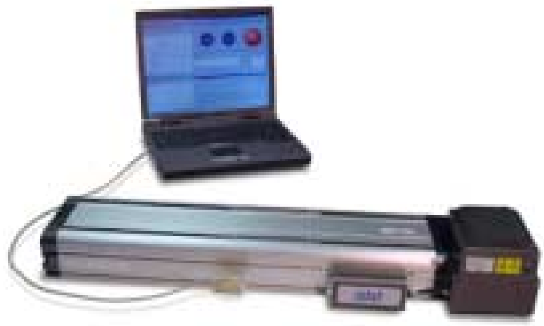
Midterm Project for

ee392m - Control Engineering for Industry

Problem description

The problem is to design a basic control system for the robotics linear motion module shown in the picture below. The module is used in semiconductor manufacturing applications.



The job consists of the following three tasks

Task 1. Design of main controller functions using simplified models

1. Servo feedback design. Use rigid body second-order dynamics model. Continuous time model, take sampling into account when defining the bandwidth. Make the controller design robust: take into account payload uncertainty, dynamics uncertainty (presence of flexible dynamics).
2. Path planning and feedforward. Use feedback loop model and controller design specs.
3. Validate the controller design using the detailed analysis model from Task 2.

Task 2. Formulate and implement detailed simulation model for analysis, V&V

Include the following pertinent detail in the model

- Saturation of actuators and sensors
- Velocity estimation from position measurement
- Digital sampling (2 msec)
- Sensor noise - quantization noise
- Structural flexibility

Task 3. Design and validation of the controller

The controller shall include the following three main parts

1. Setpoint tracking servo
2. Point-to-point motion manager: includes path planning
   - Feedforward computation can be either a part of the servo or of the motion manager
3. Control manager will provide high-level control mode change logic and user interaction

This task will also include

- Controller integration, use the Task 1 design
- Controller validation using the detailed analysis model from Task 2

Deliverables

Present results in a design report. The report would tentatively have the following sections

- Problem description
- Controller architecture and main modules
- System trade study: justify controller design parameter choice, is sampling time Ok?
- Detailed simulation model description
- Controller validation results
- Appendix: controller code

Model description

Core dynamics. Includes control/actuation, sensing, motor inductance, structural flexibility. The core linear model equations are as follows

$$m\ddot{y} + \beta\dot{y} + b(\dot{y} - \dot{x}) + c(y - x) = F$$

$$M\ddot{x} + b(\dot{y} - \dot{x}) + c(y - x) = 0$$

$$F = fI, \qquad T_I\dot{I} + I = gu$$

Add more detail including:

- Sampling
- Actuator saturation
- Sensor (position sensor only): sampling noise (repeatability), pre-filtering, saturation,
- Parameter variation (payload 0 to maximal, structural flexibility)

Optional:

- vibration generated during the motion, 0.5N excitation force amplitude

Use the following data when defining the model

System specifications for modeling	
Maximal Stroke	500 m
Payload	0-40 kg
Thrust	200 N
Repeatability	± 0.02mm
Maximum Speed	1.2 m /sec
Maximum Acceleration, no payload	16 m/sec^2
Module moving weight, no payload (motor inertia)	6 kg
Maximal slope for mounting	10 deg
Mechanical time constant: no payload, moving weight	0.1 sec
Electrical motor time constant	1 msec
Oscillations with full payload when stopped at full speed	10 Hz, ζ=0.3
Sampling interval in the digital servo	2 ms

Design of the control system

Sensor data/input ports/

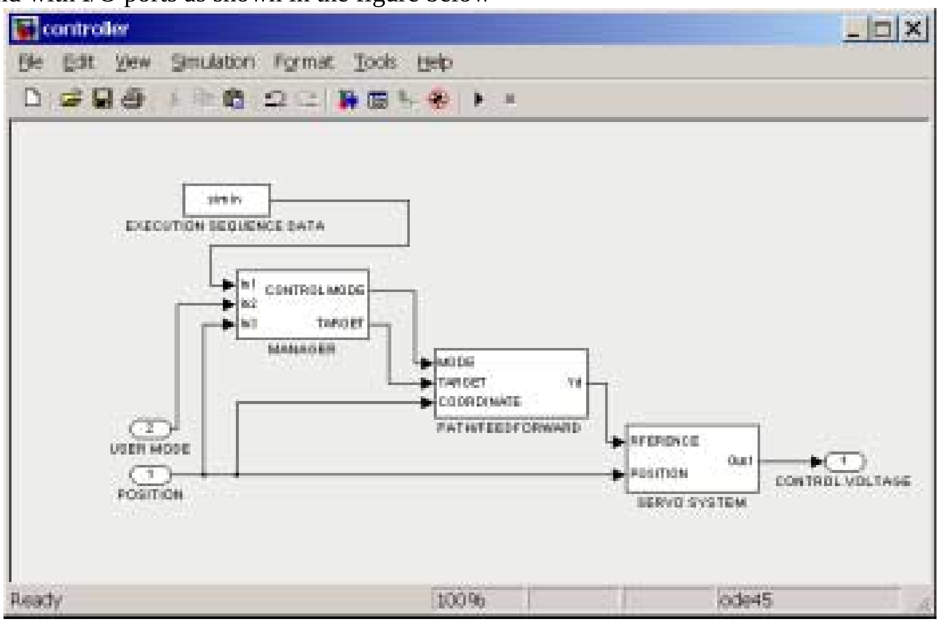
- the only measured variable is the motor position
- this is a digital measurement
- this measurement is subject to quantization noise with amplitude ± 0.02mm

Actuators/output ports/

- there is one actuator in the system, the electric motor
- the controller outputs control voltage ±10V through DAC

Controller high-level architecture:

- The controller will consists out of three main modules. Each module exchanges the data with some of the others and with I/O ports as shown in the figure below



- The **MANAGER** module will perform user interaction (processing user inputs) and processing task sequence from from a file. The user input can correspond to any of the following four commands: initialization/start/abort/restart
- The **PATH PLANNING/FEEDFORWARD** module will plan the motion path and compute feedforward. It will continuously provide the reference input to the SERVO SYSTEM
- The **SERVO SYSTEM** module will implement the feedback (servo) controller and output control voltage. It will use the actual and reference positions as an input

Control system design: constraints, specifications and suggestions

- The control performance is defined as = move time + transient time in the pick and place scenario
- This is for the worst case in the payload range
- Suggest controller design approach: PID + smooth path planning
- Might need to use some low-pass filtering, perhaps notch filtering
- Perform loop analysis: loop gain, disturbance rejection, sensitivity, etc.
- Sampling
- Use simple design model for controller design
- Use detailed analysis model for simulation, V&V, and uncertainty characterization in design

Test scenario

Task sequence:

- wake-up and initialization, go home
- home to 400mm full payload
- wait 1s (payload dropped)
- 400mm to 200mm, no payload
- wait 1s (pick payload)
- 200 mm to home half payload
- wait 1s (drop half pick full payload)
- home to 400mm full payload,
- abort in the middle of home motion
- restart the execution cycle
- back home, full payload
- home to 400mm full payload
- end of sim