ME6404 – Fall 2009

Lab 2 – PI Control of the Minicrane and Remote Control of the Tower Crane

PI Control of the Minicrane

Background:

The motion of the *minicrane trolley* can be modeled as a mass-plus-friction plant under PI velocity control. The PI velocity control is provided by the *motor*, the *encoder*, and the *motor drive*. A block diagram of the entire system is shown in Figure 1.

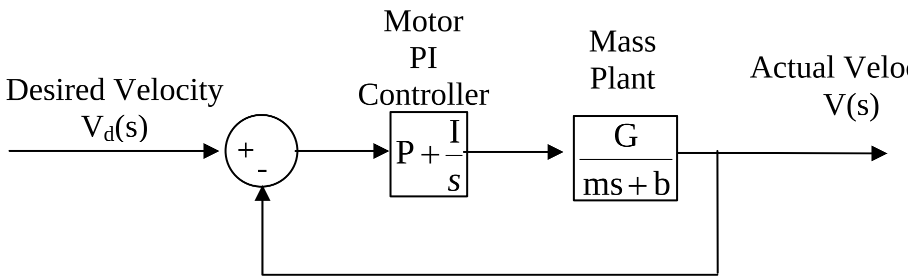


Figure 1: Trolley and Motor System Block Diagram

The transfer function of the system is:

$$G_{cl}(s) = \frac{V(s)}{V_d(s)} = \frac{GPs + GI}{ms^2 + (GP + b)s + GI} \qquad (1)$$

Proportional Control:

With only proportional control (equivalent to setting I=0) the closed loop system is reduced to a first order system. The effects of the proportional gain are shown on the root locus in Figure 2.

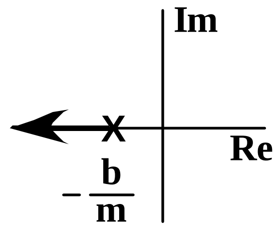


Figure 2: P Control Root Locus.

From the locus it is clear that increasing the proportional gain moves the system pole to the left, thereby creating a faster response. The root locus shows the system will never go unstable. In addition, the final value theorem can be applied to find the steady-state error of the system to a unit step input:

$$e_{ss} = \frac{b}{b + P} \quad (2)$$

From this equation we see that as P increases, the steady-state error approaches zero. The above results might suggest that P can be increased without bound to yield optimal results. However noise and unmodeled dynamics can cause stability issues that prevent very large values of P from being implemented in practice.

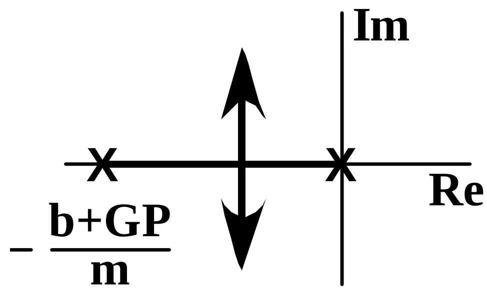


Figure 3: PI Control Root Locus.

Proportional-Plus-Integral Control:
With proportional-plus-integral velocity control the closed loop system is second order, with the transfer function given in (1). The benefit of using integral gain is its ability to eliminate steady-state error. Applying the final value theorem, the steady state error to a step command becomes:

$$e_{ss} = 0 \quad (3)$$

However, integral gain also has its drawbacks. We can use a root locus to plot the closed loop poles as a function of increasing I, as shown in Figure 3. This locus suggests that using integral control can create oscillations. Therefore the proper value of I must be chosen with care.

Trajectory used for this lab:
Has the form shown in Figure 4.

Figure 4: Trapezoidal Velocity Profile.

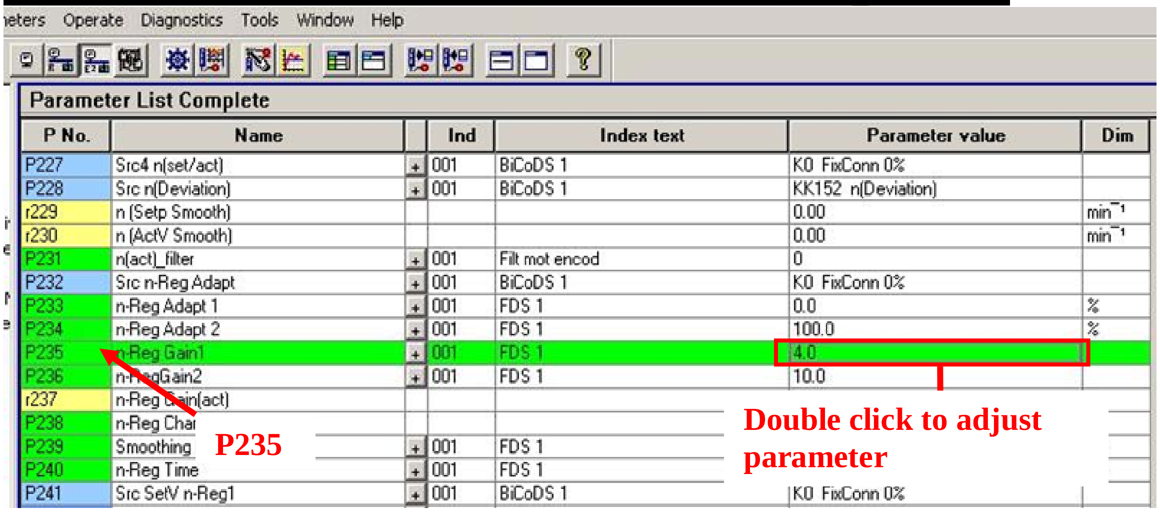
The time to initiate deceleration, t_m, will be chosen as 1 sec. The rise time, t_r, is 0.2 seconds in the trolley axis and 0.4 seconds in the bridge axis.

Objectives:

1. Find the optimal PI gains such that the crane <u>BEST TRACKS</u> the above velocity profile. It is also desired that the trolley and bridge traverse the same <u>MOVE DISTANCE</u> as the above desired command. Do this for both the *trolley* **<u>AND</u>** *bridge* axes.
2. Find the optimal PI gains that produce the <u>MINIMAL</u> payload residual oscillation when the system is given the above velocity profile.

Lab Procedure:

- Go to Simatic Manager using the desktop link
- Go to the menu on the left-hand side
- Click the "+" sign next to the first Master Drive
- Right click on the sub-menu item "Trolley Drive"
- Select PLC => Drive => Parameterization
- In the resulting window, under "Basic Functions", click "Direct to parameter list"
- **<u>This step is important! Click on View and then select the Online (RAM) option.</u>**



- For the P gain, find parameter P235. For the I gain, find parameter P240. (you can quickly find these by rapidly typing "p235" or "p240")
- Double-click in the respective box labeled "Parameter value"
- Enter the desired value and select OK
- The above procedure changes the P and I gains for the trolley
- For bridge gains, click the "+" sign next to the second Master Drive in Simatic Manager and repeat the procedure

Procedures for Data Retrieval:

- Download data from the minicrane using the same procedure as in Lab 1 (refer to lab 1 hand out). Be sure to select **6 channels, 40ms sampling rate** for recording options.

- Remember to press **ENTER** after typing the download path on the WinCC GUI. Then press the **DOWNLOAD** button.
- Ensure that the blue ethernet cable is connected to the laptop (This is needed for Matlab to check its license). Then open Matlab and change the current directory to d:\ME6404
- To analyze the data, execute the script **"newerPLCdata.m".** The program should prompt you to select your downloaded **.csv** data file. **Feel free to copy this script file and modify it to your own liking.**
- Plots of the recorded data for the camera on each axis, and the trolley motion for each axis appear.
- The data you require are available on the Matlab workspace:

```
'PLC_Time'     = time (s)
'TrDes'        = desired trolley velocity (RPM)
'TrAct',       = actual trolley velocity (RPM)
'TrCam',       = payload swing (trolley axis, rad)
'BrDes',       = desired bridge velocity (RPM)
'BrAct',       = actual bridge velocity (RPM)
'BrCam'        = payload swing (bridge axis, rad)
```

- Note that for the velocity data, 120rpm = 100% = .243 m/s

Lab Tasks:

Part 1: Finding optimal gains for velocity control of a mass

1. Optimize the P gain to achieve optimal tracking (use zero integral gain) for the trolley. **The proportional gain must lie between 0 and 6**. For each chosen gain plot the desired velocity (V_d), the actual velocity (V), and tracking error (V_d – V). Find the optimal P gain based on the background information and the observed tracking error results. Save all the data from each trial for later analysis and also write down any other observations. **This is a qualitative, non-exact process. Approximate the best gain using only 5 trials.**

2. Keeping the same P gain found above, find the optimal I gain to achieve the best trajectory tracking. **The integral gain must lie between 0 and 500 ms.** As before, plot the desired velocity, actual velocity, and tracking error. Find the optimal I gain based on the background information and the observed tracking error results. Save all the data from each trial for later analysis and also write down any other observations. **This is a qualitative, non-exact process. Approximate the best gain using only 5 trials.**

3. Repeat steps 1 and 2 for the bridge axis, **however the range for the proportional gain is 0 to 10**. The range for the integral gain stays the same.

Part 2: Finding optimal gains for control of suspended payload

Find the optimal P and I gains to move a payload suspended **24"** below the trolley with **<u>minimal residual oscillation</u>**. The desired velocity profile is the same as before, so still try to make the

trolley follow this profile as closely as possible. The gains for this part are not necessarily the same as those determined in Part 1.

Run a series of trials to find the gains that you believe will minimize the swing. The limits on the proportional and integral gains are the same as before. For each trial, write down the gains used and the resulting vibration. To ensure that your optimal set of gains is not dependant on the command, run the machine using both long and short t_m times. **This is a qualitative, non-exact process. Try to find the best gains using only 5 trials.** This part will only be performed for the **trolley axis only.**

Lab Report (One per Team):

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 should include the following:

Part 1:

1. Plot the mean absolute error of the trolley and bridge for the various proportional gains tested.
2. Plot the error between the desired total move distance and the actual move distance for the various proportional gains tested. Create plots for both the bridge and trolley.
3. Repeat the graphs from step 2 for integral gain.
4. Report the optimal PI gains you chose for trajectory tracking and justify it using the reported data. Show the desired trajectory, actual trajectory, and error for these gains. Also discuss any other observations made. Be sure to include discussions of both the trolley and bridge gains.

Part 2:

5. Plot the residual payload oscillations for all of the gains tested.
6. Report the optimal PI gains you chose for reducing payload oscillation. How do they compare to the optimal gains in 4? What disadvantages are there in using these gains?

Tower crane operation

In this section you will be familiarizing yourself with operating the tower crane remotely. It will be **important** later on in the semester that you know how to use the tower crane. No actual data collection is necessary.

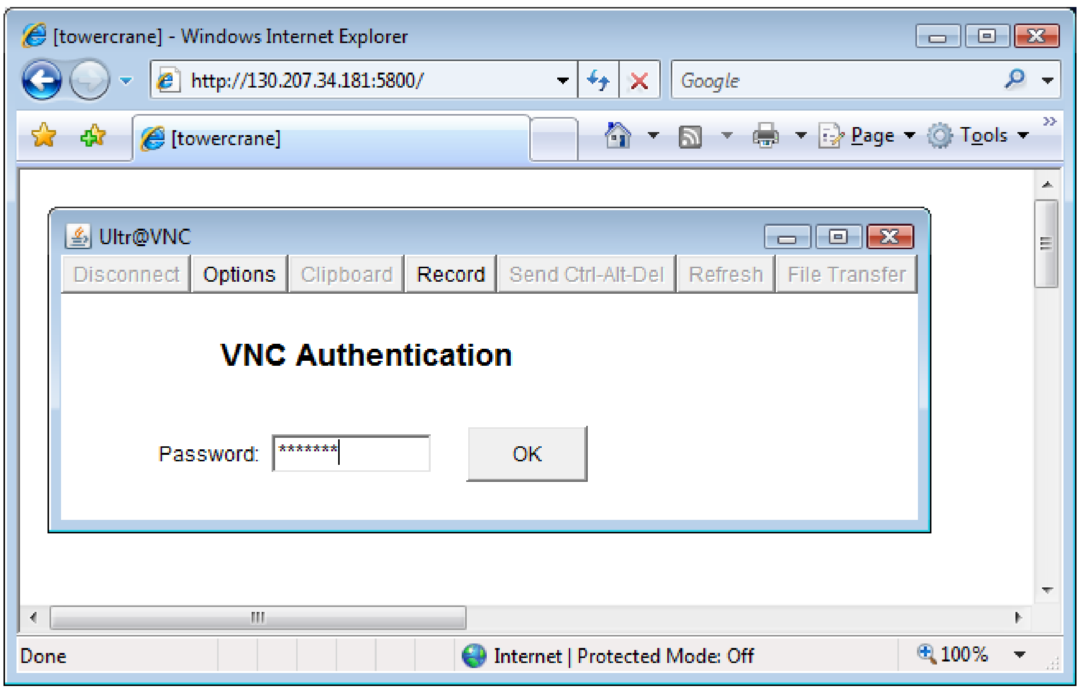
Remote Webcam:

Before connecting to the tower crane laptop, use a internet browser to view a live video stream of the physical workspace at the address:
'http://singhose.marc.gatech.edu/cranewebpage/minitower_stream.htm'.
Make sure there is no one working on the tower crane before the next step.
Use the video stream for the safe operation of the tower crane (try not to hit objects. **DO NOT HIT** people or the TA or we will track your IP down and you will receive bad grades).

Connecting to the Tower Crane remotely:

The laptop controlling the Tower Crane is running an Ultra VNC server. This means that clients can connect remotely to the laptop and use the mouse and keyboard functions as if they were physically present. You can connect to the laptop using your browser (Internet Explorer, Firefox, Safari). Make sure Java is installed on your computer.

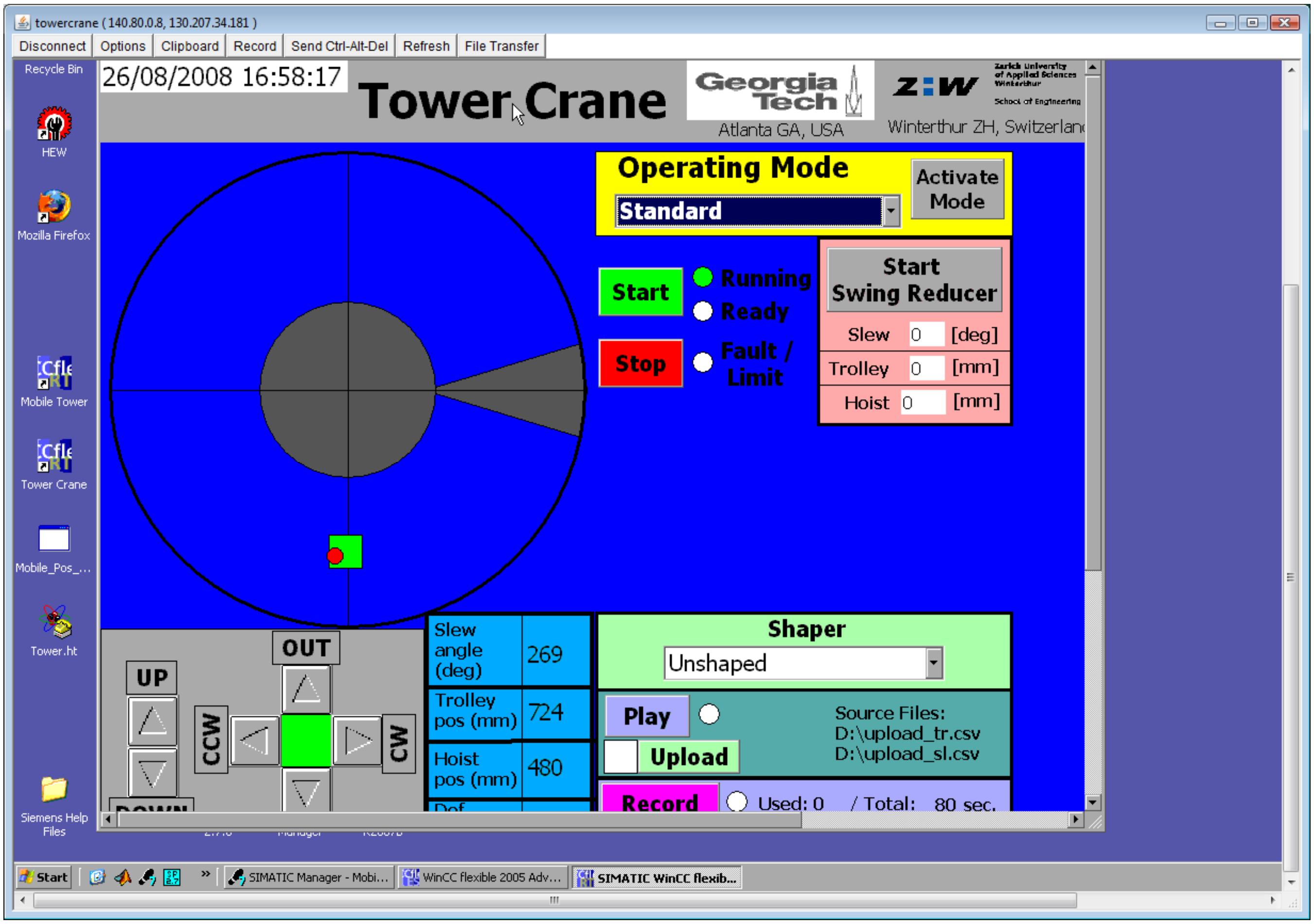
Connect to the tower crane laptop by typing in 'http://130.207.34.181:5800/' for the address. The password is 'GTcrane'.



From here on, you can run the tower crane laptop within your browser as if you were physically there.

Starting the WinCC Tower Crane Control GUI Program:

If the WinCC Tower Control GUI is not already open (check the taskbar. You may need to scroll down in the browser window), open it by double clicking ‘Tower crane’ on the desktop. You will see a GUI shown below.



Basic Crane Operation:

1. The “Operating Mode” box, in the top right corner of the screen, is used to change the operating mode for each lab module. For now select **Standard** and press the “Activate Mode” button.
2. Beneath the “Operating Mode” box are the “Start” and “Stop” buttons. **Push the “Start” button** now to turn on the power. Notice that the indicator to the right of these buttons has moved from “Ready” to “Running”. If you ever need to execute an emergency stop, push the “Stop” button.
3. Beneath the “Stop” button is the “Shaper” selection box. **Select Unshaped.** In future labs you will choose various Input Shapers (eg. ZV, ZVD, etc…) using this menu.
4. The crane is controlled using the directional buttons on the lower left of the screen. “UP” and “Down” will raise and lower the payload. “CW” and “CCW” will rotate (slew) the crane clockwise and counter-clockwise respectively. “In” and “Out” will move the trolley inward and outward in a radial motion. **Experiment with moving the crane now**.
5. As you move the crane notice that the upper left corner shows a real-time animation of the crane’s configuration. The green-box represents the trolley position and the red-circle is the payload position.

6. As you move the crane, also notice the position information indicated in the blue-box in the bottom-middle of the screen. This shows the trolley position in polar coordinates, as well as the payload height and deflection.
7. The black areas of the animated sketch indicate the limits of the crane's motion. If you ever run into these limits the crane will automatically stop. You will then only be allowed to move the crane away from that limit.

Using the Swing Reducer:

1. In many of the labs it will be important to zero-out the payload swing before running trials. This is done with the "Swing Reducer" button in the top left. **<u>Push the "Start Swing Reducer" button now.</u>** The begin moving on its own to zero-out the swing. You cannot move the crane manually while the swing reducer is engaged.
2. Underneath the "Swing Reducer" button are 3 entry boxes for the slew position, trolley position, and hoisted height. These numbers are the desired, steady-state position of the crane. The swing reducer will eliminate the swing and return the crane back to this position. Notice that when you initially pushed the "Start Swing Reducer" button the current position of the crane was instantly copied into these boxes.
3. If you want to move the crane automatically to a new position, with no swing, enter the corresponding coordinates in the swing reducer boxes. For example, **<u>enter a new slewing position (in degrees) in the slew box.</u>** As soon as you press enter the crane will move to the new desired position. This only works while the "swing reducer" button is depressed.

Record and Playback Buttons:

1. In the bottom right of the screen are the "record" and "play" buttons.
2. The "play" button is used to automate the crane. A series of velocity setpoints can be created in Excel and stored in a *.csv file using the filenames shown on the screen. This file can be loaded into the system by pressing the "upload" button. Then the setpoints can be played back automatically using the "play" button.
3. The "record" button will be used in every lab. It is used to record the position data of the crane and payload.
4. **<u>Push the "record" button now.</u>** You will notice that the recording light turns on and the recording timer starts counting. When the counter reaches the limit shown on the screen it will automatically stop. The sampling rate is also shown. You can manually stop the recording before it reaches the limit by pushing the recording button again. **<u>Push the record button now to stop recording.</u>**
5. After you finish recording the data must be downloaded to the computer. This is accomplished by pushing the "download" button.

Ending the session:

1. When you finish driving the crane **<u>press the "Stop" button</u>**. It is important that you turn off the crane after every lab session so it does not stay on for long periods.
2. Then click **Disconnect** in the top left of the browser window. **<u>Do this now.</u>**