CAD Assignment

The Segway is a two-wheeled self-balancing electric vehicle, as shown in Fig. 1. In this problem, we only consider the translational motion of the vehicle and rotation of the control panel bar. The mechanical system (Fig. 1) can be modeled as an inverted pendulum shown in Fig. 2.

For a driver with mass m, height $2L$ (effective moment of inertia $I = mL^2/3$), assume the mass of the control panel bar can be neglected compared to the driver and the inclination angle is small.

(1) System Modeling

(a) Write out all the equations of motion. Assume there is only static friction for non-slip rolling; there is no damping in the system.

(b) Show that the block diagram for the system has the form suggested in Fig.3, find G_1, G_2 and G_3. State any assumptions that you have made in deriving the block diagram (Y represents the cart position, Θ represents the pendulum angle).

(c) Derive the state-space representation of the system.

(d) Assume that the Segway has a total mass M of 47.7kg, the drive is 60 kg with a height $2L$= 170 cm respectively. Build the model in Simulink with both transfer function and state space.

(2) Controller Design

(a) With the block diagram of the control system shown in Fig. 4 (**X** is the state variable, G_c is the transfer function of controller, D is the disturbance force), design a PID controller and tune the PID parameters to keep the orientation of the inverted pendulum ($-\pi/6 \leqslant \theta \leqslant \pi/6$) to settle within 1 second to a sudden change (impulse) in disturbance. (Refer to Fig. 5 for closed-loop system in Simulink)

(b) For R(s) being a step change of −20°, simulate the system output.

(c) To check the robustness of your controller, change the weight of the driver by ± 20% but with the same height to see if your controller still works.

(d) Download “Inv_Pen.fig”, “Inv_Pen.m” and put them in the folder where your Simulink model was saved. Run “Inv_Pen.m” and see the animation. (save the simulated results of cart position, pendulum angle (in degree), cart velocity and pendulum angular velocity to variables “y”, “theta”, “v”, “w” respectively).

Notes: The transfer function of a PID controller can be obtained as,

$$G_{PID}(s) = K_P\left(1 + \frac{1}{T_I s} + T_D s\right)$$

A low pass filter can be added to replace the derivative term to avoid ‘set point kick’,

$$G_{PID}(s) = K_P\left(1 + \frac{1}{T_I s} + \frac{T_D s}{1 + \gamma T_D s}\right)$$ where, γ is a constant usually around 0.1.

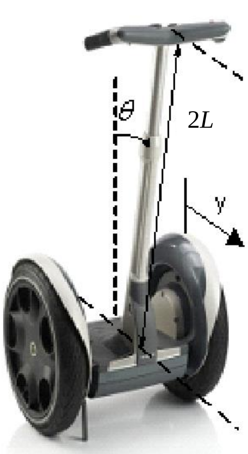

Fig. 1 Mechanical system

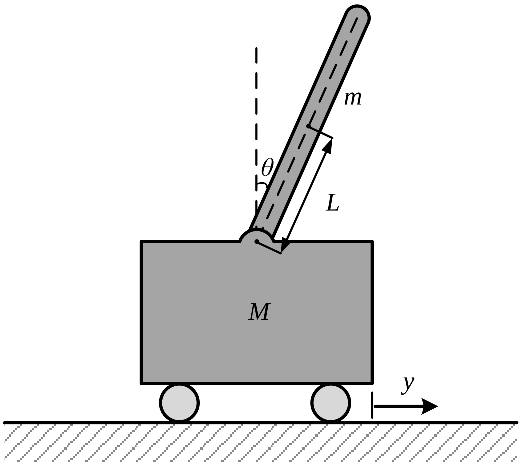

Fig. 2 Schematic of inverted pendulum

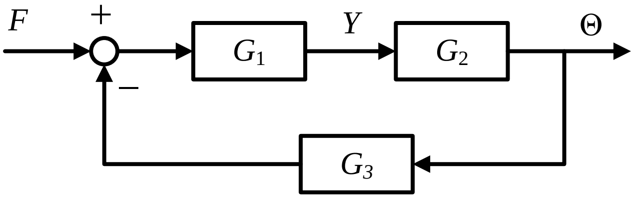

Fig. 3 Block diagram of the inverted pendulum

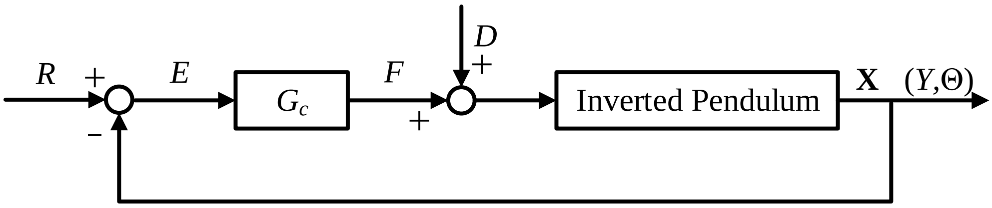

Fig. 4 Block diagram of control system

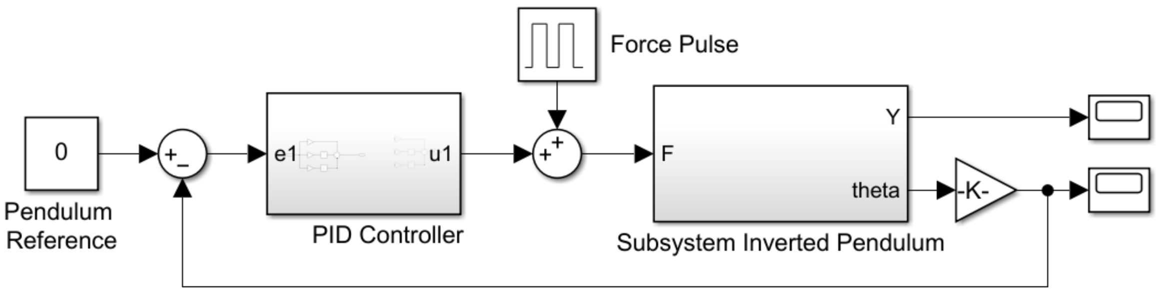

Fig. 5 Simulink model (for reference)