ELEC-E8123 Networked Control Systems

Group Project:
Controlling the Inverted Pendulum on a cart through communication channels

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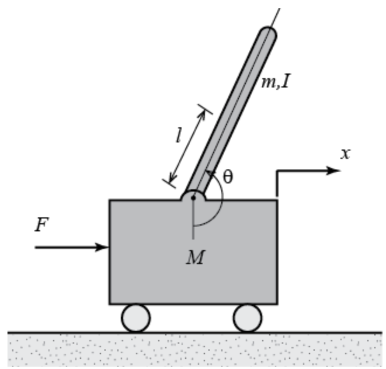
The group project should be returned electronically by Friday, 08.03.2018 at 23:55 in MyCourses portal ("Assignments").

The aim of the project is to design a Networked Control System for controlling the arm of a disk drive, by carefully designing the controller, choosing the sampling rate and the frame rate (if possible). The system in this project consists of an inverted pendulum mounted to a motorized cart. This system is unstable without control, that is, the pendulum will simply fall over if the cart isn't moved to balance it. It is very common in classical control textbooks, but they do not consider the communication effects.



For this system, the control input is the force F that moves the cart horizontally and the outputs are the angular position of the pendulum θ (angle from the vertical) and the horizontal position of the cart x. For this system, we assume the following quantities:
- mass of the cart, $M = 0.5$ kg
- mass of the pendulum, $m = 0.2$ kg
- coefficient of friction for cart, $b = 0.1$ N/m/sec
- length to pendulum center of mass, $l = 0.3$ m
- mass moment of inertia of the pendulum, $I = 0.006$ kg m^2
- coefficient of gravity, $g = 9.81\text{ms}^{-2}$

The linearized equations of motion of the system are as follows

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & \frac{-(I+ml^2)b}{I(M+m)+Mml^2} & \frac{m^2gl^2}{I(M+m)+Mml^2} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \frac{-mlb}{I(M+m)+Mml^2} & \frac{mgl(M+m)}{I(M+m)+Mml^2} & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{I+ml^2}{I(M+m)+Mml^2} \\ 0 \\ \frac{ml}{I(M+m)+Mml^2} \end{bmatrix} u$$

$$\mathbf{y} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix}$$

While conceptually simple, the highly unstable dynamics of the inverted pendulum make it a representative example of control system that requires fast control cycles, and subsequently low-latency communications, especially when being controlled over a wireless channel. Note that this system is conceived as a Network Control System (NCS) which contains a sensor that measures state information, which is transmitted to the controller over a (wireless) channel. The state information is used by the controller to determine control policies for the NCS. The communication is assumed to be over a network from the sensor to the controller and ideal from the controller to the system (actuator).

Tasks:

1. By applying a zeroth order hold (ZOH) on the continuous dynamics with a state sampling rate h seconds, obtain the discrete linear dynamic matrices of the pendulum system.

2. Investigate the performance of the system by designing a controller (you have to decide what type of controller to design) for different types of networks as modeled in TrueTime (`http://www.control.lth.se/truetime/`) simulator. Specifically, we want to consider 2 types of networks: wired and wireless.

    - For the wired network, you should consider the Controller Area Network (CAN bus) or FlexRay (both available in the TrueTime simulator), or both.
    - For the wireless network, you should consider 802.11b WLAN or/and 802.15.4 ZigBee.

    The design parameters are:

    - The controller: the purpose is to make a controller with good performance and robustness to packet losses and delays.
    - The sampling period h: ideally it should be as small as possible, but this is limited by the communication limitations and quantization.
    - The frame size: should be decided (if possible) on the quantization levels and the size of the sampling period, given the transmission rate.

3. At the end, the designs will be tested with respect to (w.r.t.) how well it can follow the command signal, while keeping the overshoot as small as possible (ideally less than 5%).

Deliverables:
Each team should submit a report and simulation files. The report should be written in LaTeX (IEEE 2-column format) and should be *concise* and *precise*. The teams should describe the designs they chose, the reasoning behind it and provide evaluation of the performance for a step response.