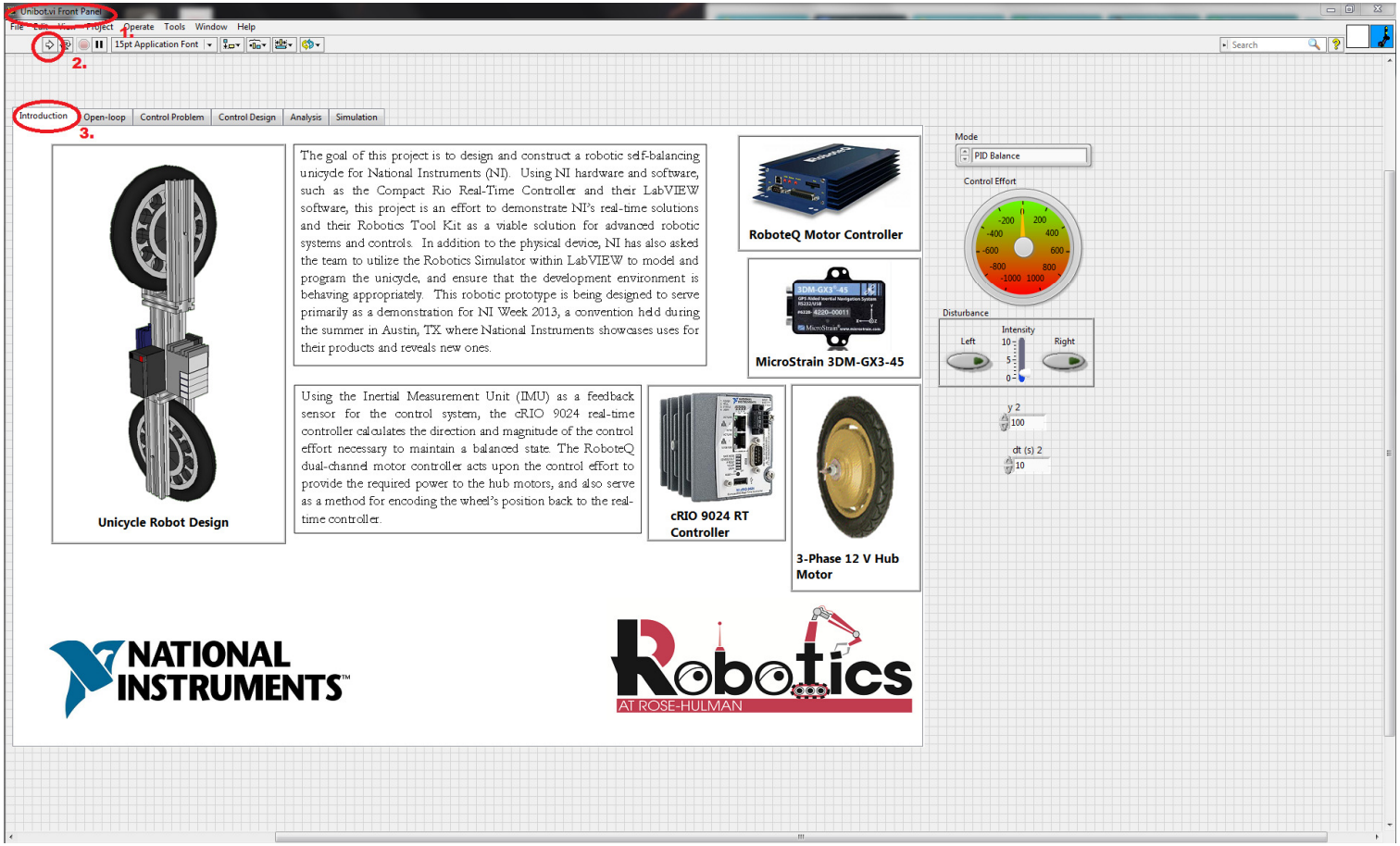
Using the Control Systems User Interface for Testing, Tuning, and Simulating the Controller

Self-Balancing Unicycle Project

Using the Front Panel UI

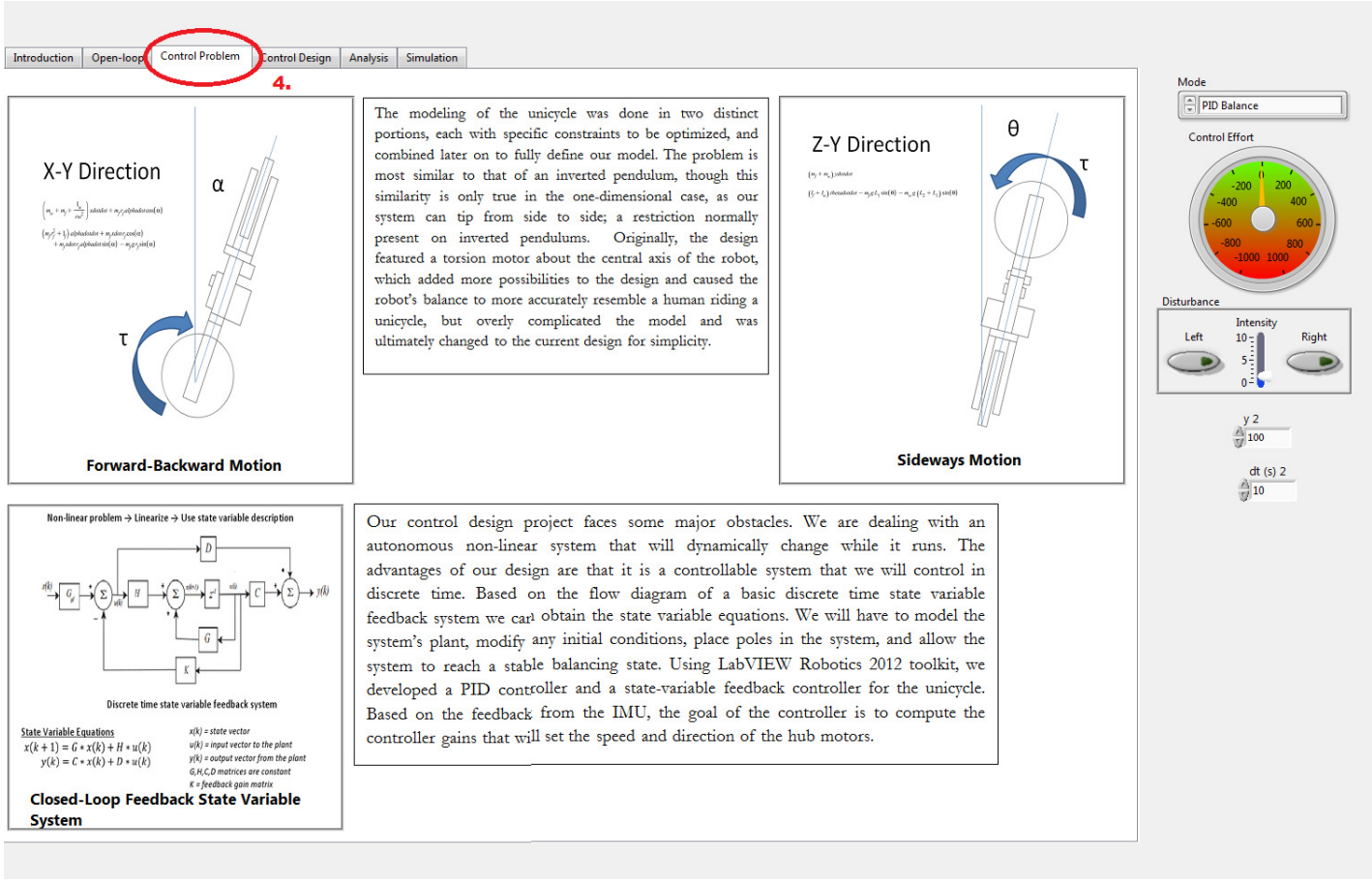
Introduction and Initialization of UI



1. Upon opening LabVIEW, check to see to that the correct Front Panel VI for the system was opened. *Press CTRL+E to swap between Front Panel VI and Block Diagram as needed.*
2. Once the VI has opened and all file dependencies correctly loaded, the Run arrow at the top left of the Front Panel should be solid white. Press the solid white arrow or hit CTRL+R to run the simulation for the control system. *If a broken arrow is shown, an error or change in the code has created a broken terminal. Errors in the code have to be addressed before executing the UI.*
3. After clicking Run, the Front Panel should initialize at the 'Introduction' tab as indicated by marker 3.

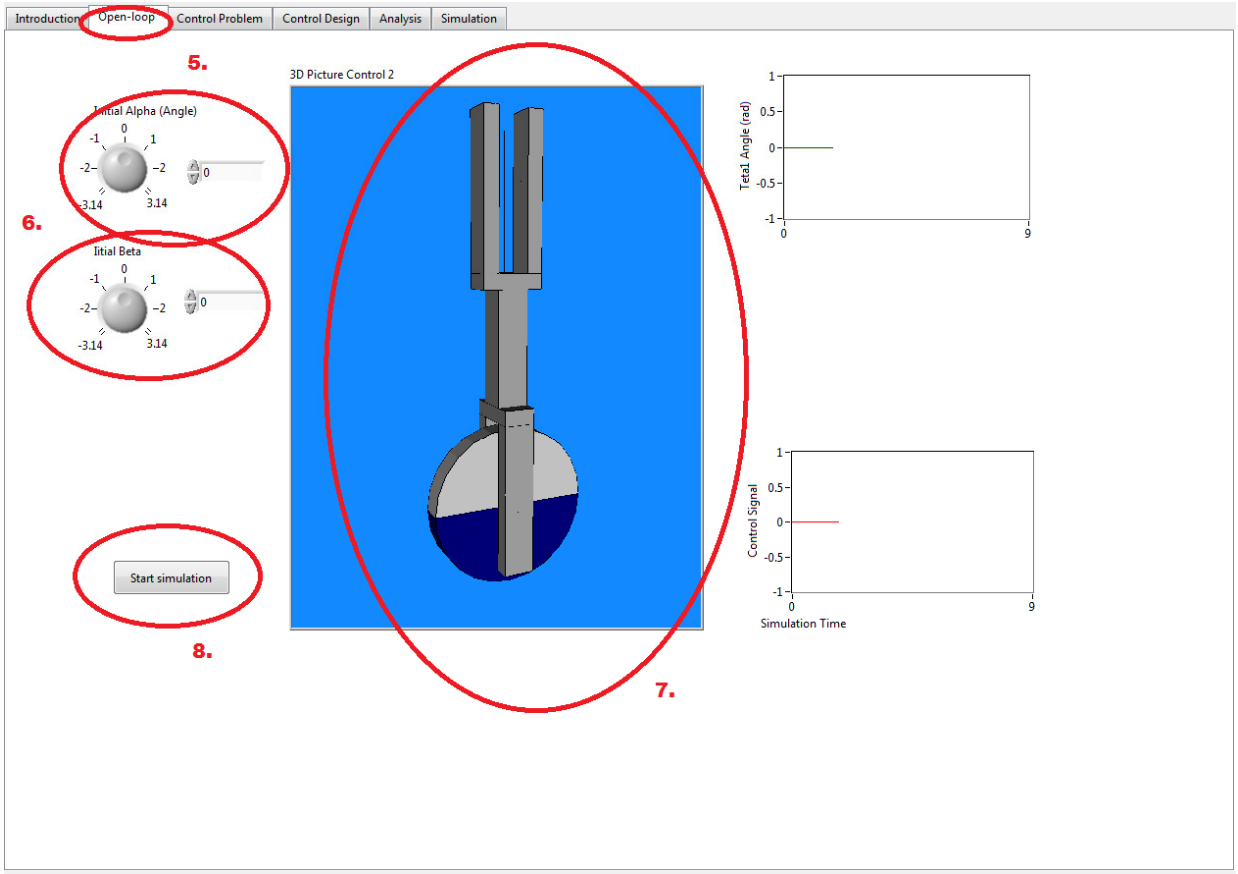
**** Caution: If an emergency stop or normal stop is required, read Instruction Step # 33 before proceeding. ****

Displaying the Control Problem Information



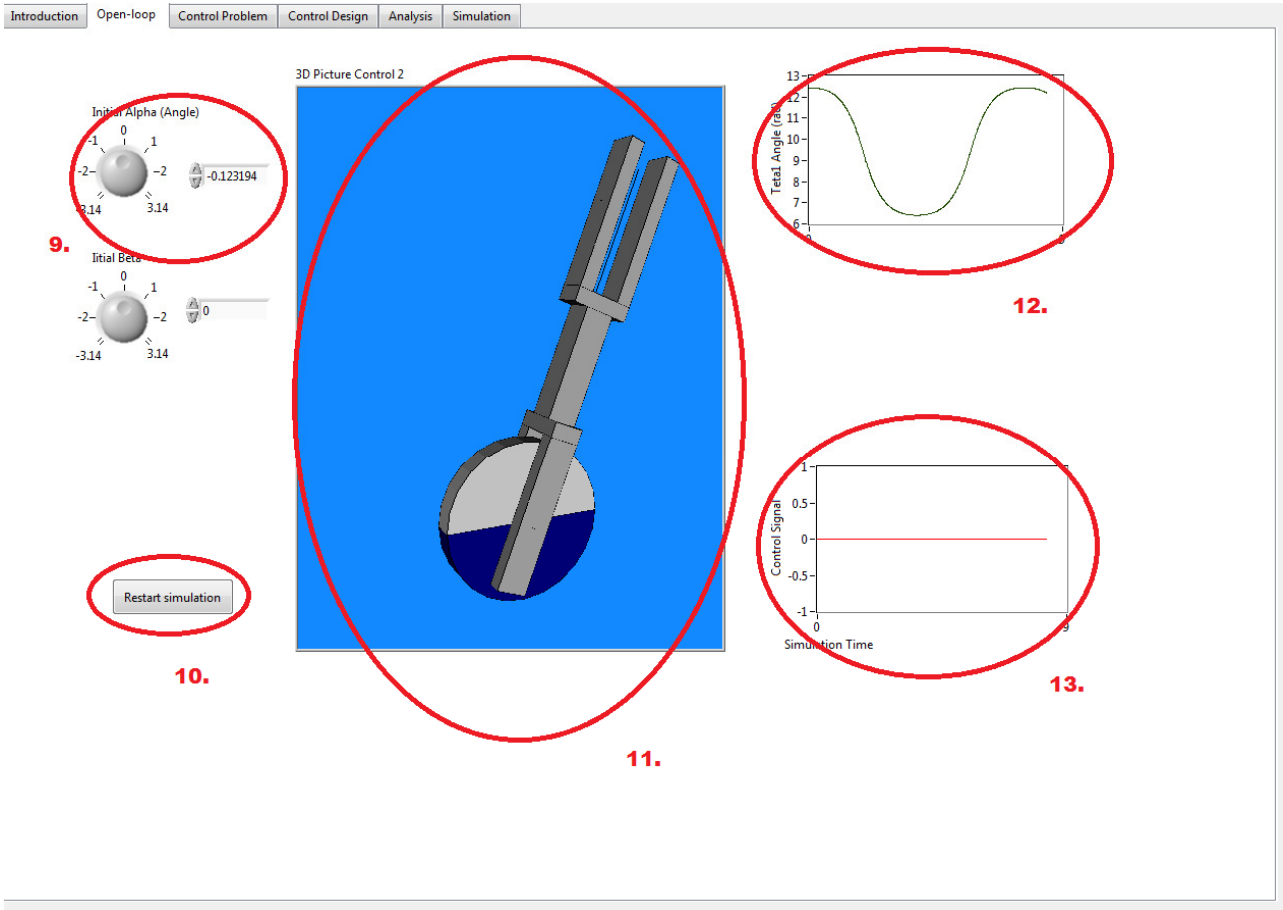
4. After the system is running, you may swap to the 'Control Problem' tab for a description of the entire control project and the approaches used to model the plant.

Observing the Plant Behavior in the Open-Loop Mode



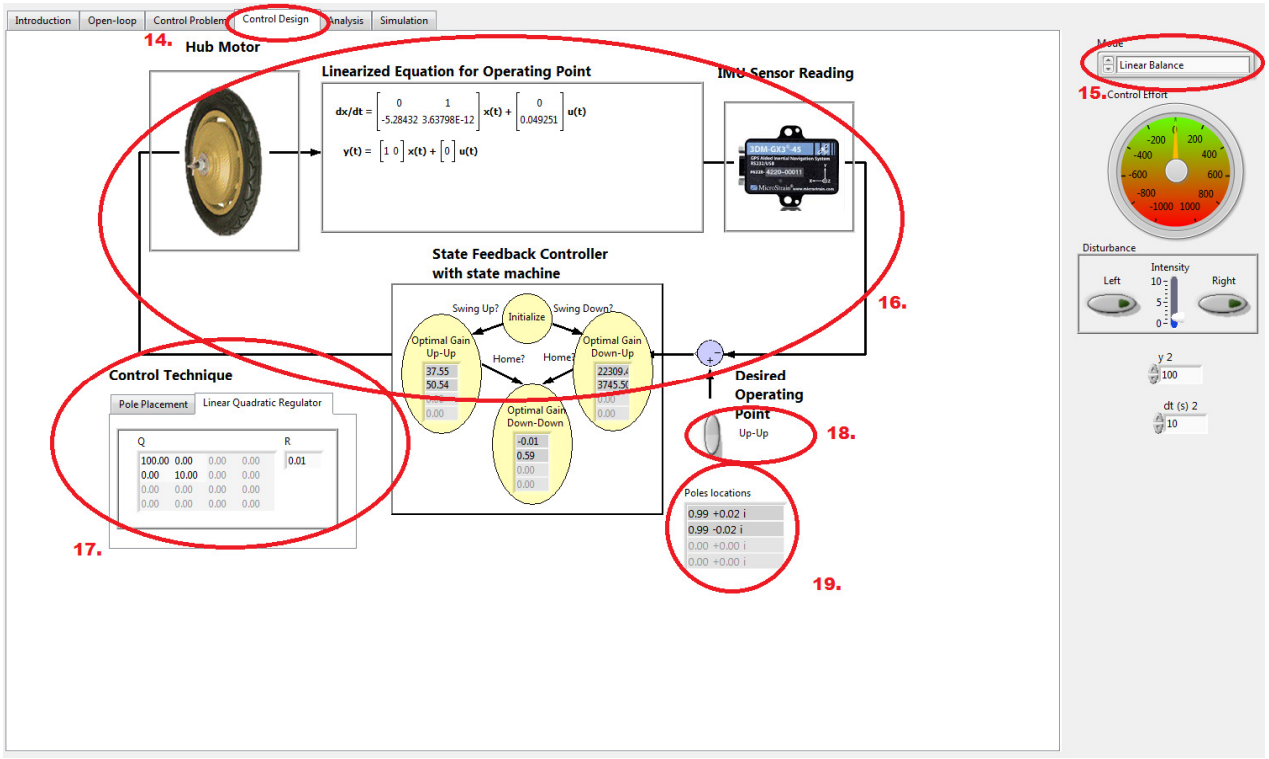
5. Select the 'Open-Loop' tab to enter in the plant simulation window. Open-loop will simulate how the plant model behaves without the controller or any feedback.
6. At the start, ensure that the 'Initial Alpha (Angle)' and the 'Initial Beta' are set to zero.
7. The '3D Picture Control' displays the plant model (i.e. the unicycle robot) as it would behave in an ideal world. The unicycle should start completely upright.
8. Click on the 'Start simulation' radio button to begin the plant simulation. Since the model is starting at a perfect zero degrees (i.e. completely upright) and the unicycle is modeled as a perfect symmetric body, the unicycle plant does not move from its starting place.

Using the Open-Loop to Model Falling Behaviors



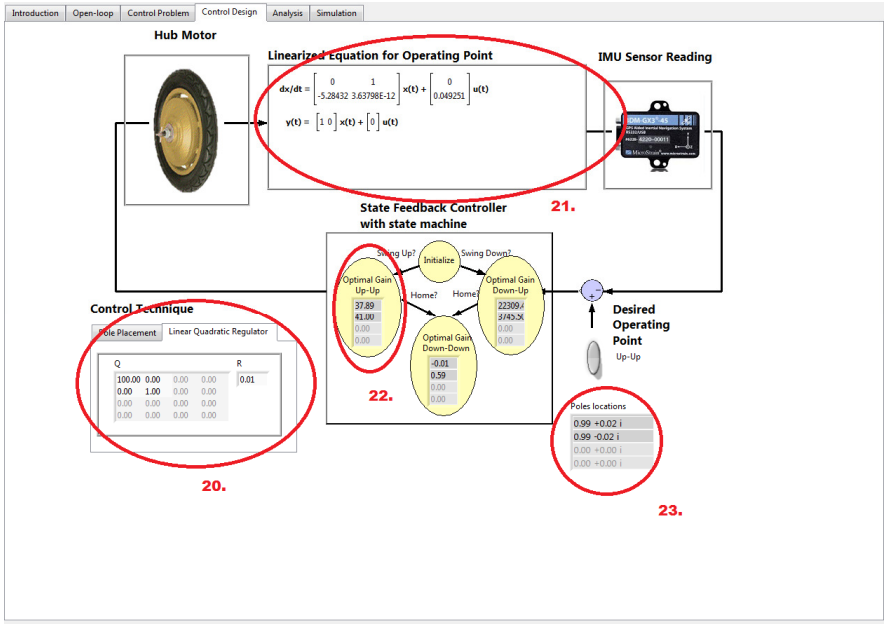
9. Change the 'Initial Alpha (Angle)' by either moving the dial or by inserting a number in the digital input entry field.
10. Click on 'Restart simulation' to reset the simulation for the plant.
11. After resetting the simulation, the '3D Picture Control' refreshes and the new unicycle model starts to fall.
12. The 'Teta1 Angle' Indicator shows the oscillations of the unicycle. *In this simulated environment, collision with the ground plane, friction between the wheel and ground plane, and energy losses in a real-life environment, are neglected. Thus the unicycle acts as a perpetual motion machine.*
13. Finally, note how the 'Control Signal' indicator does not change for the simulated Open-Loop model as expected.

Using the Linear Balance Mode of the Controller

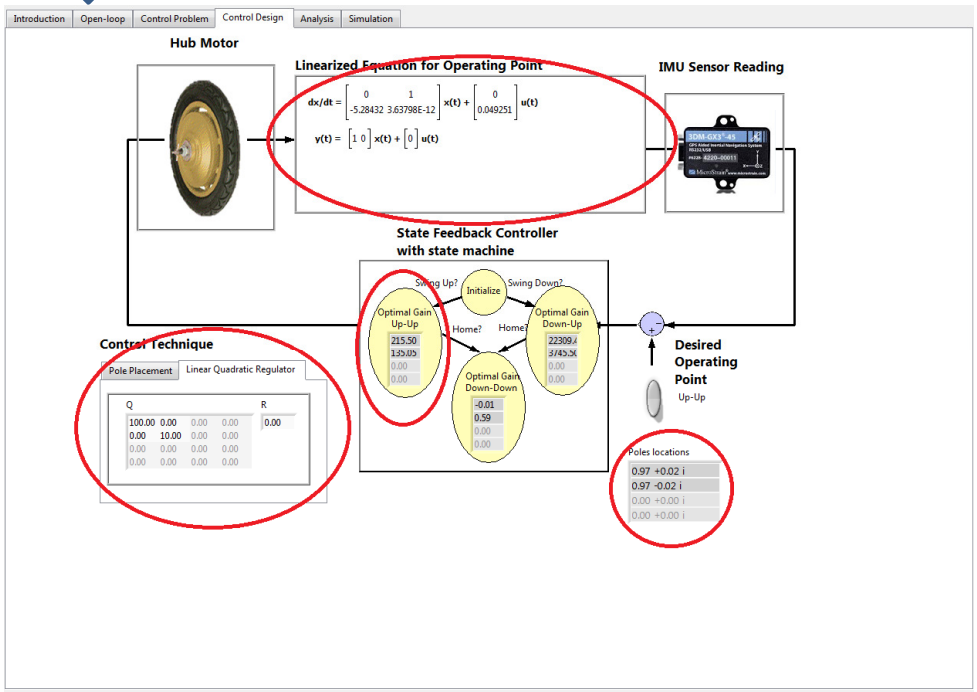


14. Select ‘Control Design’ from the tab controls to swap to the controller UI.
15. Ensure that the mode is set to ‘Linear Balance’. If it is not set to ‘Linear Balance’, change it to Linear Balance by clicking on the white space inside the field and selecting Linear Balance. Reset the UI if the mode was previously in the ‘Emergency” state.
16. This section gives the high-level overview of how the closed-loop controller is created.
17. In the ‘Control Technique’, the user can select what type of controller he or she wishes to simulate and tune. The user has (Ackermann) ‘Pole Placement’ and ‘Linear Quadratic Regulator’.
18. Ensure the ‘Up-Up’ mode is selected.
19. Here the user can see the closed-loop pole locations after modifying the controller.

Using the LQR Controller

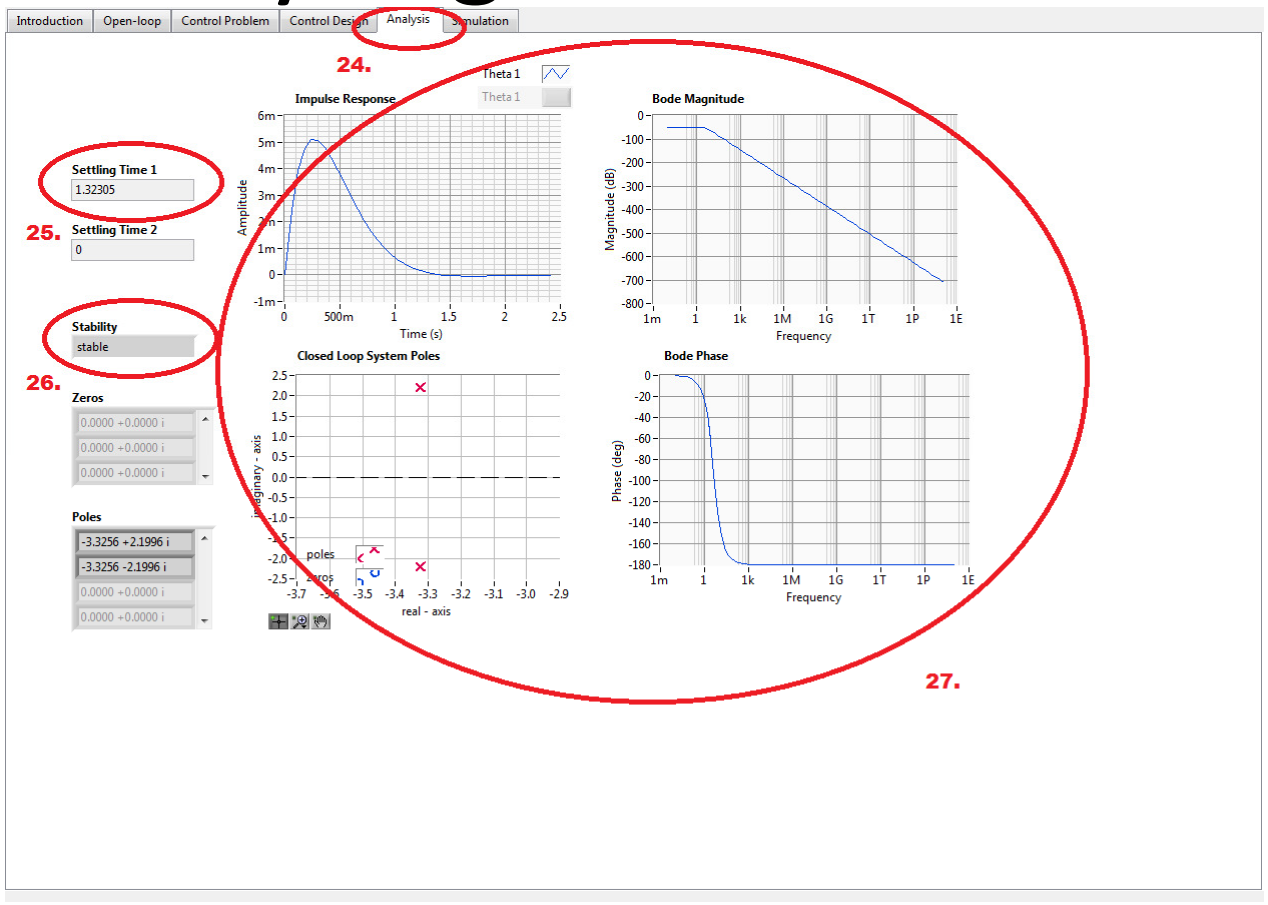


After changing the control parameters in the LQR mode, the controller computes the new control efforts, updates the state-space, and display the new pole locations.



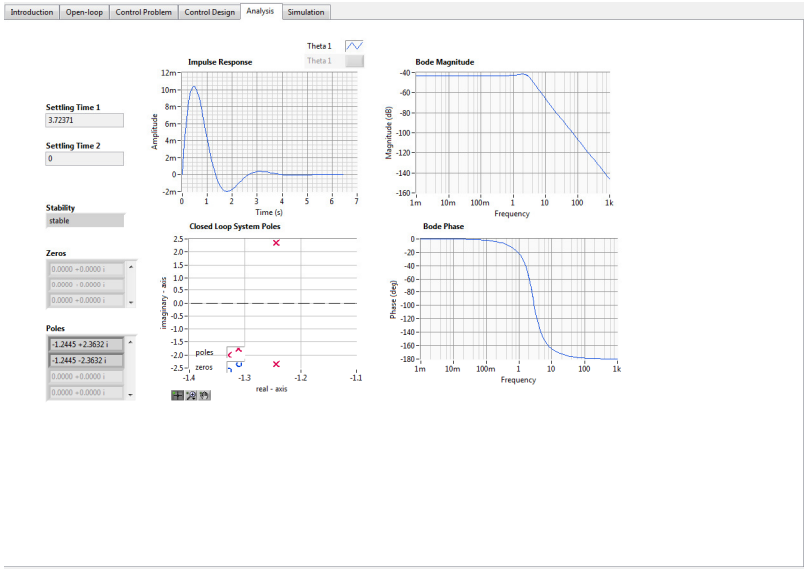
20. In the 'Linear Quadratic Regulator' tab, change the penalties to the states as needed. In this example, the greatest weight is given to the angular position of the wheel (i.e. cell[1,1]).
21. The discrete-time state-space model is then shown.
22. After changing the controller parameters, the control efforts in the 'Optimal Gain Up-Up' indicator array are shown.
23. The poles after changing the controller are shown in the 'Pole Locations' array indicator.

Analyzing the Controller

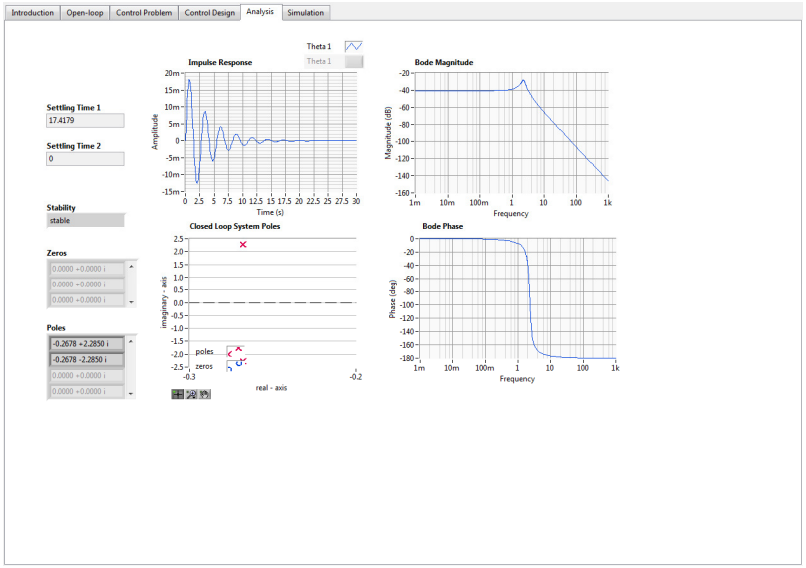


24. After selecting the parameters for the controller, switch over to the 'Analysis' tab to analyze the impulse response, stability, and settling time of the system.
25. This displays the settling of the system.
26. This displays whether the system is controllable or not.
27. The controller then analyzed to display the 'Impulse Response', 'Closed Loop System Poles', and the 'Bode Magnitude and Phase' diagrams. *For a stable system the impulse response should reach a steady-state value and be stable.*

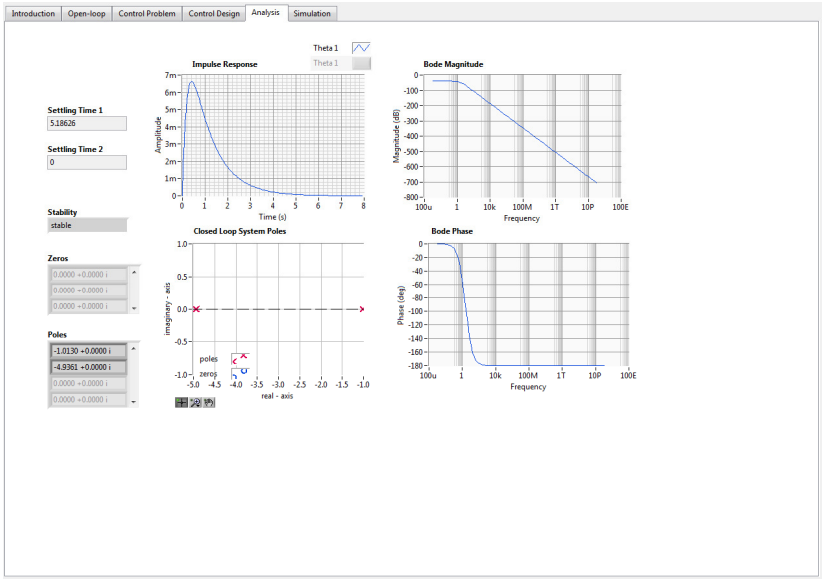
Changing the Controller to Observe Different Behaviors



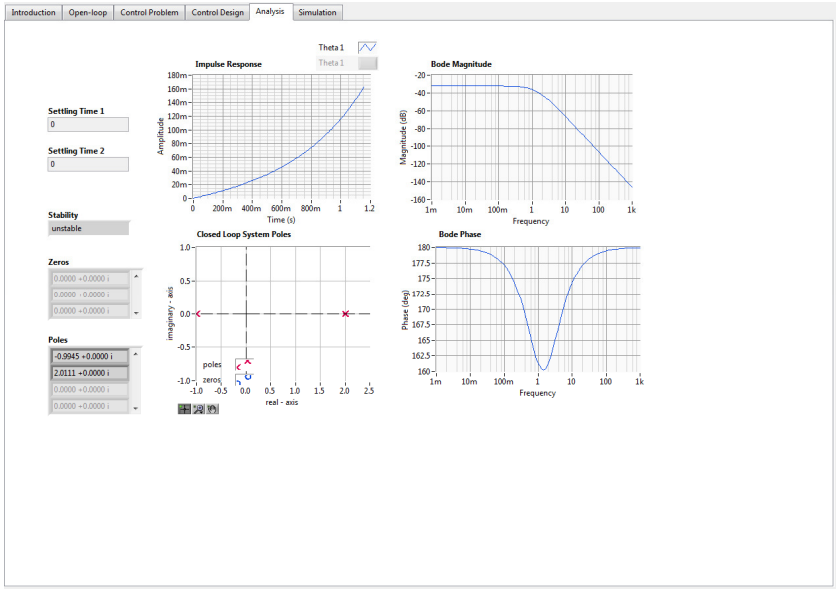
LQR



Again, using LQR approach, the control parameters were changed to show a system with a few oscillations and a system with a lot of oscillations as seen in the 'Impulse Response'.

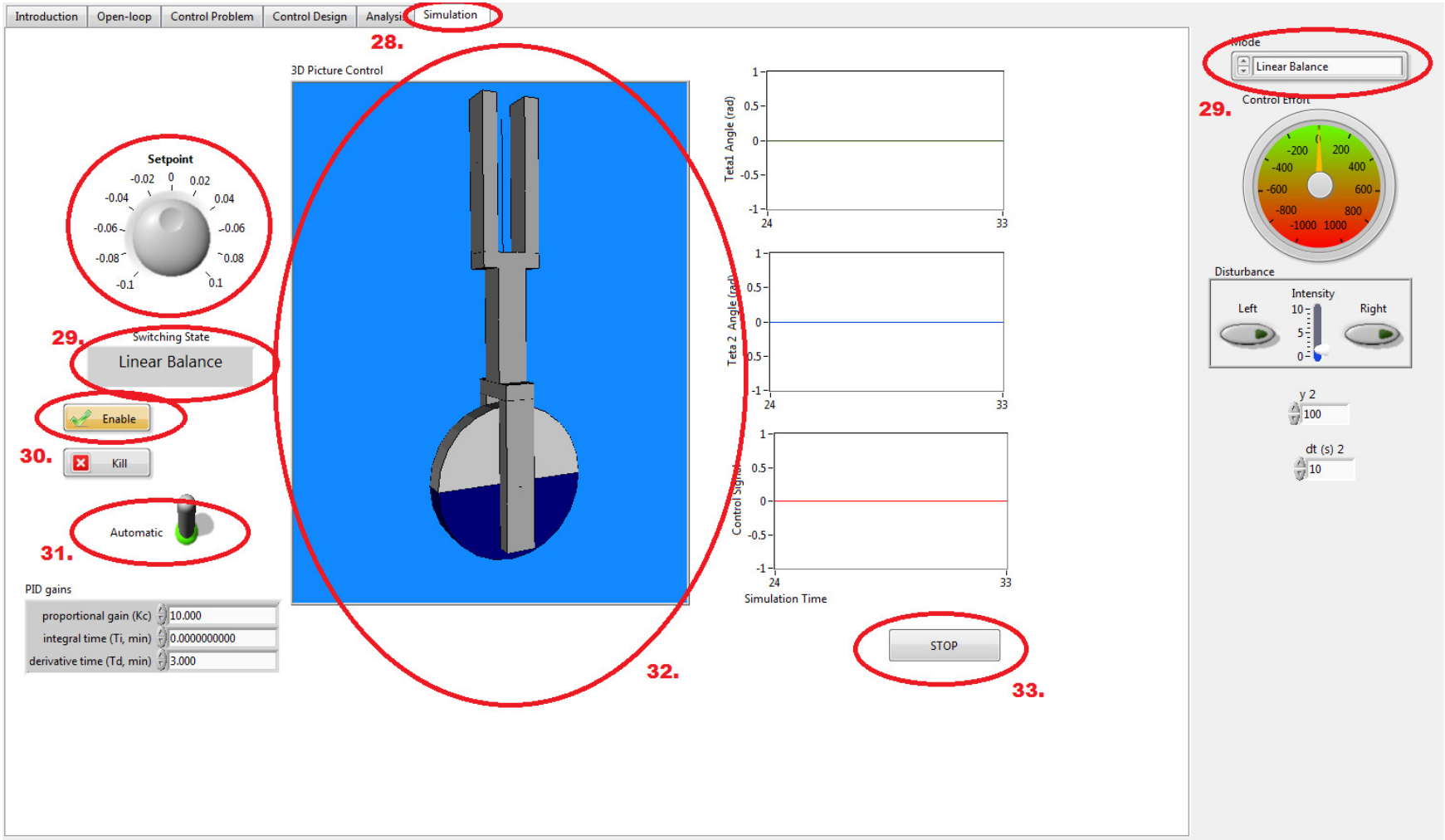


Ackermann



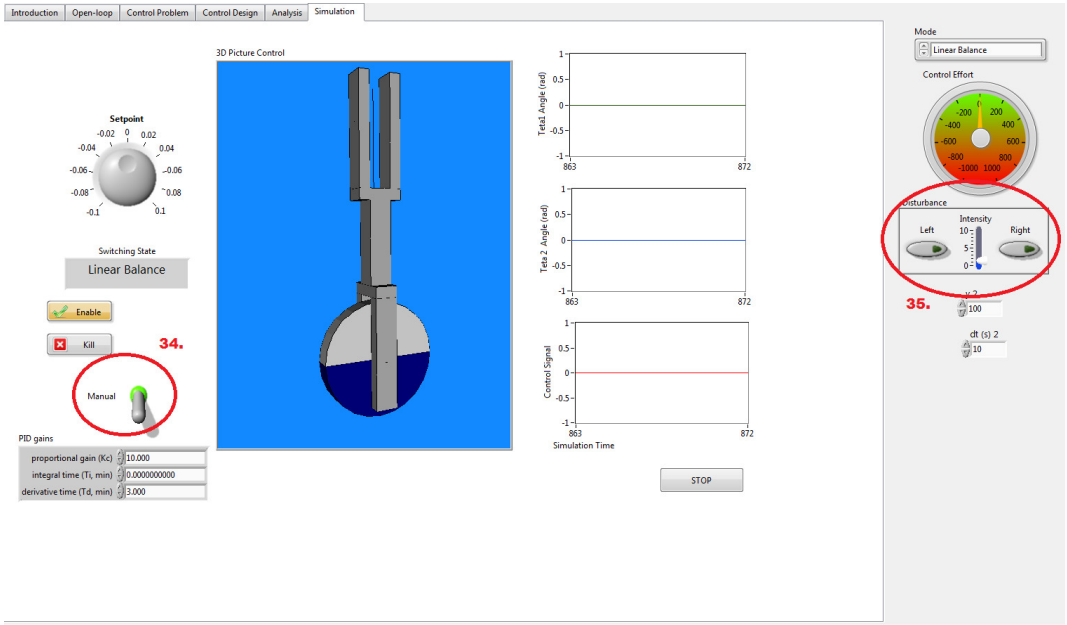
Using the Ackermann pole placement approach this time, a stable system (left) and an unstable system (right) are shown. For the unstable system, the 'Stability' indicator displays that the system is not stable. Thus no settling time can be achieved.

Simulating the Unicycle



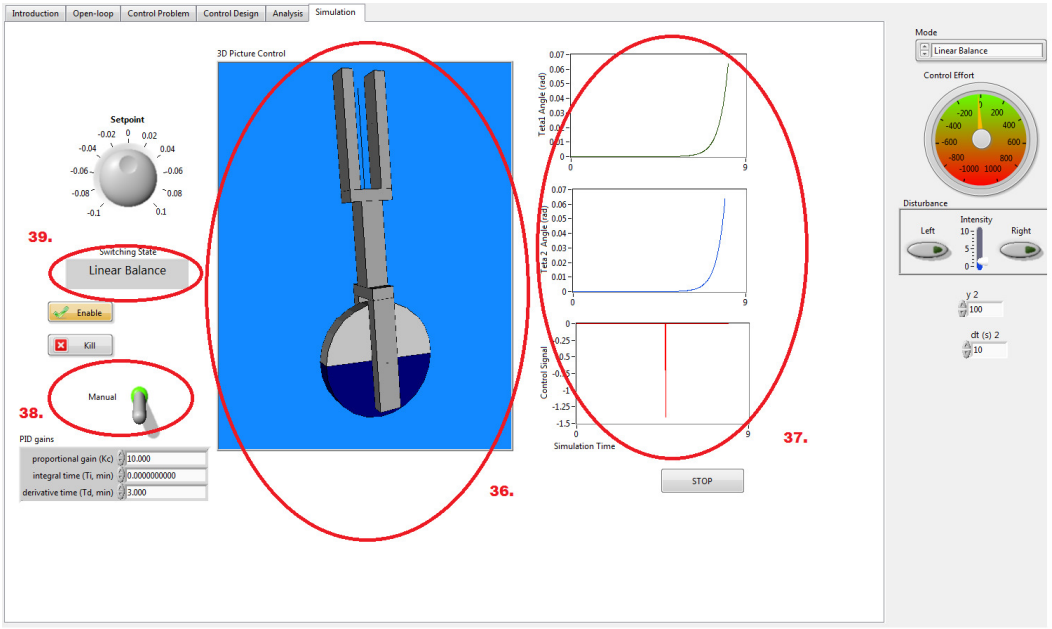
28. Select the ‘Simulation’ tab from the tab control to enter in the system simulation panel.
29. Verify that the ‘Switching State’ and the ‘Mode’ are set to Linear Balance. By changing the ‘Mode’, the ‘Switching State’ changes accordingly. If the switching state displays Emergency, restart the UI.
30. Ensure that the ‘Enable’ indicator is ON. This is dependent on the ‘Switching State’.
31. Ensure that the toggle switch is in the ‘Automatic’ position at the start.
32. This display gives a visualization of the system.
33. THIS IS THE MAIN ‘STOP’ BUTTON. If the system needs to be reset, click on this button to correctly shut off the VI’s. In case this does not work, used the hard-button ‘Abort’ stop located next to the Run arrow. A hard stop acts as the last line of defense if a reset needs to be done.

Applying a Force to the System

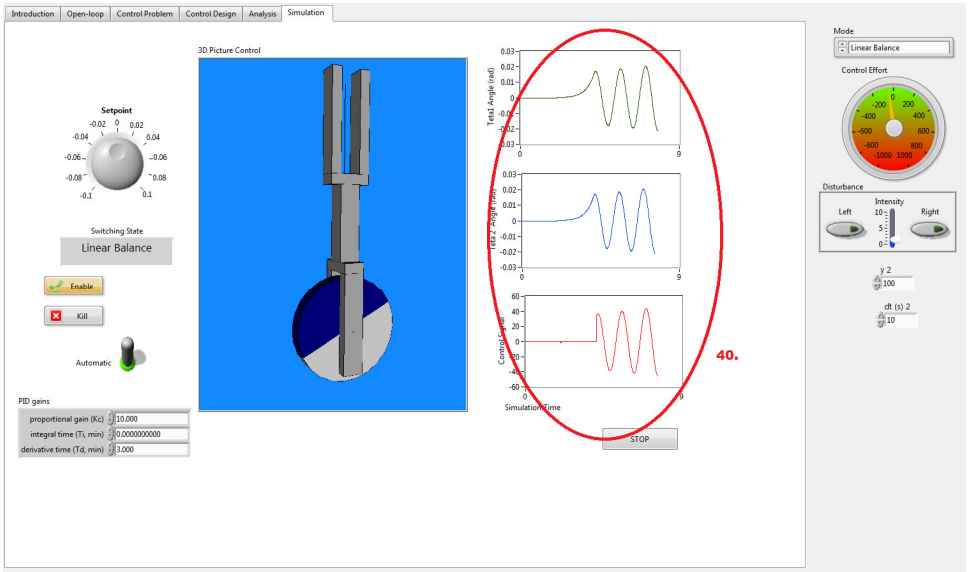


34. Toggle the 'Automatic' switch to 'Manual' so that a force can be applied to the robot.
35. Apply either 'Disturbance' either on the Left or Right side of the robot. *You may change the intensity of the force by sliding the 'Intensity' slider either up or down.*

36. The simulated model should start to lean to a side and act as an Open-Loop model after a force is applied.
37. The changes in the angle can be observed in the indicator graphs as well as the control signal. The control signal acts as the controller effort for the whole system.
38. Toggle the 'Manual' switch back to 'Automatic' to enable the controller.
39. The controller will respond to the system as long as the state is in Linear Balance and not Emergency state.

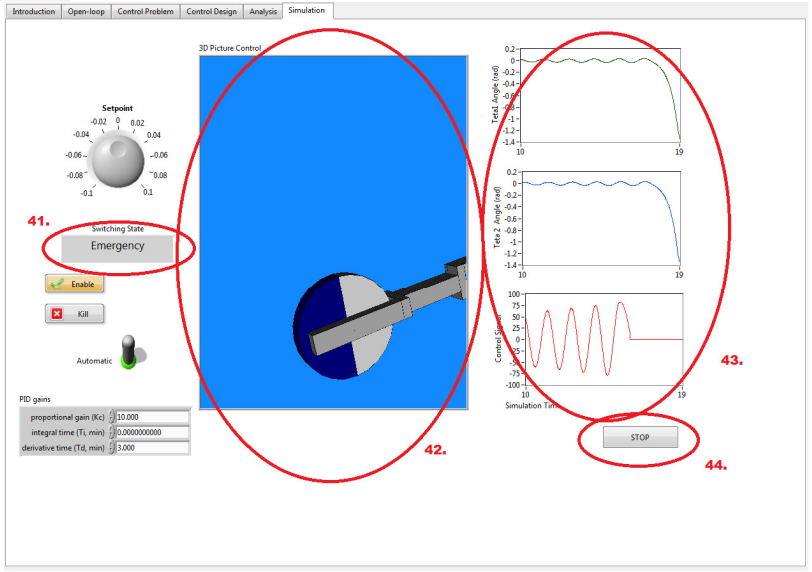


Enabling the Controller and Observing the System Response

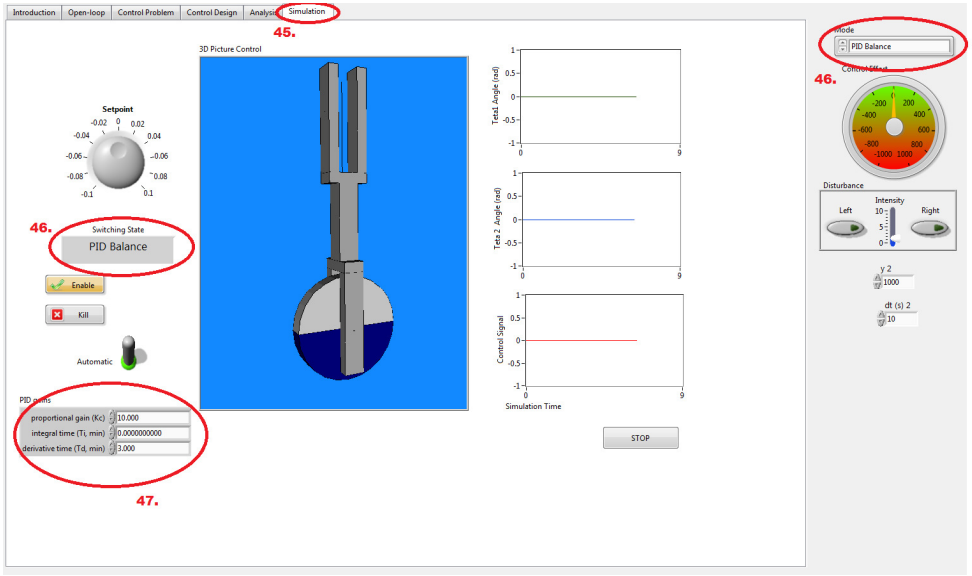


40. As the controller is enabled, the system simulates how the plant behaves as modeled by the Lagrangian equations. In this case, the system just keeps oscillating back and forth without reaching steady-state.

41. The ‘Switching State’ displays that the system has gone into the Emergency state because it is out of controlling bounds.
42. The unicycle has passed the point of no return which triggers the emergency state.
43. The control signal (in red) shows that it sends control effort values of zero to the motor controller thus preventing unwanted damage to the physical system.
44. After the system has reached the emergency state, the user must click on the ‘Stop’ button to correctly reset and reinitialize the system.

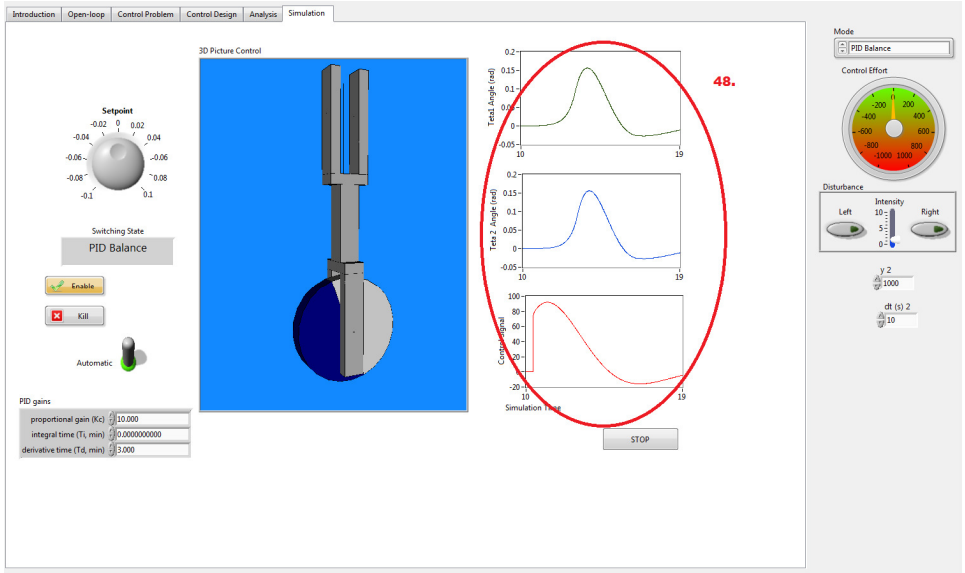


Using the PID Controller in the Simulator



45. After correctly resetting the entire UI, select the 'Simulation' tab.
46. Then select 'PID Balance' from the 'Mode" selector in the top right. The 'Switching State' indicates that the state has been switched to PID Balance.
47. Input the proportional, integral, and derivative gains as needed. Then a apply a disturbance as described earlier.

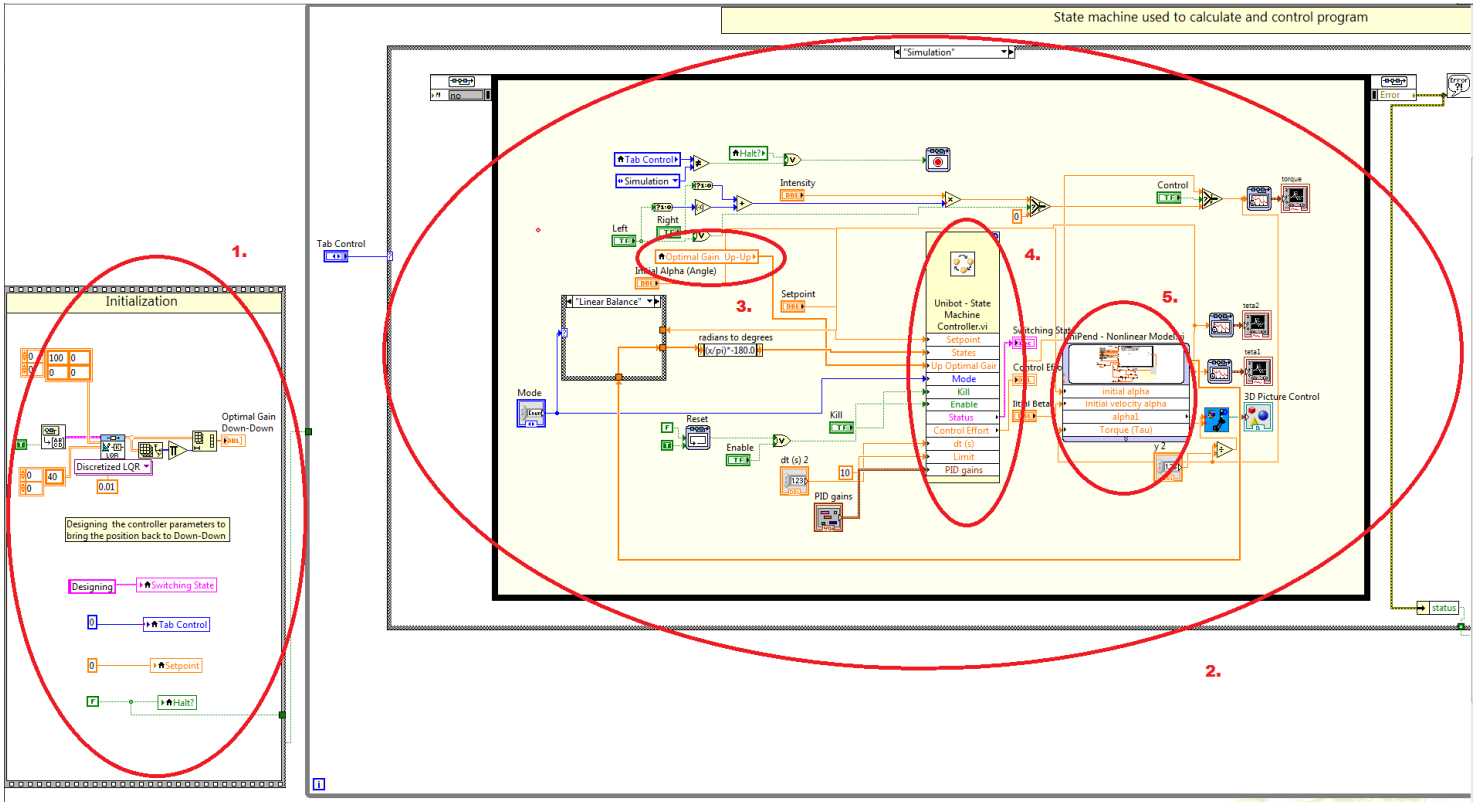
48. After applying the external simulated force and re-enabling the controller, the control signal (in red) shows that the PID controller is starting to take the system into a steady-state response.



*** *Note: The PID Controller is used only for demonstration purposes and it is not intended to function as the final controller of the unicycle. The PID controller does use information or update states from the plant model.*

Understanding the Block Diagram

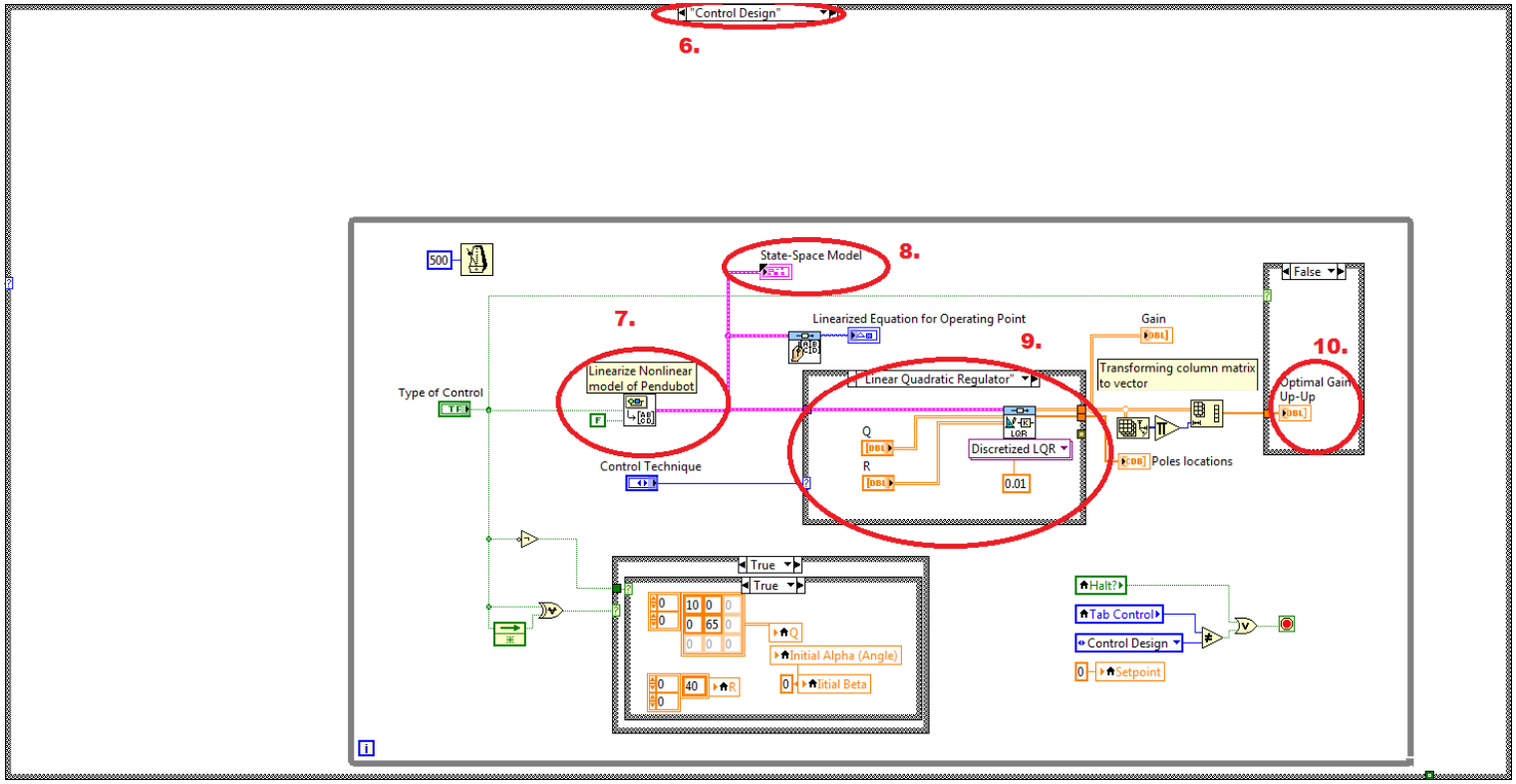
High Level Control Diagram



The control systems has 2 major control subsystems loops. Press CTRL+E to switch over to the Block Diagram view.

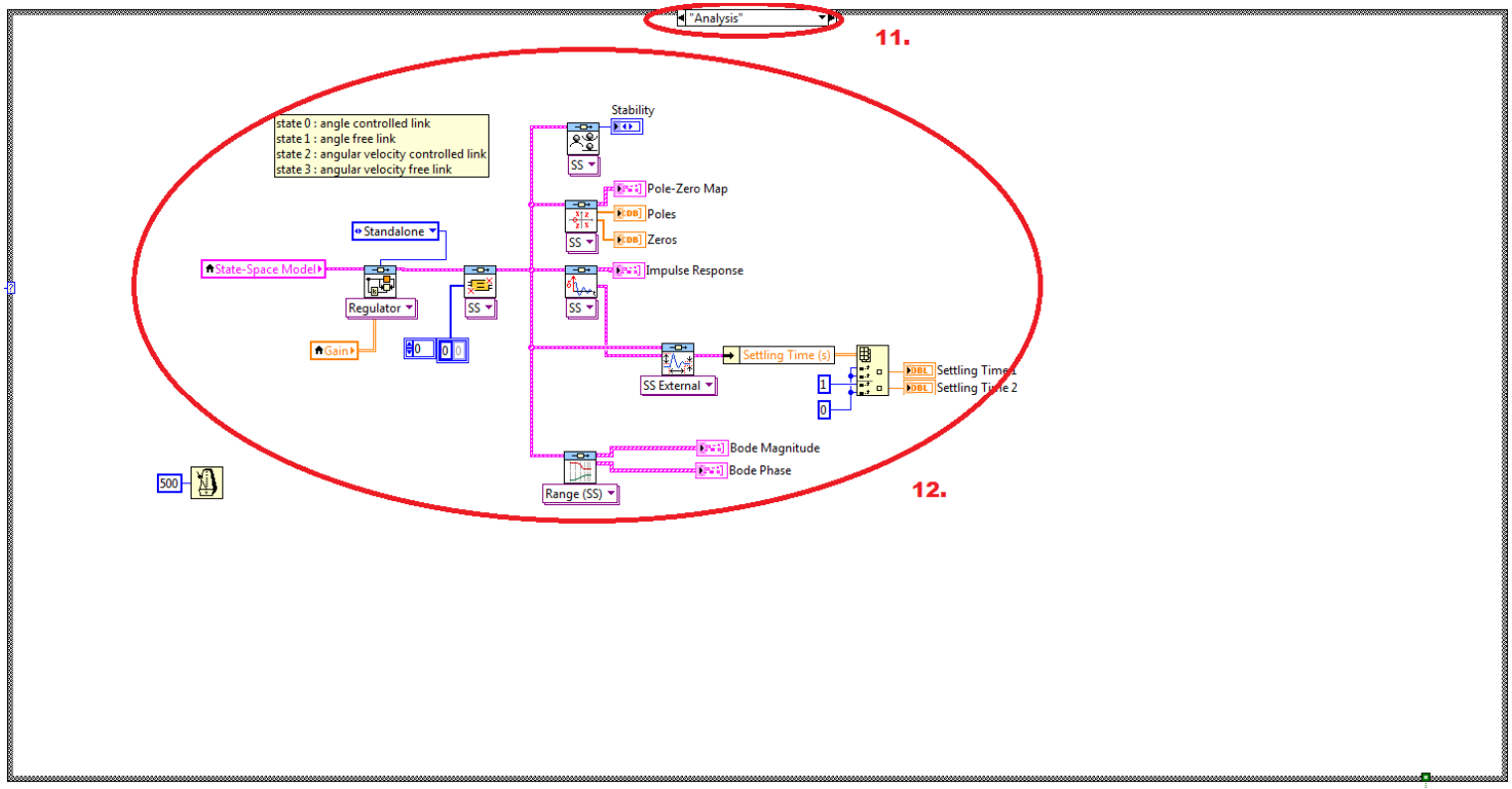
1. The first loop initializes the system, parses the states from the non-linear model, linearizes the system, organizes the states, and finally discretizes the state-space model.
2. The second loop handles the finite state machine operation of the controller.
3. The optimal gain of the discretized state-space model is used as a reference input to the plant.
4. The state-space model takes in information from the plant model and current gains to set the necessary control efforts.
5. The plant model is then updated after the new control efforts are calculated to compute the new optimal gains. After the optimal gains have been re-calculated, steps 3 through 5 are repeated until the system reaches steady-state or the system triggers the emergency state.

Control Design: Block Diagram



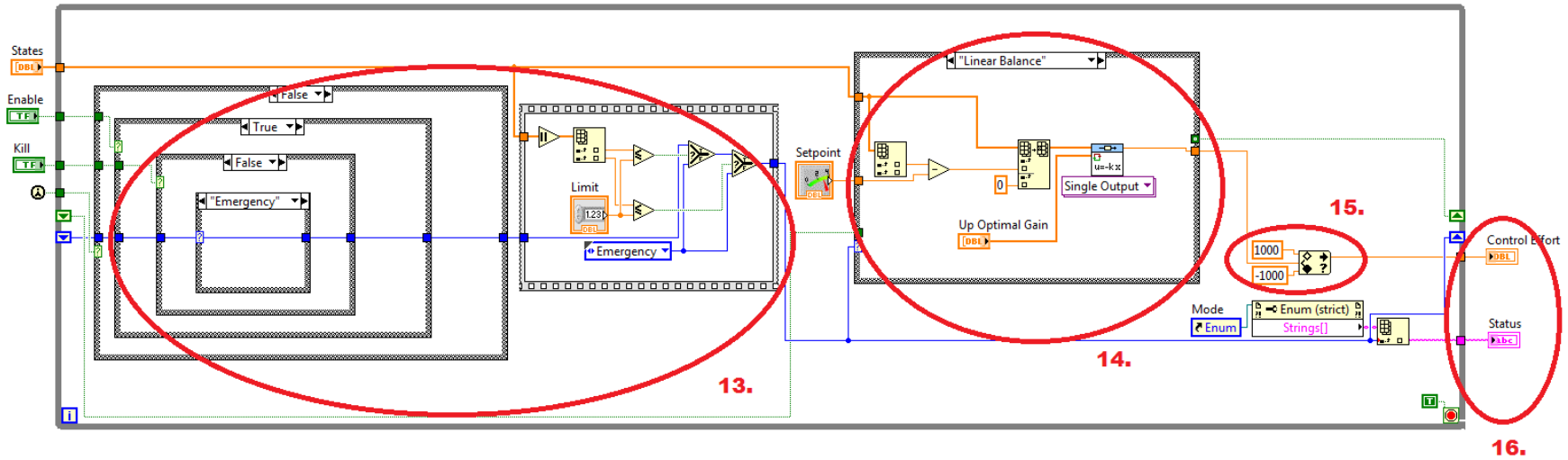
6. Switch to 'Control Design' in the block diagram loop.
7. The system is linearized before applying the control.
8. An updated 'State-Space Model' VI is updated and displayed in the Front Panel UI.
9. The type of controller is applied with the given parameter values.
10. The optimal gains of the system are then sent to the state-machine controller

Analysis: Block Diagram



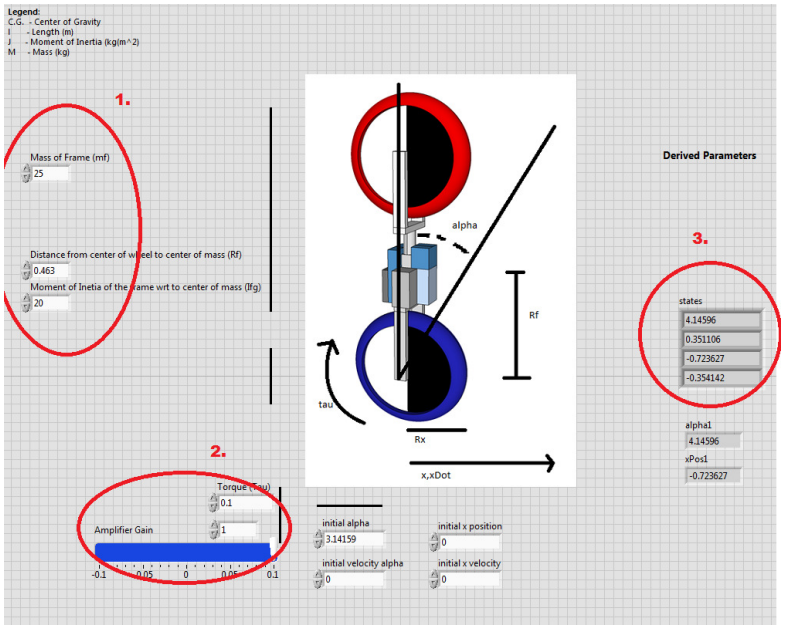
11. Select the 'Analysis' tab from the drop down menu in the block diagram to display the analysis tools.
12. Here the State-Space model has its stability, settling time, impulse response, pole locations, Bode magnitude and phase measured and plotted in the Front Panel.

Inside the State Machine Controller



13. In the machine state controller, the system first decides whether or not it is in emergency state. Emergency state is triggered if the controller detects that the unicycle system has gone past the safety operational boundaries (i.e. ±10°), the system shuts off power to the motors.
14. The system applies the selected controller (i.e. Linear Balance or PID Balance).
15. The control effort of the controller is limited to ±1000.
16. The control efforts and status of the robot are passed to the high level block diagram so they can be used update information on the plant model.

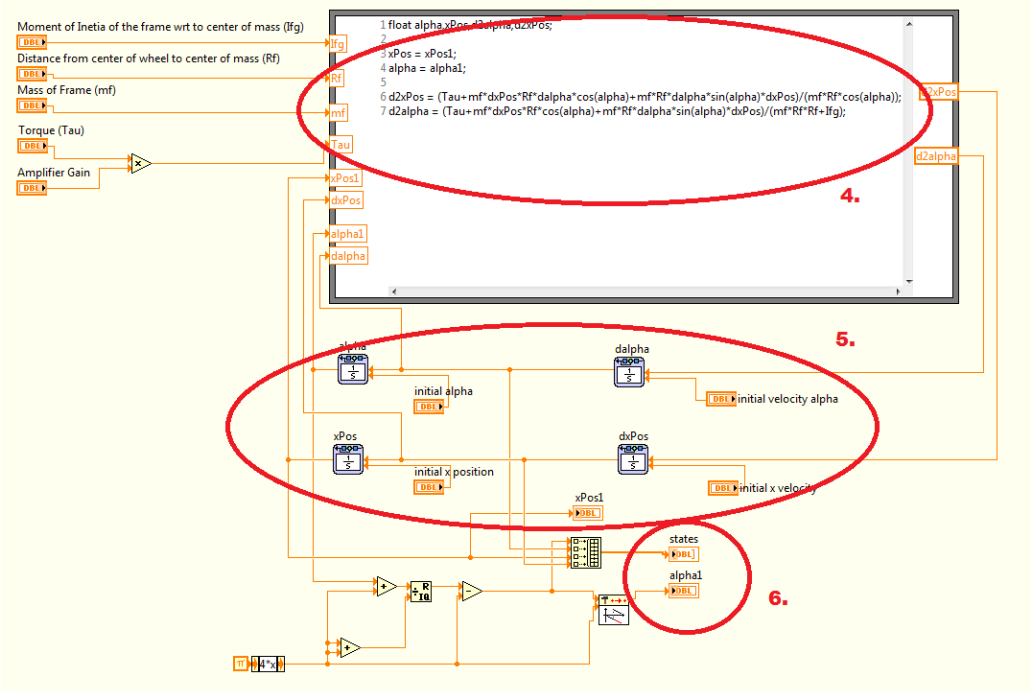
The Plant Model in LabVIEW



1. Physical parameters of the plant can be adjusted here.
2. Torque serves as the input to the plant model. Torque is set by the control effort from the controller.
3. The states are displayed and passed to the state parser so the system can be linearized and discretized.

In order the states are as follows:

- Angular position of system (alpha)
- Angular velocity of system (alphadot)
- Lateral position of system (x)
- Lateral velocity of system (xdot)



4. The Lagrangian non-linear state equations are imported into LabVIEW. Note how the equations couple together several states.
5. Information about each of the states are extracted by taking the integral of the acceleration vectors.
6. The states are then updated and displayed in the Front Panel and High Level Block Diagram.