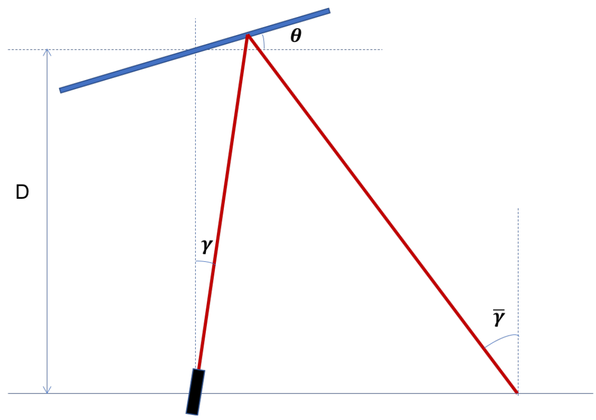
$$P_W = V_M i_W = (K_W \omega_W + R_W i_W) i_W$$

where K_M = 1.866 N-m/A, K_W = 0.0081 V/rpm, R = 2.25 Ω. The reaction wheels are aligned with the spacecraft axis.

Assume that the spacecraft moment of inertia is I_y=50000 kg-m^3 and that the reflecting panel is a perfect mirror. The RW is turned on with the goal of keeping the angle θ equal to 0°. The RW is controlled by a PD control law with k_p=50 N-m/rad and k_d=3162 N-m-s/rad. The initial conditions are θ=0 deg, and $\dot{\theta}$=0 deg/s.

1) Write the equation of θ angle and RW dynamic;
2) Plot the θ angle and the angular velocity (around the same axis), the RW's angular velocity, the RW's angular momentum, the control torque, and the RW's electrical power assuming $d=d_0 \sin(0.004\ t)$ where $d_0=10^{-6}$ m;
3) Plot the pitch angle and the pitch angular velocity, the RW's angular velocity, the RW's angular momentum, the control torque, and the RW's electrical power assuming $d=d_0\sin(0.004\ t)+d_1$ where $d_0=10^{-6}$ m and $d_1=10^{-6}$ m;
4) Provide the RW's saturation time for the cases 2 and 3;
5) Comment on the results.

Now let us make the (unrealistic) assumption that the pointing angle γ of the laser beam can be controlled through a RW. In order to simplify the spacecraft design, we wish to attempt a control of the spacecraft attitude by controlling the angle γ (see figure below), without the need to use wheels onboard.



The RW on ground has initial null angular velocity, moment of inertia I_W=1 kg-m^2, angular momentum storage capacity ± 418.88 N-m-s at 4000 rpm, and gross reaction torque ± 10 N-m, K_M= 0.0031 N-m/A, K_W= 0.0405 V/rpm, R = 7.5 Ω. The maximum power available to the RW system is 1 MW. Assume that the moment of inertia of the laser pointer is I_z=5000 kg-m^3. The RW is turned on with the goal of keeping the θ angle of the spacecraft and its time derivative $\dot{\theta}$ equal to 0°. Suppose that

- The distance from the spacecraft is D=300 km
- The measurement of the angle $\bar{\gamma}$ is available (e.g. by a set of detectors near the laser beamer measuring the return beam)
- $\gamma(0)$ is 2x10^{-10} deg and initial angular velocity (along the same axis) = 0 deg/s.

Tasks:

1) Write the equations of the system dynamics;
2) Try designing a control law able to keep the angle θ to the target value;
3) Plot the spacecraft θ angle and its time derivative $\dot{\theta}$, the angle γ and its time derivative, the RW's angular velocity, the RW's angular momentum, the control torque, and the RW's power absorption;
4) Comment on the results.

Hints: According to the Einstein's theory, each photon carries energy given by $E=hc/\lambda$, where h is the Planck's constant, λ is the wavelength, and c is the speed of light. The number of photons needed to carry 1 J is the inverse of E. If the laser pointer has a power rating of P = 1 W, or 1 Joule per second, this means that every second a laser pointer emits a number of photon equal to $n=P/E$. According to the Einstein's theory, the momentum of a photon is $p=h/\lambda$. The rate of momentum created per unit time is $dp/dt=np$.

Email a **working computer code** (Matlab, Python, Fortran 77 or 90 or 96, C or C++) and a **short note** (in pdf!) with the mathematical procedure, results, comments and figures by **Tuesday May 30 23:59:59 UTC** to
luciano.iess@uniroma1.it **AND** mircojunior.mariani@uniroma1.it .

In the note indicate your FIRST NAME, LAST NAME, AND STUDENT ID (aka “numero di matricola”). Be concise and go straight to the point.