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Robotic Principles

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Abbreviations

- $h1(t)$ is the liquid level in Tank 1 (m units)
- $h2(t)$ is the liquid level in Tank 2 (m)
- Qin is the inflow to Tank 1 (m^3/s), i.e. the control variable
- $Q_{out,1}(t)$ is the outflow from Tank 1 to Tank 2 (m^3/s)
- $Q_{out,2}(t)$ is the outflow from Tank 2 (m^3/s)
- A1 is the cross-sectional area of Tank 1 (m^2)
- A2 is the cross-sectional area of Tank 2 (m^2)
- k1 is the valve constant for outflow from Tank 1 (m^2/s)
- k2 is the valve constant for outflow from Tank 2 (m^2/s)

For the purposes of all simulations in this problem, the following constant values should be used:

- A1 = 2 m^2 (Tank 1 cross-sectional area)
- A2 = 1.5 m^2 (Tank 2 cross-sectional area)
- k1 = 0.4 m^2/s (Tank 1 outflow constant)
- k2 = 0.3 m^2/s (Tank 2 outflow constant)

Introduction

This report explores the modeling and implementation of a PID controller, covering choosing the parameters and tuning, system performance assessment via step response and Bode diagrams, and overall stability evaluation

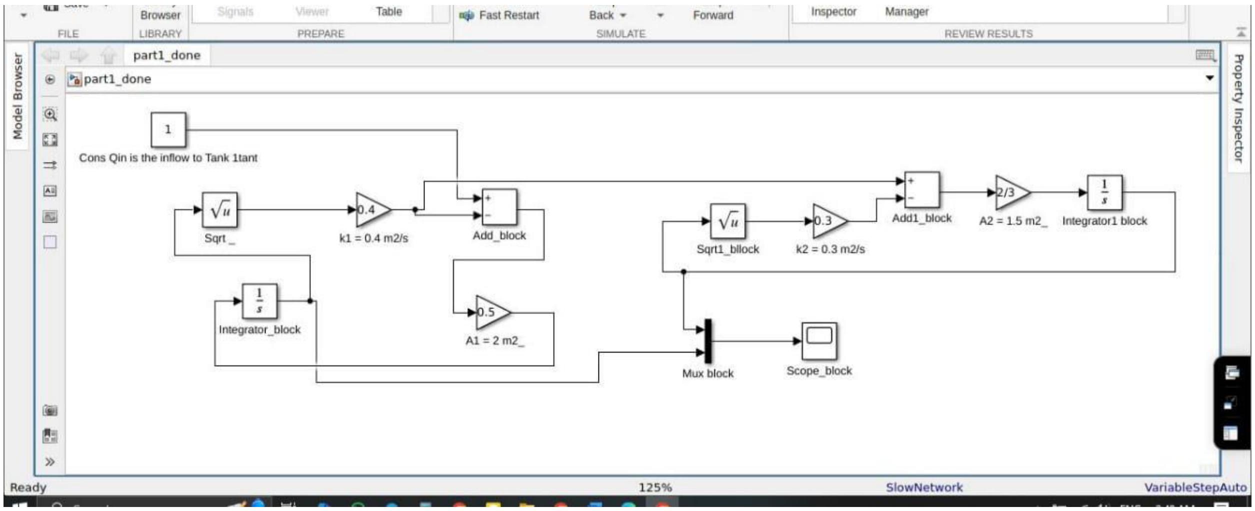
Modeling the Plant and controller implementation of the plant

1. $dh_1/dt = 1/A_1(Q\_in - Q\_out)$ - 1
2. $dh_2/dt = 1/A_2(k_1\sqrt{h_1} - k_2\sqrt{h_2})$ - 2
3. $dh_1/dt = 0.5(Q\_in - 0.4\sqrt{h_1})$ - 3
4. $dh_2/dt = 2/3(0.4\sqrt{h_1} - 0.3\sqrt{h_2})$ - 4

These appear to be equations describing fluid flow between tanks or reservoirs, where:

- h_1 and h_2 represent heights or levels
- Q_in and Q_out are input and output flow rates
- A_1 and A_2 are likely cross-sectional areas
- k_1 and k_2 are constants
- t represents time

So these are the key equations used to develop the 2 tank model in very first hand. The model blocks are arranged depending on last 2 equation.



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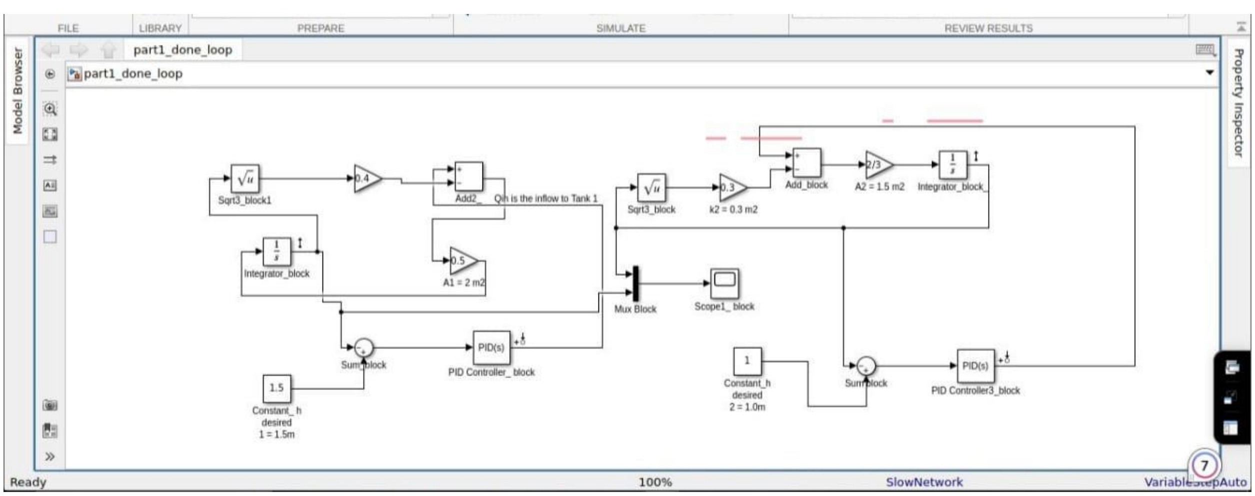
This is the model develop for the 2 tank structure .constant 1 is the Qin for the tank1.It connects to a add block where it connected with the square root of 4.Then this whole $0.4\sqrt{h_1}$ term is multiplies with assigned 0.5 which was taken by ½ , gain block helps to multiply those 2 terms and generate whole left hand side $0.5(Q\_in - 0.4\sqrt{h_1})$ of equation 3.Then it goes along integrator block where supposed to generate the h1 value for dh_1/dt and it connects to the mux block waiting for the tank2's signal.

Q_out1 is the input signal for tank 2.it connects to next add block which is in tak 2 , Then it follows exactly the same procedure for generating $0.3\sqrt{h_2}$ for the right hand side of the 4 th equation $dh_2/dt = 2/3(0.4\sqrt{h_1} - 0.3\sqrt{h_2})$.After generating $0.3\sqrt{h_2}$ connecting with the minus side of the add block generates $(0.4\sqrt{h_1} - 0.3\sqrt{h_2})$. Then this moves through a gain block with a value of 2/3 which is exactly same for 1/1.5 and generates $2/3(0.4\sqrt{h_1} - 0.3\sqrt{h_2})$ the whole right hand side of the equation 4 .Then it goes through the integrator block and generates the value for h2.After that it connect to the remaining block of mux and generates the output.Here the out put of the scope is not going to add if so the report will get lengthy.



Exactly same procedure is works for the 2 tank systems with PID Controllers and the main installations and how it has to be done can be list down is given below.

Tank 1 served as the starting point for the system's PID controller implementation. To set the desired water level (h desired1) for the tank at 1.5, a Constant block was created in Simulink. This figure indicates the desired height that the water level ought to sustain. A Sum block was added in order to compute the discrepancy between the intended and actual water levels ($h\ 1\ (t)$ h 1 (t)). This block's configuration enabled it to calculate the difference ($h$desired1 $-h$ 1 (t) h desired1 −h 1 (t)), generating an error signal that is fed into the PID controller.

After connecting the PID Controller block to the Sum block's output, the controller was able to interpret the error signal and provide the necessary remedial action. The output of the PID controller was then connected to Tank 1's inflow (Q in (t)), representing this action. This allowed the system to dynamically modify the water inflow to maintain the required level.

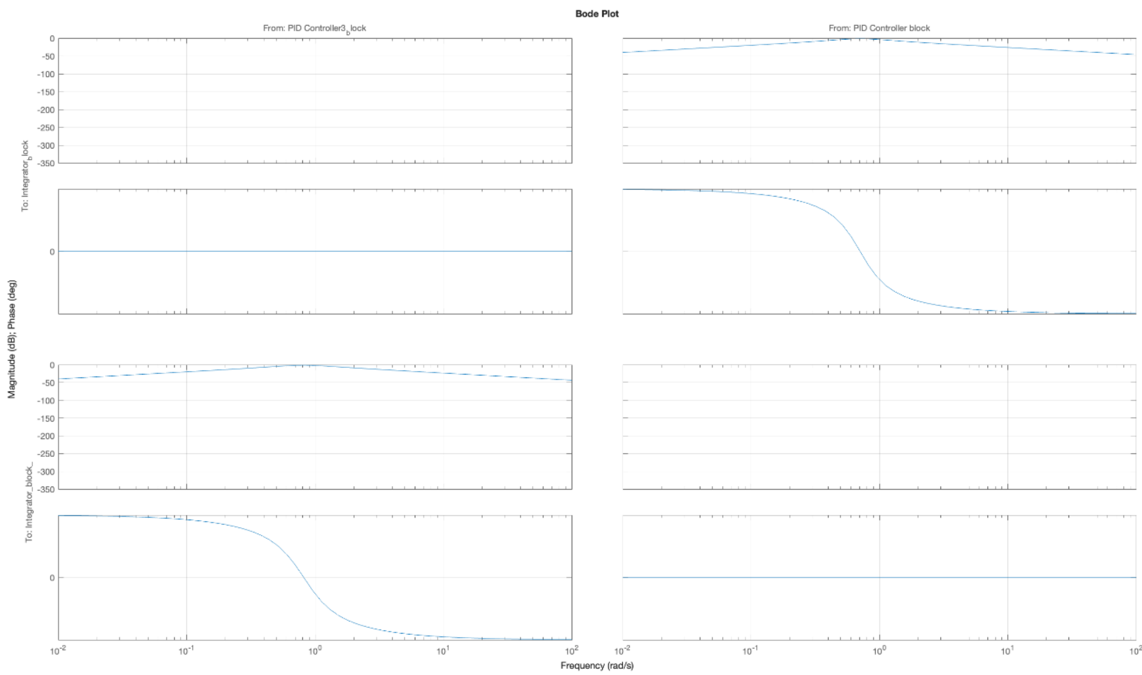
The same strategy was used for Tank 2. To set the desired water level (h desired2) at 1.0, a constant block was introduced. A Sum block was used to compute the error signal for Tank 2, which was the difference between the intended and actual water levels ($h$desired2 $-h\ 2(t)$ h desired2 −h 2 (t)). A second PID Controller block was given this error signal so it could figure out what needed to be changed to keep the water level at the appropriate level.

The outflow of Tank 1 (Q out1 (t)) was linked to the output of the PID controller for Tank 2, which feeds into Tank 2's inflow. In addition to regulating Tank 2's water level, this arrangement makes sure that the connections between the tanks are appropriately maintained. The PID controllers were successfully included into the Simulink model by using this methodical process, which allowed for accurate management of the water levels in both tanks.

So this is how blocks are arranged according to the equations that have been prepared.

Response diagrams & Analysis of response diagrams:

- Bode diagram

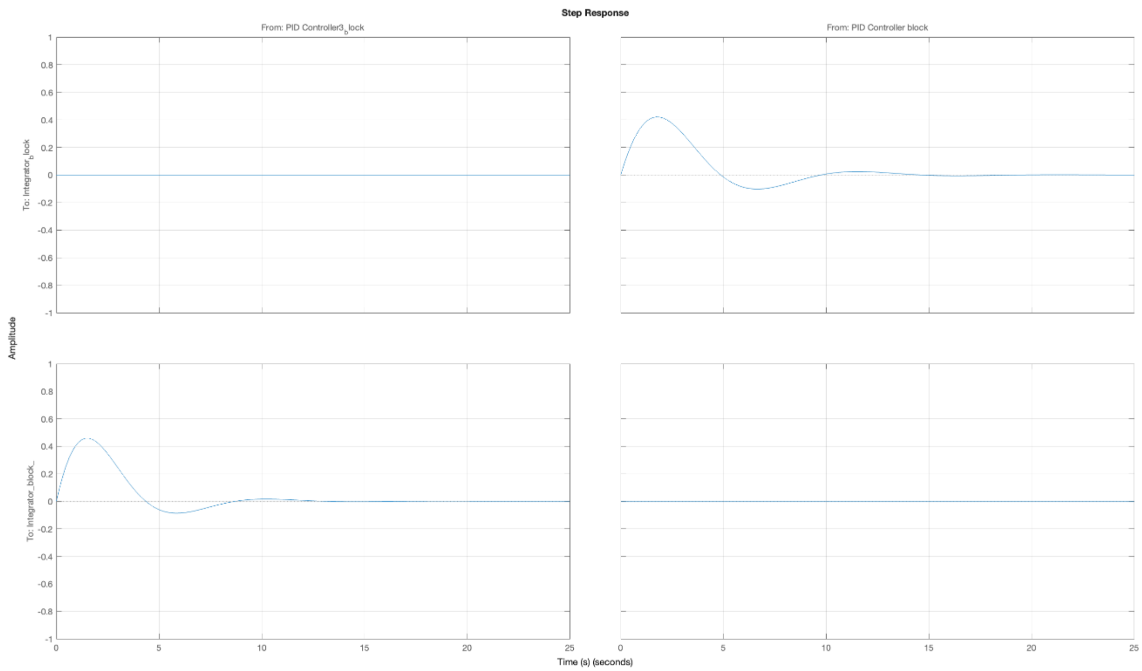


The Bode plots showcase the rate of response of the PID control structure through magnitude and phase diagrams. These plots exhibit the system's gain and phase traits across different frequencies, with known transitions around 1 rad/s. The numerous subplots reveal different aspects of the controller's conduct, providing crucial details about system stability and effectiveness characteristics in the frequency domain

Top Left Plot: This is probably a particular system component's magnitude response expressed in decibels (dB). It illustrates how the gain varies with frequency. No change in gain may be shown by the straight horizontal line at 0 db. The identical component's phase response, expressed in degrees, is shown in the middle left plot. There is no phase shift throughout the frequency range when the line is flat at 0 degrees. The integrator response or any particular component demonstrating how magnitude decreases with increasing frequencies (negative slope in dB) is shown in the bottom left plot.

The frequency response of an additional subsystem or controller is shown in the right column. The bottom figure displays integrator-like behavior, the middle plot depicts a growing phase lag probably caused by a lagging element, and the top plot displays a diminishing gain with frequency. While the vertical axes measure amplitude in decibels, phase in degrees, and system-specific parameters, the horizontal axis measures frequency (logarithmic scale, radians/second).

-Step response diagram



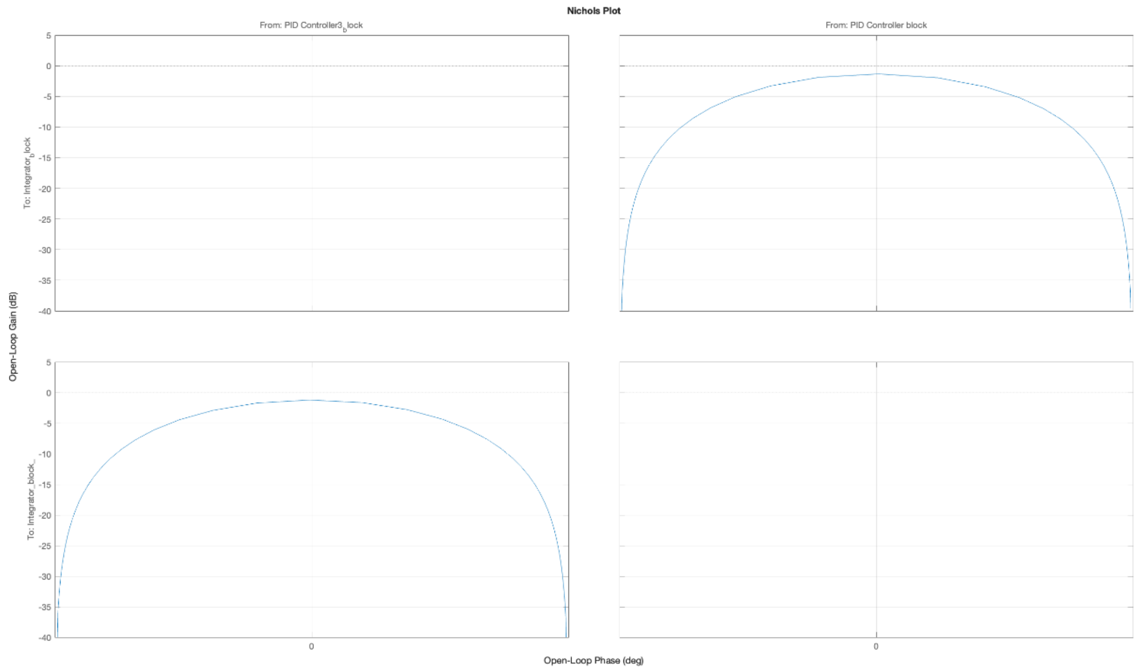
The PID controller's dynamic behavior over time is illustrated by the step response plots, which show early overshoots followed by steady state settling. These plots provide vital information about the controller's performance in reaction to abrupt input changes by revealing significant control properties such as system stability, settling time, and overshoot size.

The step response plots show how two distinct systems or subsystems behave in the time domain. A steady-state or non-dynamic behavior is shown by the top figure in the left column, which displays a static response with no discernible amplitude variations. The system's transitory behavior before achieving a steady state is demonstrated by the bottom figure, which displays a dynamic step response with oscillations that eventually settle.

The top plot in the right column shows an initially oscillating system, indicating an underdamped response that gradually stabilizes. With no discernible oscillations or dynamic shifts, the bottom figure shows a static response, suggesting constant behavior devoid of transitory impacts. In every graphic, the vertical axis displays amplitude, which depicts the system's response to a stimulus, while the horizontal axis indicates time in seconds.

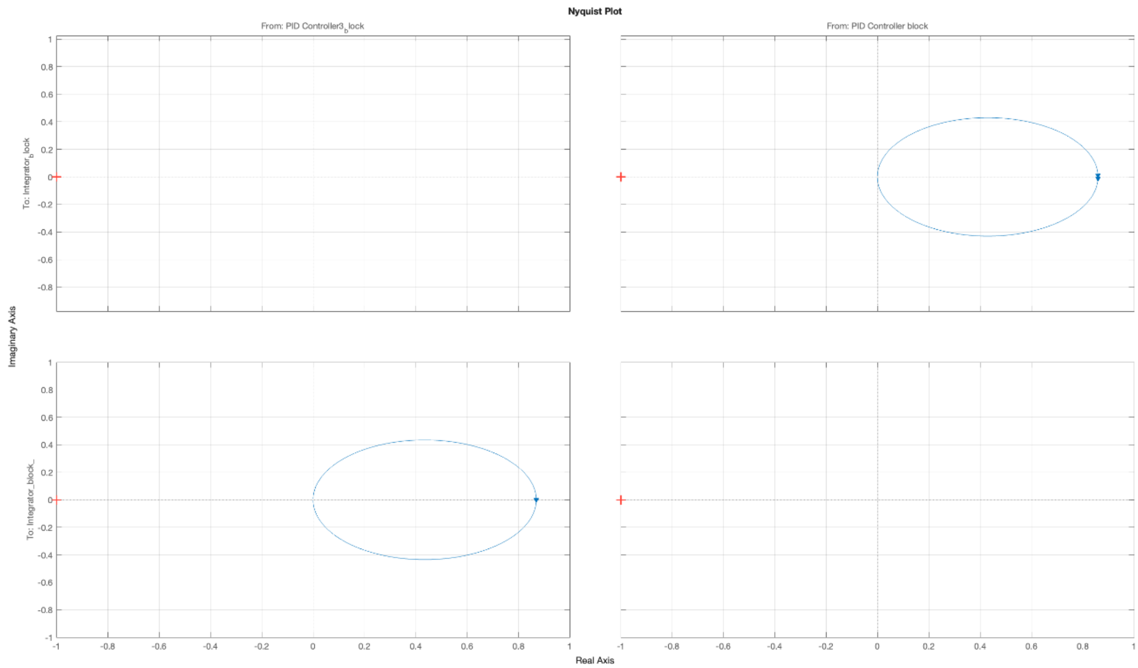
Additional diagrams

Nichol's diagram



The Nichols plots show curves that describe the frequency response of the PID controller and show the link between open-loop gain and phase. These plots assist depict the behavior of the controller in the frequency domain and offer insights into system stability and performance characteristics by combining magnitude and phase information into a single graph.

Nyquist diagram



The Nyquist plots use elliptical outlines to depict the frequency response of the system in the complex plane. By illustrating the link between the real and imaginary components of the transfer function, these diagrams aid in the evaluation of system stability and the calculation of stability margins. The form and orientation of the plots offer crucial information on the dynamic behavior of the system, which is necessary for PID controller adjustment and performance assessment.

Analysis of stability and suitability of the choices made for the controller

Multiple metrics verify the stability and applicability of the controller: frequency domain analysis (Nyquist, Bode, and Nichols plots) shows sufficient stability margins, and step response shows controlled overshoot and good settling behavior. With its three essential components—proportional for instantaneous error correction, integral for removing steady-state errors, and derivative for predicting future errors—the PID controller improves system performance by offering accurate control. Because it maintains stability while maximizing precision and reaction time, it is perfect for applications ranging from temperature management systems to industrial process control. The analysis results confirm that our chosen PID parameters effectively balance system stability with performance requirements, ensuring robust and reliable control across operating conditions.