ME6404 – Fall 2009
Lab 5: Multi-Mode Dynamics and Trajectory Tracking

Background:

In the previous labs, you have investigated the effects of various control laws on systems undergoing fairly simple motion. In many applications, more complex trajectories are required, creating additional control design requirements. In addition, the systems that you have controlled have contained one dominant flexible mode. Systems with additional modes further complicate the control design process.

Certain crane payload configurations, like the one shown in Figure 1, can result in double-pendulum, two-mode responses. Unlike single pendulum oscillations, these two-mode oscillations are nearly impossible to eliminate by a human operator without assistance. This makes proper control design, accounting for both vibratory modes, essential.

This lab will investigate these problems utilizing the portable tower crane. Each portion of the lab will involve navigation of the obstacle course shown in Figure 2. Note that some of the obstacles will require you to hoist over them, meaning the frequencies of your system are varying. Robustness to these changes should be part of your control design.

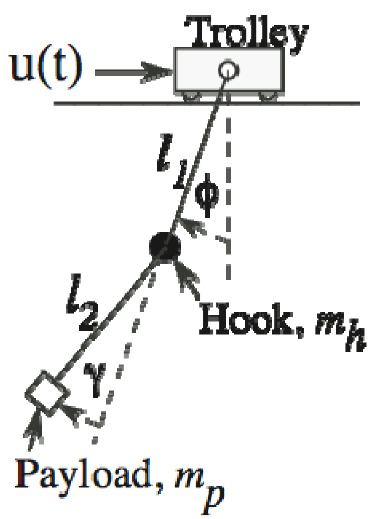

Figure 1: Double-pendulum Crane

Objectives:

1. Design and implement multi-mode input shapers for a multi-mode system with frequency variations as well as mode variations
2. Navigate an obstacle course using several control strategies, including preprogrammed trajectories

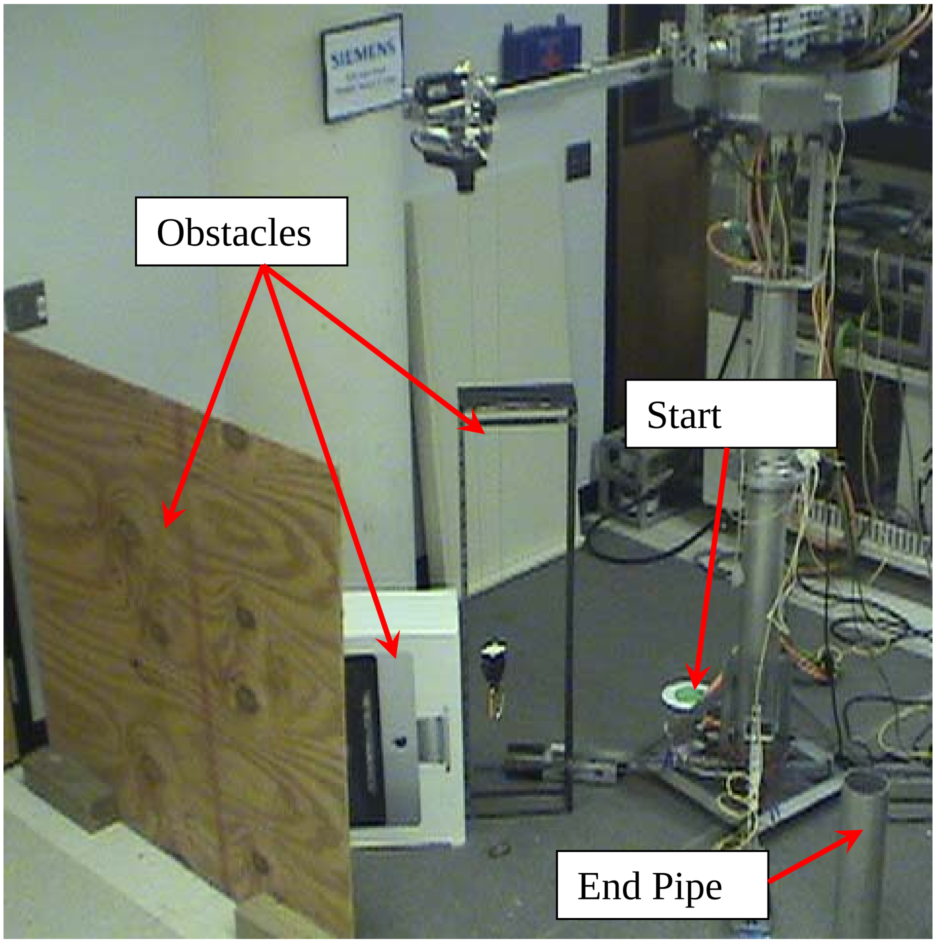

Figure 2: Picture of the Obstacle Course

Lab Procedure:

The main goal of this lab is to complete the obstacle course in the shortest amount of time and with the least number of obstacle collisions as possible. Your team will compete with other teams in the class to claim the bragging rights and prize(s). The rules of the competition are:

- Timing begins when the crane starts moving.
- The hook must start in its lowest position (with the carabiner just above the floor), anywhere inside the green start zone.
- The payload will be attached to the hook via. the carabiner. It will also be placed inside the green start zone.
- The hook must be hoisted and slewed CCW over and around the obstacles. The obstacles are – the high metal frame, the iMac box, the plywood barrier, the walls, and the floor. Collisions with any obstacle will be time-penalized by **2 seconds**.
- The end zone is a vertical end pipe. Timing stops when the payload is lowered within the end pipe and the top of the hook (where the reflective surface is) is submerged completely within the pipe (the top of the hook cannot hang on the rim of the pipe).
- Collisions with the end pipe will not be penalized.
- However, knocking the pipe over is an automatic disqualification.

- The location of all items in the obstacle course are marked by tape on the floor.
- The Hook weighs **190g**, and the carabiner weighs **20g**.
- There are two payloads – A and B. Payload A is **200g** with a rigging length of approximately **30cm**. Payload B is **330g** with a rigging length of approximately **15cm**.
- The competition will be held on **October 23rd**.
- There are three categories of competition. The team with the fastest completion time (including penalized times) wins each category:
    1. "Unassisted operator" – Each team will be represented by one person. This person must complete the obstacle course without input shaping – i.e. completely manual operation. Either the control box or the GUI is allowed.
       Payload A will be used for this category.
    2. "Assisted operator" - Each team will be represented by one person. This person must complete the obstacle course with the assistance of an input shaper designed by your team. Either the control box or the GUI is allowed.
       On competition day, after your team has programmed the input shaper into the PLC, either payload A or B will be assigned to your team by coin toss.
    3. "Preprogrammed trajectory" – Each team will compete by uploading a start-to-end trajectory to the portable tower crane. Once uploaded, the trajectory will be played and the crane will complete the obstacle course autonomously.
       On competition day, after your team has programmed the trajectory into the PLC, either payload A or B will be assigned to your team by coin toss.

Due to the payload attachment, the dynamics of the system is similar to a double pendulum. Furthermore, due to the randomly assigned payloads, as well as the need to hoist over obstacles, you will need to design an input shaper and autonomous trajectory that is robust to both factors. You can use any trajectory planning algorithm.

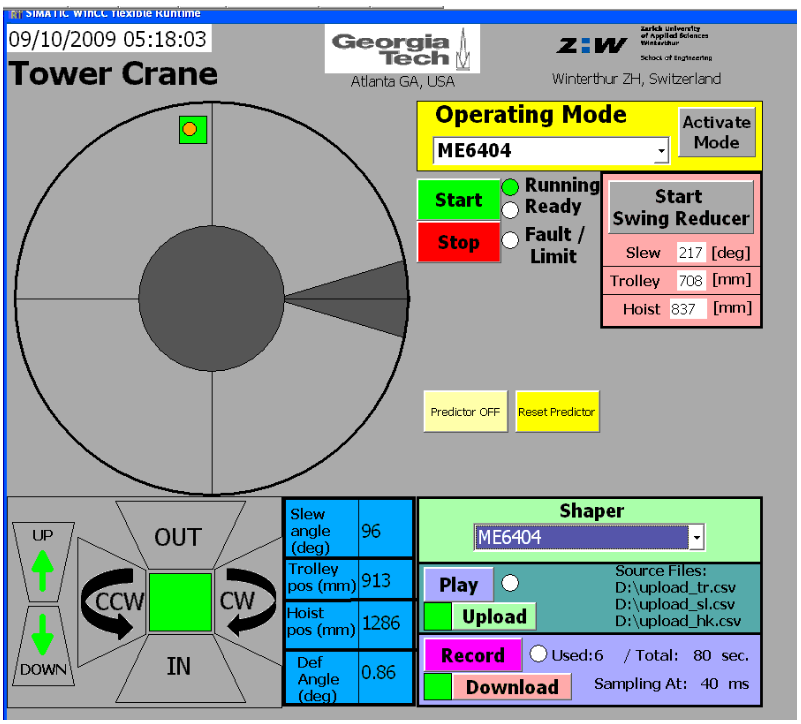

Figure 3: Tower crane GUI

Using the Tower Crane

A picture of the GUI is shown in Figure 3. You should be familiar with running the tower crane from previous labs.

- Use operating mode "**ME6404**". Click **Activate Mode.**
- Use the "**ME6404**" shaper.

Changing Input Shapers

Changing the parameters and downloading them to the PLC is done identically to the mobile boom crane.

- Open Simatic Manager on the desktop
- Open the project located in **D:\ME6404\Default_Tower_crane**
- Navigate to: **…\Default_Tower_Crane\Simatic 300(1)\CPU 317T-2 DP\S7-Program(1)\Blocks\DB6 ME6404.**
- After you open DB6 (data block), go to **View->Data View.**
- This data block contains the amplitudes and times of the shaper impulses. Modify for your own input shaper and click on the **Download** icon to download to the PLC.

Recording and Processing Data

Data recording on the tower crane is accomplished by clicking the **Record** button on the tower crane GUI. Up to 80 seconds of data can be recorded at a sampling rate of 40ms. Once the data is recorded, you must click **Download** on the GUI to transfer the data to the laptop for further processing in MATLAB. You should record data for your report.

Processing Data

Once the data is downloaded to the laptop, MATLAB is used to process the data. To do so, open MATLAB, navigate to **D:\ME6404** and type "**ME6404"**, and press return. This will begin to process the data. You will be asked for a filename to save your processed data. A figure of an overhead view of the path of the trolley and the hook took through the course will also be plotted.

Uploading Trajectory

Preprogrammed trajectories are implemented on the tower crane by using three text files with comma separated values (saved with .csv extensions). The header section of each file must remain unchanged. You can make the changes in Excel, but it must be saved in its original format. Each file contains velocity values representing **the percentage of the maximum velocity** for the given axis for each 20ms sample in time. You will need to figure out the maximum slew, radial, and hoist velocities of the crane. This information may or may not be useful.

The sign conventions for the velocities are shown in Table 1. Examples of each file can be found In the "**D:**" or the "**D:\ME6404**" directory. The filenames for each axis must remain the same; the names for each are shown in Table 2. In addition, the crane will only playback trajectories located in the main directory of the "**D:**" drive on the laptop computer.

The crane needs to be in **Ready** mode (press **Stop** on the GUI) before you press the **Upload** button. When uploading is complete, press **Start**, and then press **Play** to execute your trajectory. Press **Play** again to stop. The **upload files cannot be opened by other programs during uploading**.

Table 1: Trajectory Playback Velocity Conventions

Axis	Convention
Slewing	+ = Counter Clockwise
Trolley	+ = Out
Hoisting	+ = Up

Table 2: Trajectory Playback Filenames

Filename	Axis
upload_sl.csv	Slewing
upload_tr.csv	Trolley
upload_hk.csv	Hoisting

Lab Report:

Present your work and prove that you have met the objectives using **less than 3 pages of text (put all the figures at the end)**. Your report must include the following:

1. A summary of your team's efforts at navigating the obstacle course in all three competition categories. What were the challenges? What were your average times? Include results to support your claim.
2. Your choice of input shaper for the "assisted operator" category. Why did you chose the shaper you did? How did you design it?
3. Your trajectory design method with support for your choice. Why did you choose the trajectory planning method that you did? How did you design it?
4. You must show evidence that you have designed robustness for both
    a. The payload uncertainty
    b. The variation in frequency due to hoisting and lowering

You should think carefully about the plots that you include in your report – these must be neat, clear, non-redundant, and convey the desired message in an efficient manner. Furthermore, in the text, you should comment appropriately on the plots and say what is significant about them.