1 General Guidelines

Three projects are available, as described below. Each project will be carried out by a group of students. Only one report per group will be submitted. Groups will be assigned during class time. Projects have a set of minimum requirements, but they are open-ended. Students are encouraged to expand their experiments and analyses beyond the minimum requirements, as these activities will contribute to making a solid final report and presentation. A high standard will be used in grading the final project. Any hardware problems that could prevent achievement one or more of the minimum requirements must be clearly identified, and suggestions must be offered for solving them. Finally, the project descriptions given below are not step-by-step recipes. Constant communication and coordination with the instructor will be required during the project.

1.1 General Objectives

The objective of these projects is to apply modeling, simulation and control skills at all levels, that is, mathematical models and analytical tools will be followed by computer simulation and hands-on implementation. The projects are not just “make-it-work” attempts, nor are they purely theoretical. Success will be measured not only by the end result, but by how theory is applied to tune the controllers and analyze the results.

2 Project A: Analog and Digital PID Control of a DC Motor

The goal of this project is to demonstrate velocity control of a DC motor (the same one used for Lab 3) by analog and digital means. The previously obtained transfer function will be compared to measurements using a spectral analyzer. Upon successful model validation, an analog PID controller will be tuned and simulated in Matlab/Simulink. The PID controller will be tested for transient response and disturbance rejection capabilities, taking into account motor current ratings and other practical restrictions. The PID controller will be built using Op Amps and tested with the actual DC motor. The above will then be repeated for a digital PID controller, which will be implemented using the LabJack USB interface. Note that the LabJack interface has serious sample rate limitations (minimum sample period is 0.02 seconds). You will need to downgrade the control performance specifications accordingly during the simulation phase.

2.1 Minimum Requirements

1. Run a transfer function estimation using the HP Spectral Analyzer and compare it to the time-based model obtained in Lab 3. Check the open-loop transient response of the DC motor and fine-tune the math model to a reasonable bandwidth.

2. Build a Simulink diagram with the motor transfer function and a PID controller. Include a disturbance torque which adds to the induced torque $\alpha_i$ and friction torque. You will have to estimate the torque that can be applied with the wheel in the hardware setup. Include also blocks that limit and monitor the voltage and current circulating through the armature. Limit the voltage to 24 V and the instantaneous current to 0.5 A.

3. Tune the analog PID controller to give a “good” performance that is possible to obtain under the above limitations. You should evaluate settling time, overshoot, steady velocity error due to disturbance (if using a type zero control loop) or disturbance recovery time (if using type 1).

4. Design an Op-Amp circuit that will implement the PID control law. Make sure the Op Amps are not saturated. The reference input should be compatible to the output impedance of a signal generator.
(please consult the instructor on this). You should plan for gain adjustments via variable resistor. If you need additional electronic components, every effort will be made to purchase them.

5. Revise the simulation diagram based on real components and re-tune the PID if necessary.

6. Put the system to work and demonstrate the controller in two ways: following a square wave (tuned using the step response) and disturbance rejection (run at constant reference velocity and turn the wheel to apply disturbance. The controller should “fight”, trying to maintain speed.)

7. Obtain a ZOH discrete equivalent of the DC motor model using a symbolic sampling period $T_s$.

8. Build a simulation diagram in Simulink showing the continuous-time plant and all data acquisition hardware. Include current and voltage limits as in the analog case.

9. Tune a digital PID controller assuming the maximum sample rate (corresponding to a period of 0.02 seconds). Evaluate the performance as in the analog case, including quantization.

10. The actual implementation will be carried out via a Matlab m-file rather than a Simulink diagram. Write an M-file that will carry out sampling, control calculation and control output. Try to write the M-file so that the sample rate can be adjusted (the file must choose the appropriate gains). The reference output will be internally generated (within the M-file) but easy to change.

11. Demonstrate digital closed-loop operation and note the limitations arising from slow sampling.

12. Write a report detailing every aspect of the project.

13. Present your work to the class and demonstrate the hardware.

3 Project B: Interfacing and Control of a Hard Disk Drive

This project places emphasis on sensor interfacing, but basic closed-loop operation must also be demonstrated. An optical sensor is available to measure the position of the drive arm. Part of the project involves designing and building a sensor mount and analog interface. The transfer function from voltage to arm position will be obtained to the maximum possible bandwidth using the spectral analyzer. The model will then be used to design and build an analog PI controller designed to track a fast square wave.

3.1 Minimum Requirements

1. Design a simple sensor mount allowing fine adjustments. It is recommended that the sensor be attached to the central hub of the drive, taking advantage of the rotation to find the best orientation for the sensor. You must include a simple way of stopping the central hub from moving once the best position has been determined. Soldering of wires to the sensor is a delicate operation due to the small scale, and should be done by a Fenn College technician. Coordinate with the instructor for this step.

2. Run a transfer function estimation using the HP Spectral Analyzer. Use the physics of the drive along with direct measurement of impedance and resistance to fit a transfer function to the experimental measurement.

3. Build a Simulink diagram with the drive transfer function and a PI controller. Include also blocks that limit and monitor the voltage and current circulating through the armature. Consult the instructor for voltage and current limits.

4. Tune the analog PI controller to give a “good” performance that is possible to obtain under the above limitations. You should evaluate settling time and overshoot.

5. Design an Op-Amp circuit that will implement the PI control law. Make sure the Op Amps are not saturated. The reference input should be compatible to the output impedance of a signal generator (please consult the instructor on this). You should plan for gain adjustments via variable resistor. If you need additional electronic components, every effort will be made to purchase them.

6. Revise the simulation diagram based on real components and re-tune the PI if necessary.

7. Put the system to work and demonstrate the controller by following a square wave (tuned using the step response).

8. Write a report detailing every aspect of the project.

9. Present your work to the class and demonstrate the hardware.
4 Project C: Modeling and Vibration Control of a Piezo Beam

In this project you will obtain a mathematical model of a cantilever beam fitted with a piezoelectric actuator and a strain sensor. The objective is to obtain a basic model of the forced vibrations of the beam and use it to implement an active vibration control system. This project is reserved for students who had exposure to modeling of beams using modal analysis, in particular using bond graphs (MCE503). A strain gage and a piezoelectric sensor will be used to measure the vibrations of the beam, while special drive electronics will be used for the piezoelectric actuator. The active control stage of the project will be done digitally, with a National Instruments M-Series DAQ, capable of very fast sampling. Either LabView or Matlab/Simulink can be used to develop the control interface. The transfer function from actuator voltage to beam tip deflection will be obtained by analytical methods (first two modal frequencies only) and verified/adjusted with the spectral analyzer. The model will then be used to design a PID controller to actively cancel vibrations.

4.1 Minimum Requirements

1. Coordinate with the instructor and the machinist (Dave Epperly) to build a support that allows to mount the beam with the thin dimension parallel to the table.

2. Derive a dynamic model of the beam using the first two modal frequencies. The model must be capable of describing the tip displacements as a function of actuator voltage. Additionally, equations must be provided to convert a strain gage or piezoelectric sensor voltage into tip displacement.

3. Measure the first natural frequency of the beam as done in MCE503 (record the free oscillations and measure the frequency). Compare with model predictions.

4. Compare the tip displacements predicted from each sensor.

5. Use the spectral analyzer to compare the theoretical and experimental transfer functions.

6. Obtain a simulation model of the beam under analog PID control of tip vibrations. Specifically, the beam model should have the strain at the strain gage location as output. The output equation will be nonlinear. Linearize it considering small strains around zero. The controller block should calculate the tip displacement from the strain gage reading and use the tip displacement in the calculation of the control law.

7. Tune the PID controller and simulate the performance of the vibration control system. Include voltage limits in the simulation (consult amplifier ranges). Use the time required for the vibrations to die out (use a 2% criterion) as performance measure.

8. Implement the analog PID controller in a computer, using a sufficiently fast sample rate. Put the system to work and demonstrate the controller by giving an initial tip displacement and comparing the settling times with and without control.

9. Write a report detailing every aspect of the project.

10. Present your work to the class and demonstrate the hardware.

5 Schedule

Project work starts on 04-05-2006. A meeting of each group with the instructor is scheduled for the third week of April. Each group will present their progress to the instructor. This meeting will be considered to be part of Lab 4 for this semester (there will be an additional assignment for Lab 4). Presentations are scheduled for the week of May 1st. All reports are due on May 5th, 6PM. The final exam will be on Monday, May 8. Groups will coordinate with the instructor for lab time and equipment checkouts.