Instruction Manual for using Inverted Pendulum

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Abstract

In this manual, I go through a step-by-step procedure on how to use the inverted Pendulum setup. The hardware and software implications will be discussed.

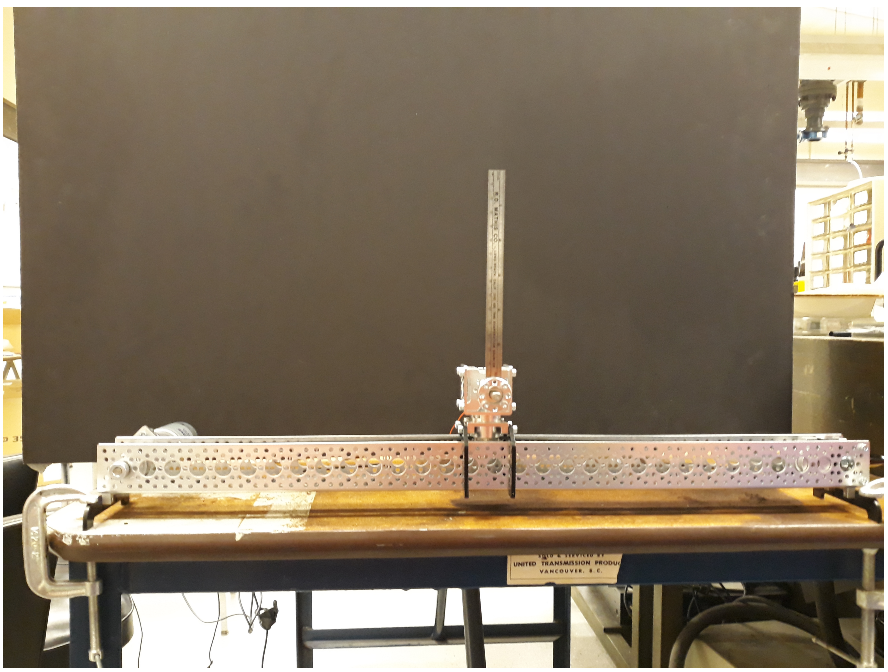

Figure 1:

1 Introduction

The inverted pendulum is a very important tool in Control theory as it is used as a standard test bench for testing out various Control algorithms. This manual explains how to use the setup by testing out the standard LQR algorithm. It is intended to be used for testing out new Control algorithms by extending the standard procedures used before. The setup can be used for other applications as well (such as the Chaotic Pendulum) by perturbing the pendulum from the down equilibrium state.

2 Software requirements

2.1 Simulation and hardware implementation

- LABVIEW 2017 with Control, Design and Simulation Module and VISA installed.

2.2 Motor

Go to www.basicmicro.com/downloads. Under RoboClaw 2X7A motor Controller section, Download the following:

- Ion Studio Setup App.
- USB RoboClaw Windows Driver.
- LABVIEW Driver
- Data sheet and the manual.

3 Hardware

- Pendulum attached to the cart on the channel slider kit with the motor attached on one end to drive the cart.
- Angle encoder
- 12V Power Supply
- Roboclaw 2X7A Motor Controller
- USB 6009 DAQ
- Computer to interact with the hardware.

4 Wiring

- The Motor Controller is wired as directed by the manual for USB Control Mode.
- The Angle Encoder's output is given to the Analog input AI1 in the DAQ and is used in differential mode.

5 Input/Output to the system

- The system has one input and two outputs.The voltage to the motor will be the input.
- Angular position of the pendulum and linear position of the cart are the outputs.

6 Check working of motor

- Before going through the following instructions, please make sure that the software requirements are installed and the hardware parts are working fine.
- The first step is to make sure that the motor is working using the Ion Studio application. After making sure that the windows USB driver is installed correctly, connect the USB cable from the motor controller to the computer and open the Ion Studio set up app. It will detect the connection and you have to Click on "Connect Selected Unit".
- Now go to general settings and select the Control mode as Packet Serial mode. Baud rate is recommended to be set to 115200.
- The tuning of Proportional, Integral and Derivative (PID) gain values for position and velocity control has already been done once from a different computer. But if it seems like it is not applicable since a different computer is being used, go through the RoboClaw manual carefully and follow the steps to auto-tune the right PID gain values for velocity and position control.
- Now, we can proceed to the next step if the cart moves back and forth upon moving the PWM Duty Cycle slider up and down. So what's required next is to directly go to LABVIEW and see if all the devices are working properly.

6.1 Angular position

- The angle of the pendulum is measured by the encoder. The output is analog, and it is fed into the USB 6009 DAQ's analog input in differential mode.
- The file Pendulum_read_angle.vi under the folder Pendulum Modelling displays the encoder angle.

  NOTE: Before running the previous code (or any other code that involves the encoder), it is extremely important to run the file Angle_reset_offset.vi while the pendulum is at rest in the gantry position. Copy the value displayed in the indicator by the name "mean" . This is the offset in the voltage of the angle encoder. This value is to be pasted in the control box by the name "Offset" in the block diagram of the file Pendulum_read_angle.vi. All the codes are written in such a way that the value that is given in the control "Offset" is subtracted to cancel the offset and display the right value of the angle.

6.2 Cart position and input to motor

6.2.1 Motor input

- The motor is used in PWM mode and the codes are written with subvi called Motor-dutycycle.vi which gives the input command to the motor.

- The input to be given to these subvi is the percentage duty cycle.

  NOTE: Before executing any code that involves the motor, you will need to find the motor voltage from the Ion Studio App (Don't forget to close it!) and then paste it in the constant block that is an input to the divide block just before the input to the subvi.

  Reason: This is necessary as the battery discharges and will have different voltage at different points of time. The voltage that needs to be given to the motor comes from the code and we convert to percentage duty cycle for input to the PWM mode. This input needs to be divided by the motor's actual voltage and multiplied by 100 to get percentage duty cycle.

6.2.2 Position encoder

- The motor has an encoder attached with it, and there are LABVIEW drivers that are available in the int.lib file to give read commands to the motor.
- A scaling factor has to be included to convert the encoder counts to metres.
  All the necessary conversions are done already and the file Motor_modelling_1.vi under the folder Motor Modelling, illustrates simultaneous read and write to the motor.

7 Motor Modelling

- Open the folder named Motor modelling and open the vi by the name Motor_Modelling_1.
- Go back to the block diagram and give a square input of 1 V and 0.2 Hz. (This exercise is recommended to be done without the pendulum)
- Then, make sure the cart is in the middle of the track and then run the vi. The cart should start moving back and forth.
- Tune the values of K and τ to match the simulated velocity with the measured velocity.
- The transfer function that models the motor is $\frac{V_c(s)}{V_m(s)} = \frac{K}{1+\tau s}$, where $V_c(s) \rightarrow$ Laplace transform of cart's velocity, $V_m(s) \rightarrow$ Laplace transform of input voltage, $\tau \rightarrow$ time constant and $K \rightarrow$ Gain factor.

8 Pendulum Modelling

- Now attach the pendulum back to the cart.
- Go the folder called Pendulum modelling and open Angle_reset_offset.vi.
- Make sure the pendulum is at rest in the gantry position and then run the vi. The value that is displayed is the mean of a 100 samples of the data taken.

- This says the offset in the voltage of the encoder. Copy this value and close the vi.
- Open the vi called Pendulum_friction_calculation.vi and fill in the input channel details correctly.
- Select the input Terminal Configuration as Differential and the units as Volts.
- Paste the copied value in the Offset_voltage control block.
- Run the vi to record the angle of the pendulum as a function of time. Use this to find the damping ratio, natural frequency etc.

Now that the motor and the angle encoder are working fine, we can proceed to do the gantry position modelling of the cart-pendulum system.

9 Gantry Position Modelling

9.1 Simulation

- Navigate to the Linear Pendulum gantry Folder and open the vi named SPG Model Design_Sim.
- Enter the right state space model (Only A and B matrices) in the space given.
- Give a name under which the model needs to be saved in the Model Name box and run the vi.
- While it is running,click on Save button. Now the model is saved in Model files folder.
- Go to SPG Modelling_sim.vi and in the front panel double click on the state space block and load the model that was saved.
- Run the vi to get the simulation results.

Now that the simulation works, proceed to SPG Modelling.vi. (This vi is to take the real data and compare with the simulation).

9.2 Real time data

- Enter the right parameters/values in the block diagram for configuring the DAQ and the Roboclaw correctly.
- Enter the right value of the motor voltage in the constant as pointed in the front panel (This can be checked from the ION Studio Desktop app).
- Change the input amplitude (Recommended to be less than 5 V) and vary the signal type and observe the waveforms.
- Give the same input as that of the simulation and see how close they are.

Now we proceed to the inverted pendulum position.

10 Control Design and Simulation

- After getting the right state space model which is linearized about the top (vertical) position, go to the folder named Linear Inverted Pendulum → SIP Balance Control Design.
- In the front panel, enter the obtained state space matrices and run the vi.
- Go the Block diagram and tune the values of Q and R appropriately to achieve the desired response that is close to the setpoint in the simulation.
- Copy the values of the Feedback Gain vector.

11 Real-time Implementation

- Navigate to the block diagram and paste the values copied earlier in the Feedback Gain block in the vi SIPBalanceCtrl.vi
  NOTE: Make sure that you interchange the second and the third values as the order of the elements of the state space vector here is different from that of the simulation.
- Make sure that the cart is in the middle of the track.
- Check that the pulley is clamped properly to the D-shaft of the motor.
- Adjust the belt tension accordingly.
- In the front panel, enter the motor's current voltage value.
- Enter the right configuration parameters for the Angle encoder and RoboClaw, and then run the vi.
- Bring the pendulum slowly from the gantry position to the top vertical position. The controller should take over now, and the pendulum will start balancing.

12 Other notes

- In case of any emergency, e.g, the cart suddenly behaves erratically or hits any side of the slider, switch off the the power supply first and bring the cart to the middle position and start over again.

13 References

www.basicmicro.com/downloads