Rectilinear Position Control Experiment – MAE171a

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1 Learning objectives

- LLO1: Gain practical experience with the physics and modeling of dynamical systems
- LLO2: Gain practical experience with the design and application of digital control algorithms
- LLO3: Be able to apply dynamical systems and control theory that was previously seen in lecture courses, including Bode plots, step response functions, and the root-locus method.
- LLO4: Demonstrate the course learning objectives within a dynamical systems and controls physical setting.
- LLO5: Gain experience comparing experiment with reduced order theoretical and simulation models.
- LLO6: Be able to construct your own dynamical systems state space analysis and simulation code.

2 Aim

We will study a forced mechanical system that can be described in terms of reduced-order inertial, spring, and damper elements. The system is physically composed to two carts connected via springs, forming a two degree of freedom (2DOF) system, as shown in Fig. 1. **The aim of this experiment is to develop and validate a control algorithm that prescribes a step rotation of a cart in the 2DOF system with less than 25% overshoot that reaches a 2% settling time as fast as possible.**

3 Procedure

- Review the "position control ECP software manual.pdf" document and note the existence of the "rectilinear control hardware manual.pdf" document.
- With the help of your TA, adjust the number of masses on the carts, as shown in Fig. 1. You are free to choose any configuration of masses you wish.

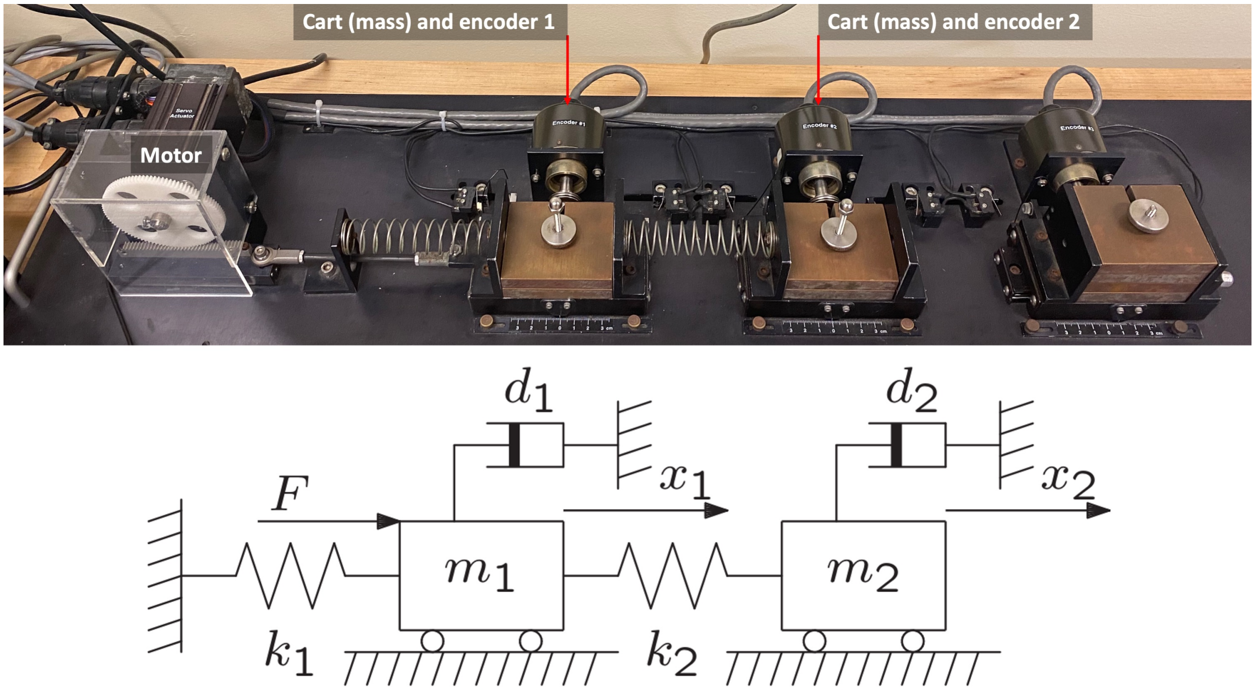

Figure 1: Photo (top) and reduced-order model (bottom) of the rectilinear position control system.

- Write the equations of motion for your 2DOF system in terms of the following quantities and their corresponding units: time t [s], relative position of cart 1 x_1 and cart 2 x_2 [counts], force F [V], stiffness k_1 and k_2 [V/counts], damping d_1 and d_2 [V·s/counts], and masses m_1 and m_2 [V·s^2/counts]. Force is applied to the first cart via a motor.

- Create list of open-loop (no control, force input and position output) 1DOF step response experiments you will do to estimate the unknown parameters (m_1, m_2, k_1, k_2, d_1, and d_2) of the 2DOF system. This can be done by holding one mass still and perturbing the other to create 1DOF subsystems, and removing the spring temporarily between the two carts. The position of both carts are obtained via encoders. **You may assume** $k_1 = k_2$.

- Perform the 1DOF open-loop step response experiments several times (min. 5x) and to obtain the system parameters. **Ensure your open loop voltage is less than 0.75 V**. Mean value and standard deviation will have to be part of your report. **Before peforming both open and closed loop experiments, be sure to choose "Rephase motor" and "Reset controller" under the "Utility" menu. There is an issue when the cart hits the limit switches, it modifies the encoder calibration. It is important that your open loop and closed loop experiments are consistent.**

- When saving your measured data from your experiment to a text file (extension `.txt`), use the `export raw data` option in the `ECP` software. Do not start the filename with a number and make sure you save your data under your working directory!

- Write a Linear Time Invariant (LTI) model in Matlab to simulate the step response of your 1DOF systems. You may also use the instructor provided example codes (StateSpaceandControlExample_rectilinear.m or the older but more sophisticated, maelab.m) for this and later portions.

- Validate your estimated parameters by comparing the measured 1DOF step responses with simulation.

- Measure the step response of your 2DOF system.

- Write a 2DOF version of your LTI system and compare the measured step response of your system to the simulated one.

- Measure the frequency response of the 2DOF system by sweeping the frequency of a sinusoidal excitation with the ECP system. Compare the frequency response to the Bode plot simulated using your LTI system. This can be thought of as an alternative or complementary method to the series of 1DOF experiments for identifying your 2DOF system's parameters. For instance, you have 6 unknown parameters, so you can use a nonlinear fitting algorithm, such as Matlab's nlinfit() to either fit the analytical transfer function of your 2DOF system or the amplitude spectrum of the Bode plot directly.

- Use your LTI model to design a P-controller and identify the k_p^{max} (where k_p denotes the proportional gain) before the closed-loop system response becomes unstable. Design a P-controller that is stable and has gain $k_p < k_p^{max}/2$, with the objective of **prescribing a 1000 count step to one of the carts**. Use the same target translation count for later controller designs, and make sure k_p**,** k_d **and** k_i **satisfy the following bounds to avoid excessive control signals:** $0 < k_p < 1$**,** $0 < k_d < 0.02$ **and** $0 < k_i < 1$. You can only use the position of one cart for feedback control of the motor. You are free to choose which cart will be used in your feedback control and you must state in your report which was used. When using the first cart (encoder 1) for feedback, the type of control is called co-located (as force location and position measurement are at the same location). When using the second cart (encoder 2) for feedback, the type of control is called non co-located.

- Implement your P-controller and test it's response with the `ECP` software. When implementing your controller, be careful – **the feedback system might become unstable, and in that case, turn off the controller using the red button the ECP unit as soon as possible**. Perform closed-loop step experiments and compare with your simulation. **Important note: The rectilinear control system often flips the polarity (sign) of all three gains together. Check with** k_p **only to see if the controller is pushing the cart away from your target instead of towards.**

- Design a PD or PID-controller with the objective of a prescribed step response of one of the carts, satisfying the design requirements of small-as-possible steady-state error, less than 25% overshoot, and fast as possible convergence to 2% settling time, and **avoiding control signal saturation (± 5 V), and simulate the controlled repsonse of your system**. When designing this and the PID controller, heuristic tuning rules such as Ziegler and Nichols can be used. Given that you have an efficient computational model, parameter studies may also be conducted. Alternatively, stabilizing controller can be found via the root-locus, Nyquist, or frequency domain methods. You may also use the Matlab function pidtune() for comparison.

- Using the `ECP` software, measure and compare the closed-loop step response with your simulations.
- Evaluate the final design of your controller via sensitivity analysis. Measure the change in overshoot and settling-time by performing at least three experiments in which the inertial elements have been slightly changed.