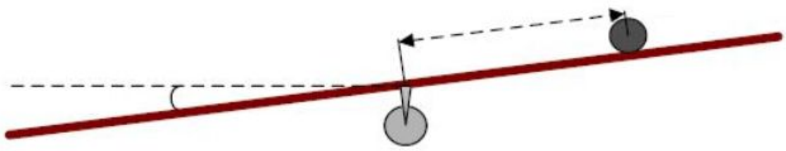
EE407 - Process Control Laboratory



Experiment X

Ball and Beam

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1 Objectives

The objective of this experiment is to investigate the operation of an electronic PID controller in a closed loop control system and to get familiar with the arrangement of various system elements such as proximity sensor as a distance measurement element and servo motor as a final control element in a position control loop.

2 Preliminary Work

2.1 Background Information

A related block diagram for the Ball and Beam system is shown in Figure 1.

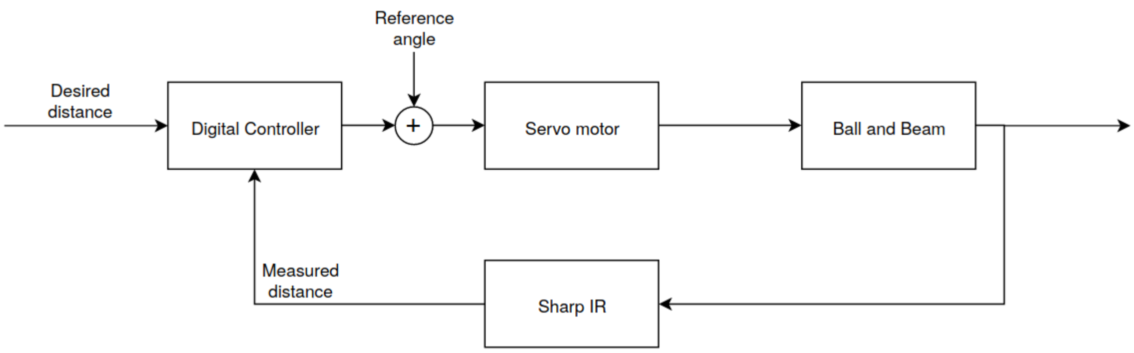


Figure 1: Block Diagram of the Closed Loop System

The individual blocks will now be explained further.

Ball and Beam: This block is responsible for changing the position of the ball when the angle of the servo motor, and consequently the angle of the beam, is changed. When the closed loop error is not taken into account ($e(t) = 0$), the position of the ball stays constant when the beam is perfectly horizontal, whereas the ball rolls down the beam with any further change in the angle toward either direction. In an ideal, errorless closed loop case, the steady state angle of the beam is the reference angle, at which the beam is horizontal, so that the ball stays at the desired position.

Servo Motor: Servo motor rotates to its input angle, also rotating the beam to the corresponding angle. The reference angle of the servo motor needs to be decided before advancing any further in the experiment. The angle of the beam decides the direction of movement for the ball.

Sharp IR: This IR distance measuring device, GP2Y0A21YK0F, has a range of 10-80 cm. It takes advantage of infrared light reflection from objects and includes a

PSD (Position Sensing Device), an IR LED and a signal processing unit. Figure 2 shows how this sensor emits light, then detects an object's reflection of the light.

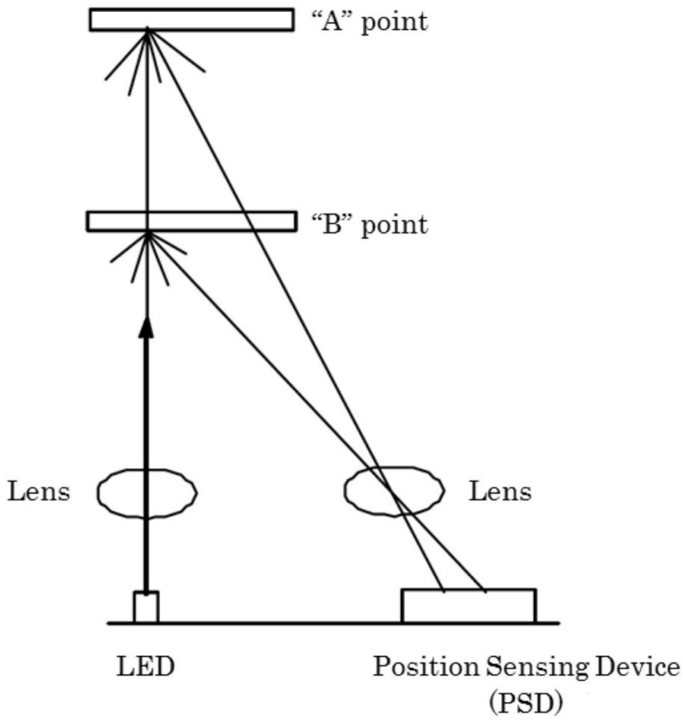


Figure 2: Working principle of the IR sensor

Digital Controller: In this experiment, you will be using an Arduino UNO as your digital controller. Graphical user interface will work realtime and output data can be collected from there. This controller takes the desired position from the user and current position from the proximity sensor. Then, it gives an output to the servo motor, trying to minimize the error in accordance with the controller coefficients.

You will use a controller design procedure based on Ziegler-Nichols tuning method. To obtain the controller parameters, necessary procedures will be followed. After obtaining the ultimate gain and period, you can define the controller parameters as

Type	K_P	K_I	K_D
P	$0.5K_U$	-	-
PI	$0.45K_U$	$0.5\frac{K_U}{T_U}$	-
PID	$0.6K_U$	$1.2\frac{K_U}{T_U}$	$0.075K_UT_U$

Table 1: Ziegler Nichols Tuning Parameters

where

K_U: Ultimate Gain
T_U: Ultimate Period (Oscillation Period)

2.2 Assignments

1. Discuss the advantages and disadvantages of the Ziegler-Nichols ultimate cycle method. How can you apply this method when the Integral and derivative control modes cannot be disabled?

2. What does the terminology of Reset Time stand for? Is it possible to limit the action of Integral control by choosing a small value for reset time. Could it be used to disable the Integral action while applying Ziegler-Nichols ultimate cycle tuning.

3. Download “Ballandbeam.mat” file from ODTUCLASS. It contains the experimental data from the Ziegler-Nichols test for a certain fundamental gain between 1.5 and 2. According to Ziegler-Nichols method,
   a. Find the Fundamental Period T_U from the data.
   b. Approximately design a
   b.i. P Controller
   b.ii. PI Controller
   b.iii. PID Controller

4. Referring to Figure 1. What is our control objective? Explain what each of the following corresponds to in our system: Process Variable, Measurement Sensor, Measured Process Variable (PV), Set Point (SP), Controller Output (CO), Final Control Element (FCE), Manipulated Variable (PV), Disturbances (D).

3 Experimental Work

1. Connect the Arduino UNO to PC and from Desktop, open the "ball_and_beam.ino" file inside the folder with the same name.

2. From the top bar, under the "Tools" menu, choose the correct port to upload the code, if it is not chosen already. Note that this port will be used in Step 5.

3. When the code is uploaded, open the command prompt:
Use the shortcut "windows + R", then type "cmd" and enter.

4. Change directory to run the command that opens the Graphical User Interface (GUI):
"cd Desktop\ball_and_beam"

5. Run "python ballandbeam_gui.py −−port COMX"

6. The GUI consists of three real-time plots: the distance between the ball and the infrared sensor, the desired distance value, and the corresponding error. There are also several slides that control the parameters of the system.

Figure 3: Graphical User Interface

When you open the GUI, experiment with the "direct" value to find when it corresponds to a horizontal beam. You need to keep this reference value the same throughout the experiment.

Ziegler Nichols Method:

7. With $K_D = K_I = 0$, experiment with the K_P value to find when the system is critically stable. What is the ultimate gain value? (Hint: The K_U value for marginal stability should be between 1.5 and 2.5.)
8. After you found the ultimate gain, be ready for checking the "Save CSV" box at the bottom left of the GUI, because when you checked, it immediately saves the data and you cannot save another data by rechecking it.
9. Check the box and observe the step response of the system.
10. After being sure you have taken the correct data, uncheck the box to stop saving data. You can find the resulting file in the "csv" folder.
11. Start MATLAB, and navigate your working directory to "User\Desktop\ball_and_beam\csv".
12. Double click on the csv file that you have just generated. Choose the necessary values and import them to the workspace.
13. Plot the measured distance value by using the data in workspace.
14. Find Fundamental Period T_U from the plot.
15. Using the fundamental gain K_U and fundamental period T_U, find the controller parameters for:
    a. P controller
    b. PI controller
    c. PID controller
16. Implement these values with the GUI's sliders. Then observe and plot the step response of the system for three cases.
17. Comment on the system behaviours. Did you observe any discrepancies or unexpected results?
18. What can be the reasons of discrepancies if there is any?

System Identification and PID Tuning Method:

19. Select Apps ¿ PID tuner in the Toolstip as shown in Figure ?? in order to reach the screen provided in Figure 4.

Figure 4: Toolstip menu

20. Select Identify New Plant in the Plant dropdown menu as demonstrated in Figure 5.

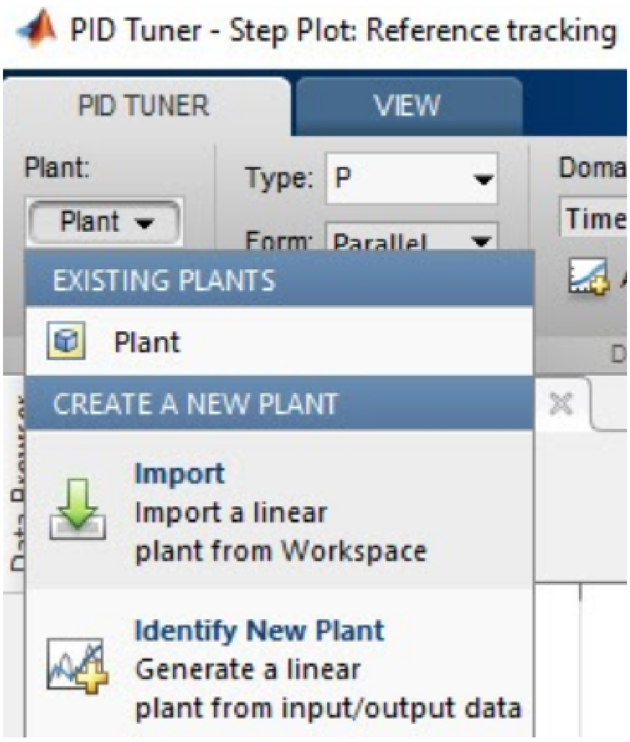


Figure 5: Plant dropdown menu

21. Several methods are provided in the Get I/O Data dropdown menu under PLANT IDENTIFICATION toolstrip as illustrated in Figure 6.

22. After selecting the desired method, select proper labeling for a proper identification for the plant. Specify the names of the input and output vectors as the appropriate variables saved in Workspace.

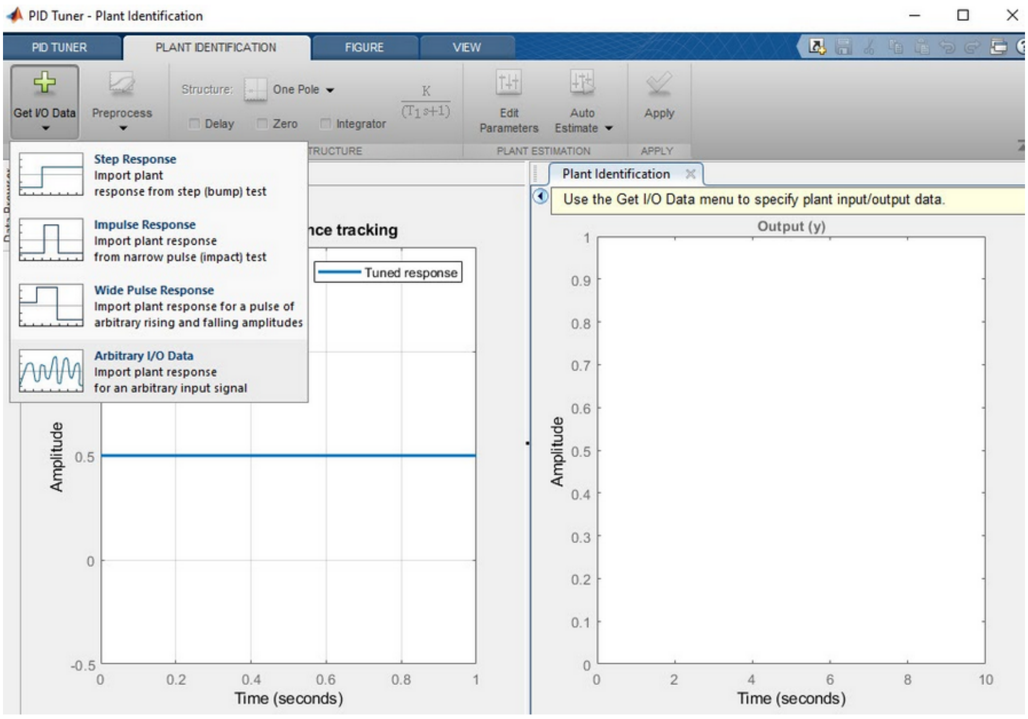


Figure 6: Get I/O Data Methods

23. Estimate the plant. You can choose Auto Estimate to get an average estimation of the plant. You can change the estimation by adjusting the root locations in the resultant figure if you prefer. Export the estimated model to workspace simply clicking on the Export button placed on the right upper corner when you are satisfied with the current estimation.

24. Apply PID Tuning to the estimated plant in the PID TUNER window. Note the Kp, Kd and Ki values.

Name:

Section:

Date:

4 Preliminary Work Answers

1. Ziegler Nichols:

   Ziegler-Nichols ultimate cycle method is an empirical method which is based on closed-loop testing (also called on-line tuning) of processes which are inherently stable, but where the system may become unstable. It is not guaranteed to be optimal, perfect or rational, but which is nevertheless sufficient for reaching the controller parameters.

   Advantage:
   Ziegler-Nichols ultimate cycle method can be applied to the models whose transfer functions are not known. Although it may be the most convenient method, it is a very useful tool controller tuning when the plant model is too complex to derive or it is not possible to derive the model at all.

   Disadvantage:
   It is not a good practice to push the plant to unstability region in real life as it may not be possible to recover to the stable region once the plant goes into unstable region.

2. Reset Time:

   Reset time stands for the limitation in the integral sum of the error. It prevents error cummilation to exceed a certain value which may be defined in the controller as a parameter.

   When Ziegler-Nichols ultimate cycle method is used, integral and derivative control modes shall be disabled. If it is not possible to disable the integral and derivative control modes, it is possible to set the integral time to its maximum value and the derivative time to its minimum. One can also limit the action of Integral Controller by setting the Reset time to a very small value.

3. P-only Controller:

   $K_P = 0.96$

   PI controller:

   $K_P = 0.833$
   $K_I = 0.48$

   PID controller:

   $K_P = 1.11$
   $K_D = 0.29$
   $K_I = 1.07$

4. Control objective and the variable names:

   In the control loop, it is aimed to control the position of the ball on a beam.

   Measurement Sensor: Sharp IR
   Process Variable: Ball Position
   Set Point: Desired Distance
   Measured Process Variable: Measured Distance
   Controller Output: Angle Signal
   Final Control Element:
   Manipulated Variable: Angle of the Beam
   Disturbances:

Name:

Section:

Date:

5 Experimental Procedure Results

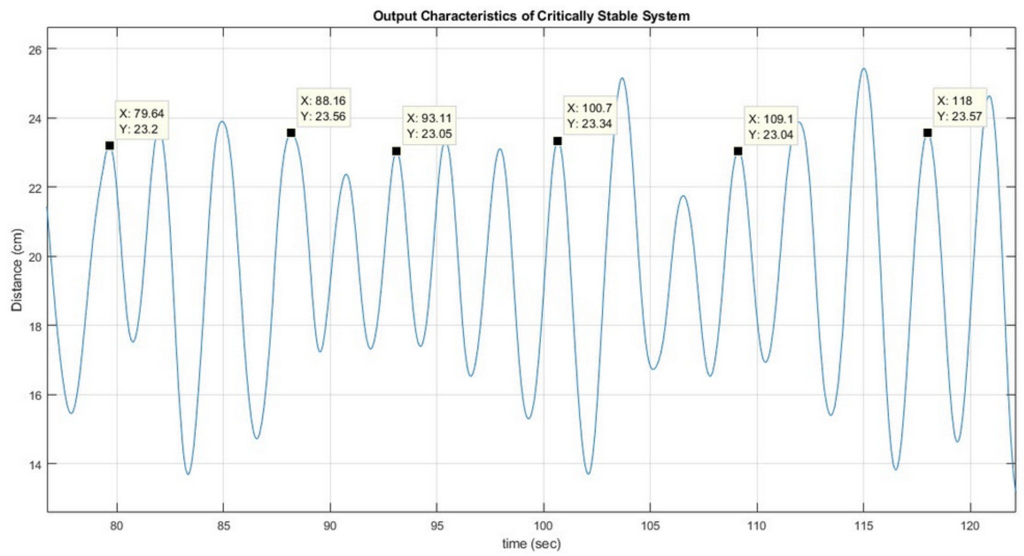
6. Direct value (reference angle):

97

7. K_U:

$K_U = 1.85$

14. T_U:



$$x_1 = 118 - 109.1 = 8.9\ , \quad x_2 = 100.7 - 93.11 = 7.59$$

$$x_3 = 88.16 - 79.64 = 8.52\ , \quad x_{avg} = 8.33 \quad \Longrightarrow \quad T_U = \frac{x_{avg}}{4} = 2.08$$

15. Controller parameters:

$K_U = 1.85$ & $T_U = 2.08$

Type	K_P	K_i	K_D
P	$0.5\ K_U = 0.925$	-	-
PI	$0.45\ K_U = 0.832$	$0.54\ K_U / T_U = 0.480$	-
PID	$0.6\ K_U = 1.11$	$1.2\ K_U / T_U = 1.06$	$0.075\ K_U T_U = 0.288$

16. Step responses:

17. Comment:

    In Only-P controller case, when Kp is slow, large steady state errors were observed. As Kp closes to the ultimate gain, faster behaviour were observed, but the system began to oscillate.
    In PI case, There is no steady state error but big oscillations were observed.
    In PID case, because of the derivative term, very sharp responses were observed and this is the optimum case between all three cases. There is also no steady state error in this case.
    For all cases, the system tends to behave unexpectedly.

18. Comment:

    The reasons of discrepancies mostly arised from mechanical issues. Because of the friction force between ball and beam, although the angle was necessary for the ball to slide it, the position of the ball maintain its value at the same point.