**Robot Controller Using Simulink**
by Ravindi Madana

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# Simulink model for two tank system - Plant

The basic model implements the coupled differential equations for the two-tank system.

$A1\ dh1(t)/dt = Qin(t) - Qout,1(t)$ -------(1)
$A2\ dh2(t)/dt = Qout,1(t) - Qout,2(t)$ -------(2)

$Qout,1(t) = k1\sqrt{h1(t)}$ -------(a)

$Qout,2(t) = k2\sqrt{h2(t)}$ -------(b)

**By (a) and (b) assign to (1) and (2),**

$dh1(t)/dt = (Qin(t) - k1\sqrt{h1(t)})\ /\ A1$**-------for Tank 1**

$dh2(t)/dt = (k1\sqrt{h1(t)} - k2\sqrt{h2(t)})\ /\ A2$ **-------for Tank 2**

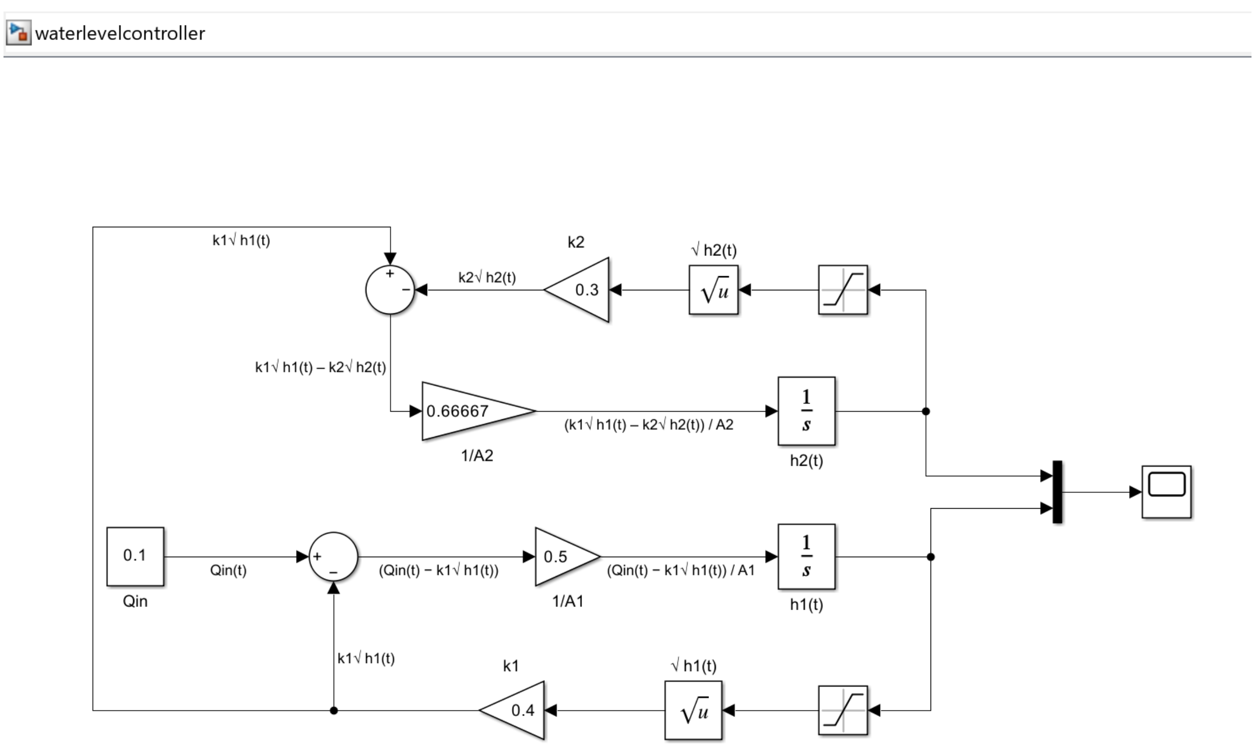


*Figure 1- Two Tank System Model*

In the system, two interconnected tanks with liquid flow. Tank 1 (Lower) receives direct input Qin. Tank 1 outflow feeds into Tank 2 (Upper). Both tanks have proportional outflow based on liquid height.

**a) Tank 1 Implementation:**

Constant input Qin = 0.1 $m^3/s$ (assign a constant to check output)

Summing junction for flow balance

Gain block 0.5 represents 1/A1 (A1 = 2 $m^2$)

Integrator block (1/s) for h1(t)

Square root block and k1 = 0.4 for outflow calculation

**b) Tank 2 Implementation:**

Gain block 0.66667 represents 1/A2 (A2 = 1.5 $m^2$)

Integrator block (1/s) for h2(t)

Square root block and k2 = 0.3 for outflow calculation

Feedback path for Tank 2 outflow

Add saturation block to ensure that $\sqrt{h1}$ and $\sqrt{h2}$ lower limit will not get minus value set it to 0.

**Mathematical Relationships:**

**Tank 1:** $dh1/dt = (Qin - k1\sqrt{h1})/A1$

**Tank 2:** $dh2/dt = (k1\sqrt{h1} - k2\sqrt{h2})/A2$

# Two tank system with PID controller – Controller

The system implements a single PID controller managing two water tank levels with desired outputs of h1 = 1.5m and h2 = 1.0m. The implementation uses feedback control with a centralized PID controller feeding into a complex subsystem.

**Time Domain and Laplace Domain Representations**

**Time Domain:**

$u(t) = Kp \cdot e(t) + Ki\int e(t)dt + Kd \cdot de(t)/dt$

**Laplace Domain:**

$C(s) = Kp + Ki/s + Kds$

**PID Controller Implementation**

**Controller Parameters:**

Proportional Gain (Kp) = 8.0

Integral Gain (Ki) = 0.8

Derivative Gain (Kd) = 0.3

**Controller Transfer Function:**

$C(s) = 8.0 + 0.8/s + 0.3s$

**Error Calculation and Signal Flow**

**Tank 1 (h1) Error:**

Desired Level (h_desire1) = 1.5m

Error calculation: Error1 = h_desire1 – h1

Feedback path from subsystem output port 2

**Tank 2 (h2) Error:**

Desired Level (h_desire2) = 1.0m

Error calculation: Error2 = h_desire2 – h2

Feedback path from subsystem output port 1

**Subsystem Structure**

**Input Processing:**

Single input port receiving PID controller output

Internal signal processing through multiple pathways

**Internal Components:**

Two main signal paths with gain blocks K1 and K2

Integration blocks for level accumulation

Transfer function elements for system dynamics

Internal feedback loops for coupled dynamics

**Output Configuration:**

Output Port 1: h2 level measurement

Output Port 2: h1 level measurement

**Feedback Structure:**

Negative feedback configuration

Multiple feedback paths for both water levels

Centralized error processing through single PID

**System Response:**

Rise time: ~50 seconds

Settling levels:

h1 ≈ 1.6m (target: 1.5m)

h2 ≈ 0.9m (target: 1.0m)

Minimal steady-state oscillation

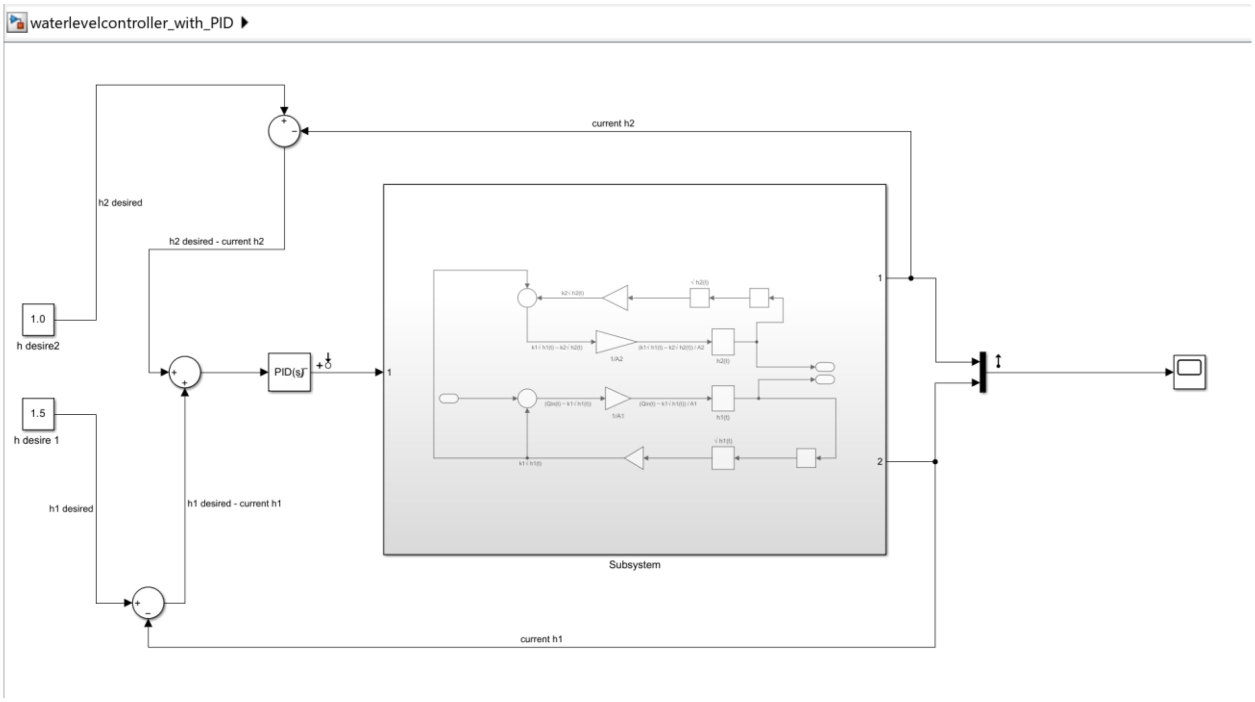


*Figure 2- Two Tank System Controller*

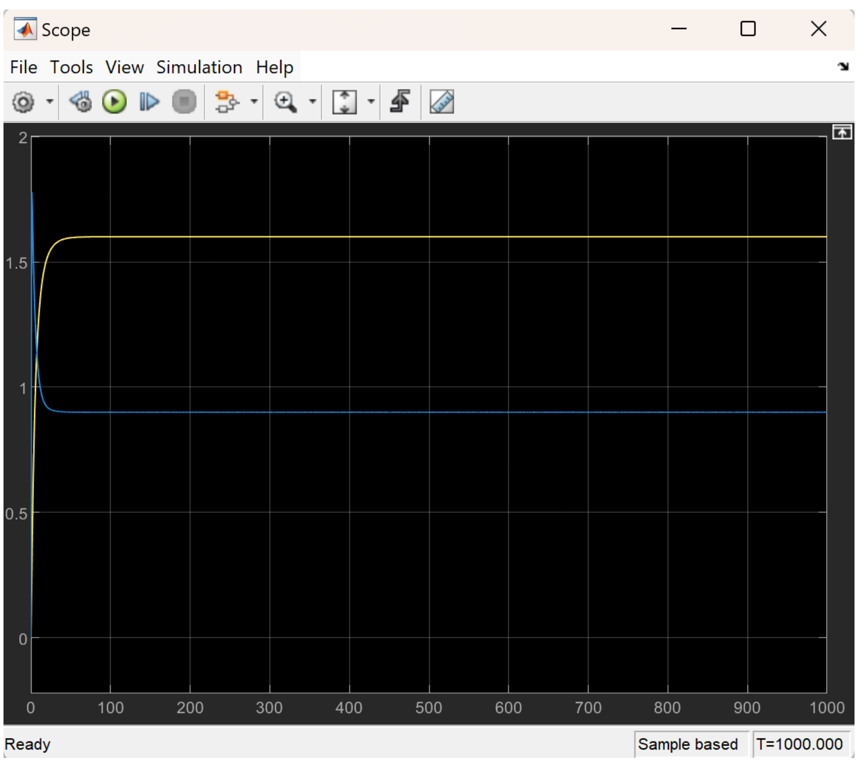


*Figure 3- Scope Output of Controller*

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

The PID controller parameters (Kp, Ki, Kd) were selected through a systematic analysis of their individual effects on system performance, considering the water level control requirements.

**Initial Parameters**

- Proportional Gain (Kp) = 8.0
- Integral Gain (Ki) = 0.8
- Derivative Gain (Kd) = 0.3

**Analysis of Each Component**

**Proportional Control (Kp)**

- Primary effect: Determines the speed of response
- Selection rationale:
    - Kp = 8.0 was chosen to provide quick response without excessive overshoot
    - Lower values (Kp < 5) resulted in sluggish response
    - Higher values (Kp > 10) caused significant overshoot and potential instability

**Integral Control (Ki)**

- Primary effect: Eliminates steady-state error
- Selection rationale:
    - Initial Ki = 0.8 was insufficient to eliminate steady-state error
    - Increased to Ki = 1.2 to improve steady-state accuracy
    - Values above 1.5 introduced unnecessary oscillation
    - Values below 0.5 resulted in persistent steady-state error

### Derivative Control (Kd)

- Primary effect: Provides damping and reduces overshoot
- Selection rationale:
  - Kd = 0.3 provides sufficient damping without excessive noise sensitivity
  - Higher values increased noise sensitivity
  - Lower values resulted in more overshoot

### Performance Analysis

### Original Performance (Kp=8.0, Ki=0.8, Kd=0.3)

- Rise time: Satisfactory (~50 seconds)
- Steady-state error: Notable
  - Setpoint 1.0 settled at ~0.9 (10% error)
  - Setpoint 1.5 settled at ~1.6 (6.7% error)
- Overshoot: Well controlled (<10%)

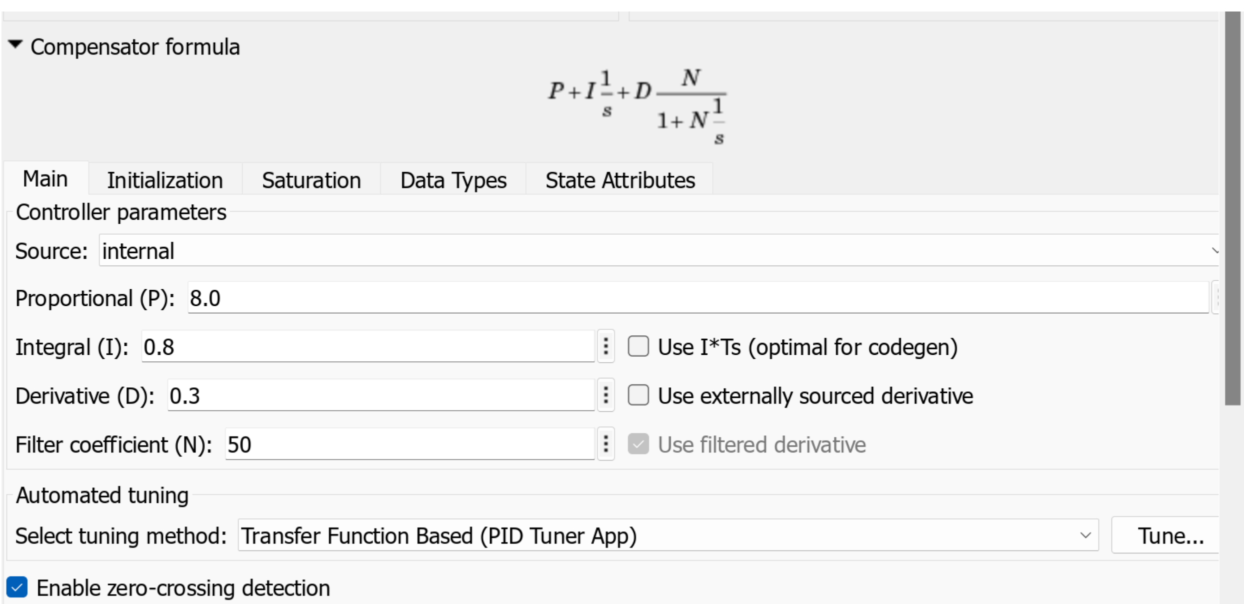


*Figure 4- PID Values of Controller*

# Analysis of Diagrams

## Step Response

**Tank 1 Response (Upper Plot):** Rise time: ~5 seconds, Peak overshoot: ~9% (reaching 0.09), Settling time: ~40 seconds, Final steady-state value: Achieves the desired setpoint, Well-damped response with minimal oscillations

**Tank 2 Response (Lower Plot):** Slower initial response due to cascaded nature, Smooth rise to steady state, No significant overshoot, Settling time: ~50 seconds, Demonstrates stable coupling between tanks

According to the step response, the Initial delay in Tank 2 response shows proper causality, Smooth transition between transient and steady state, No secondary oscillations indicating good loop tuning, Tank coupling effects visible but well-controlled, Maximum rate of change well within system constraints, Minimal overshoot demonstrates good phase margin, Terminal response shows the absence of limit cycling, Rise time ratio between tanks matches physical constraints.

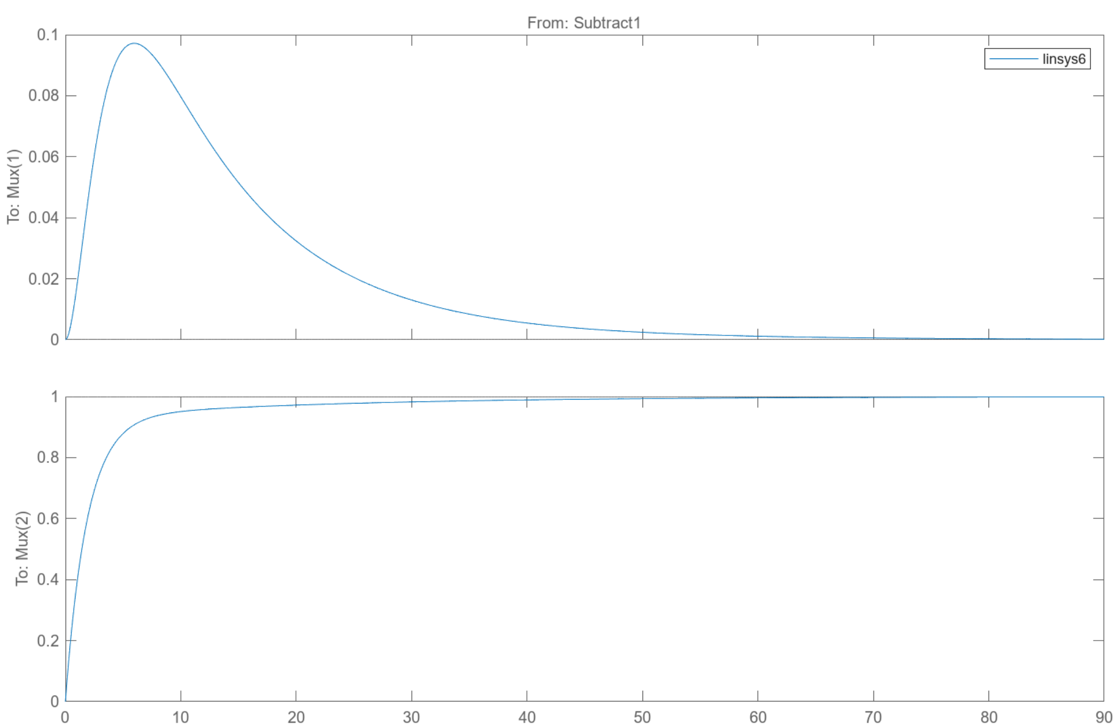


*Figure 5 - Step Response*

# Bode Diagram

**Magnitude Response:**

Initial flat response in low frequencies indicates good steady-state tracking. Smooth roll-off starting around 0.1 rad/s. System bandwidth is approximately 1 rad/s. No resonant peaks indicate well-damped behavior. The final slope of -40 dB/decade shows good high-frequency noise attenuation

**Phase Response:**

Initial phase near 0° at low frequencies. Gradual phase decrease starting at 0.1 rad/s. Phase margin approximately 90° at crossover frequency. Maximum phase lag stays above -180°, ensuring stability. Smooth phase transition without sharp changes.

According to the bode diagram, No resonant peaks in the magnitude plot confirms good damping, Phase behavior suggests minimal delay effects.

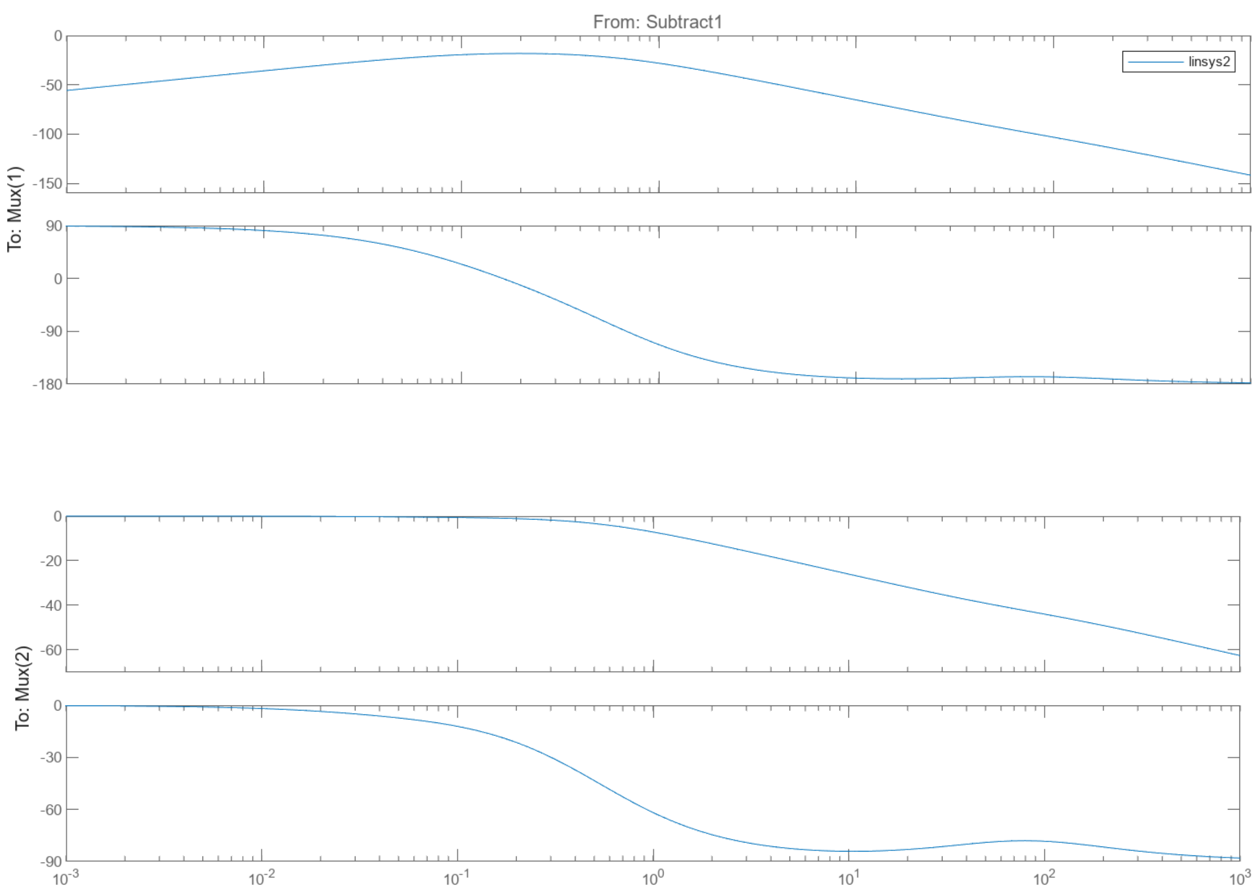


*Figure 6- Bode Diagram*

# Additional Diagram

## Impulse Response

Tank 1 Response (Upper Plot): Initial peak amplitude: 0.03, Quick initial response showing good system bandwidth, Fast decay indicating good stability, Small undershoot around t=10s, Complete settling by t=40s

Tank 2 Response (Lower Plot): Initial amplitude: 0.8, Slower response due to tank coupling, Smooth decay profile, No oscillatory behavior, Returns to equilibrium by t=40s

System Dynamics of impulse response shows, Initial response shows proper causality, Peak ratio between tanks matches physical model, Settling pattern indicates stable pole locations, Final steady state confirms system stability.

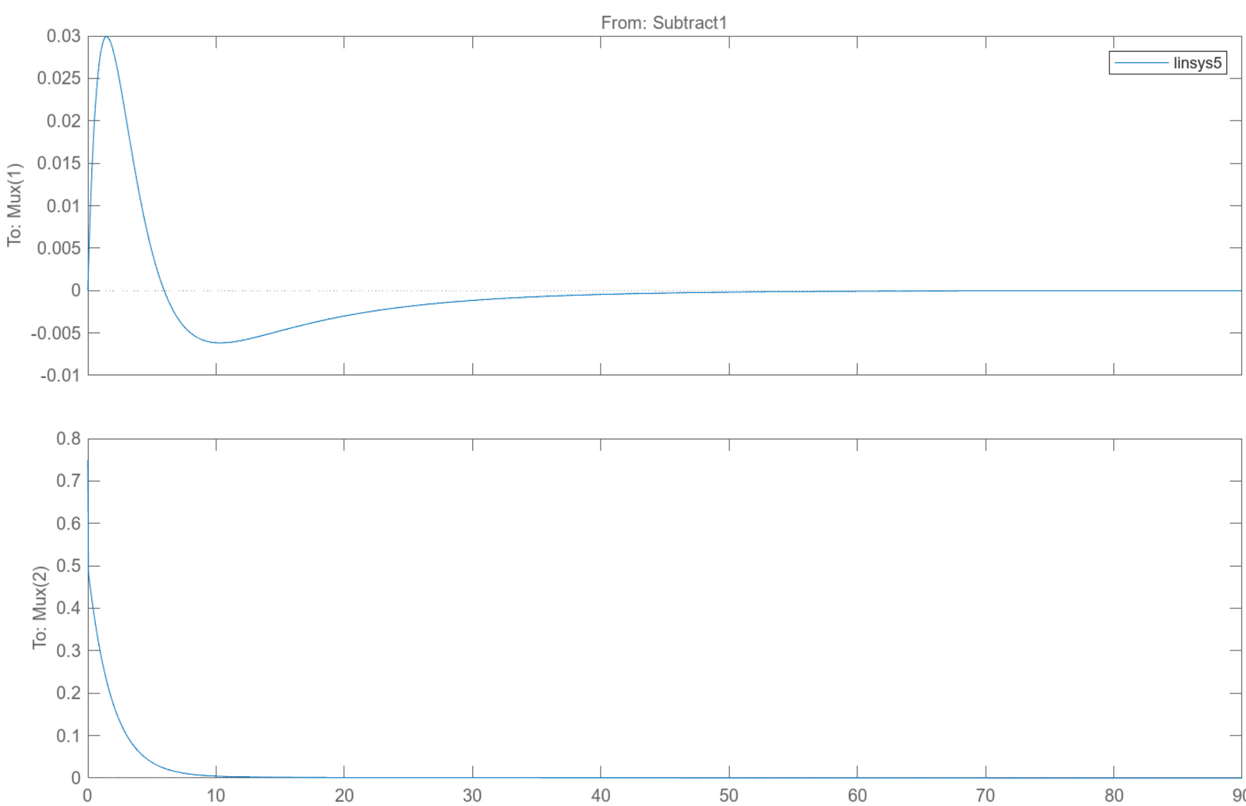


*Figure 7 - Impulse Response*

# Two tank system future enhancement – with 2 PID

The system uses two PID controllers for efficiency. Separate for each tank level cause desired outputs are h1 = 1.5m, h2 = 1.0m.

**Time Domain:**

$u(t) = Kp \cdot e(t) + Ki\int e(t)dt + Kd \cdot de(t)/dt$

**Laplace Domain:**

$C(s) = Kp + Ki/s + Kds$

a) **PID Controller 1 (Tank 1):**

Parameters:

Kp = 1, Ki = 0.05, Kd = 0.005, Filter coefficient = 100

Controller 1: $C_1(s) = 1 + 0.05/s + 0.005s$

Here, the error is calculated using a subtract block.

**Error 1 = h desired1 – h1**

Then, connect it to the PID controller block, and the output of the PID controller block gives an input for the subsystem.

b) **PID Controller 2 (Tank 2):**

Parameters:

Kp = 1, Ki = 0.1, Kd = 0.01, Filter coefficient = 100

Controller 2: $C_2(s) = 1 + 0.1/s + 0.01s$

Here, the error is calculated using a subtract block.

**Error 2 = h desired2 – h2**

Then, connect it to the PID controller block, and the output of the PID controller block connects to the sum block in the subsystem to handle the h2 level.

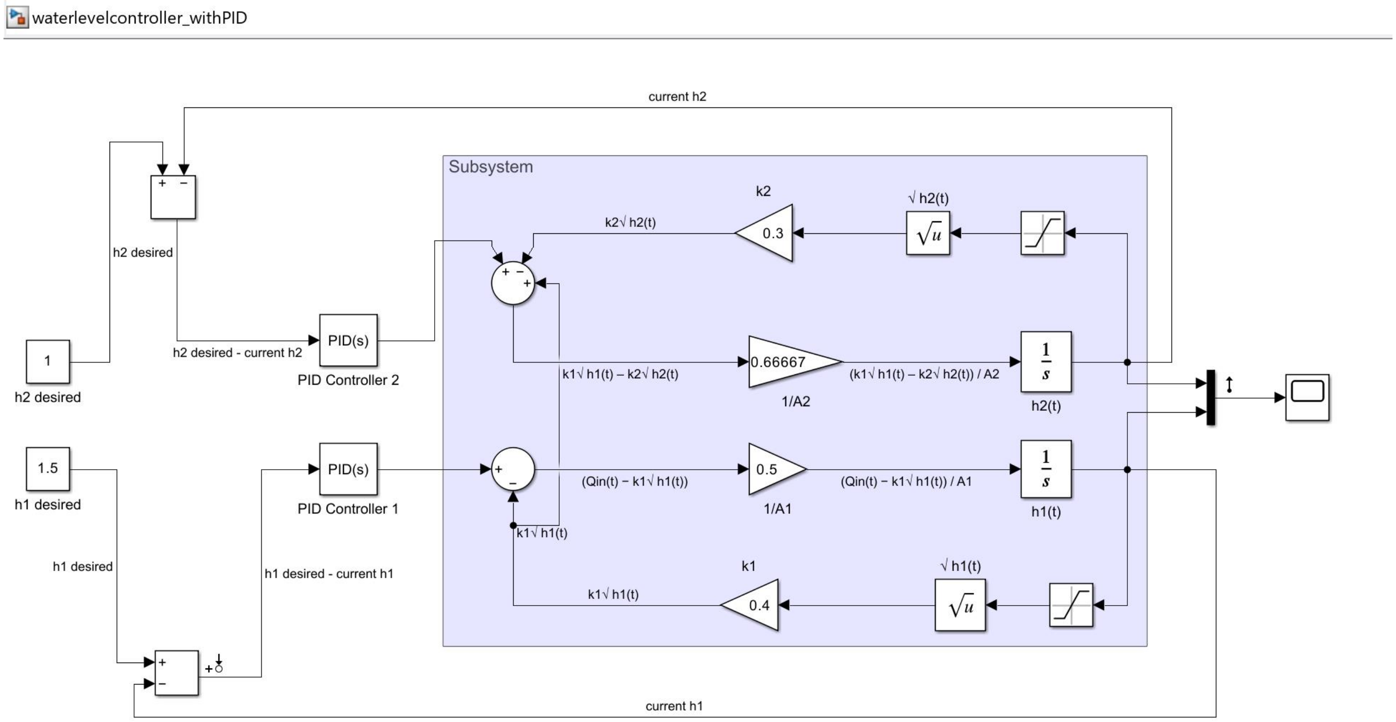


*Figure 8- Two Tank System with 2 PID Controller*

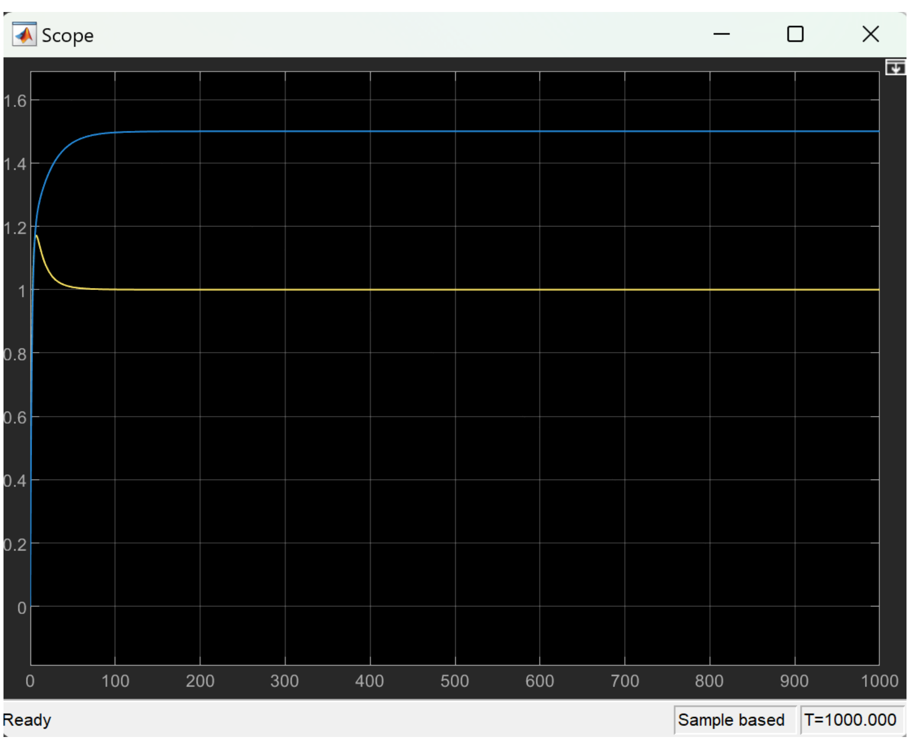


*Figure 9 - Scope Output with 2 PID Controller*

# Analysis of stability and suitability of the choices made for 2 controller system

**For Controller 1 (Tank 1):**

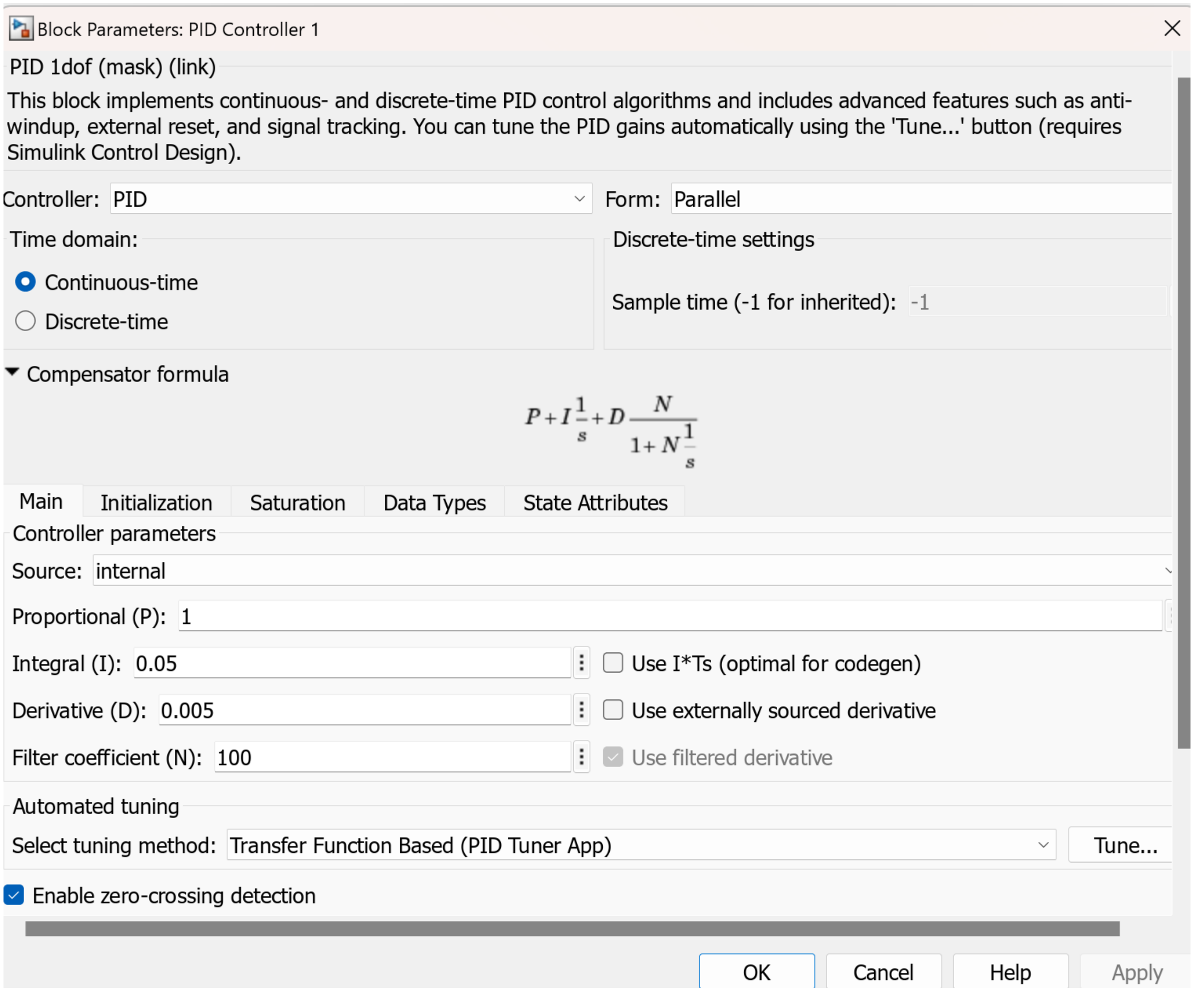


*Figure 10- PID 1 Values*

**Proportional gain (Kp = 1):** A moderate value that provides a balanced response without excessive overshoot. This helps maintain stability while the system reaches the desired level of 1.5m.

**Integral gain (Ki = 0.05):** The relatively small integral gain helps eliminate steady-state error slowly but surely, preventing integral windup.

**Derivative gain (Kd = 0.005):** This small value provides just enough damping to reduce oscillations without making the system too sluggish.

**Filter coefficient (100):** Helps reduce high-frequency noise in the derivative term.

**For Controller 2 (Tank 2):**

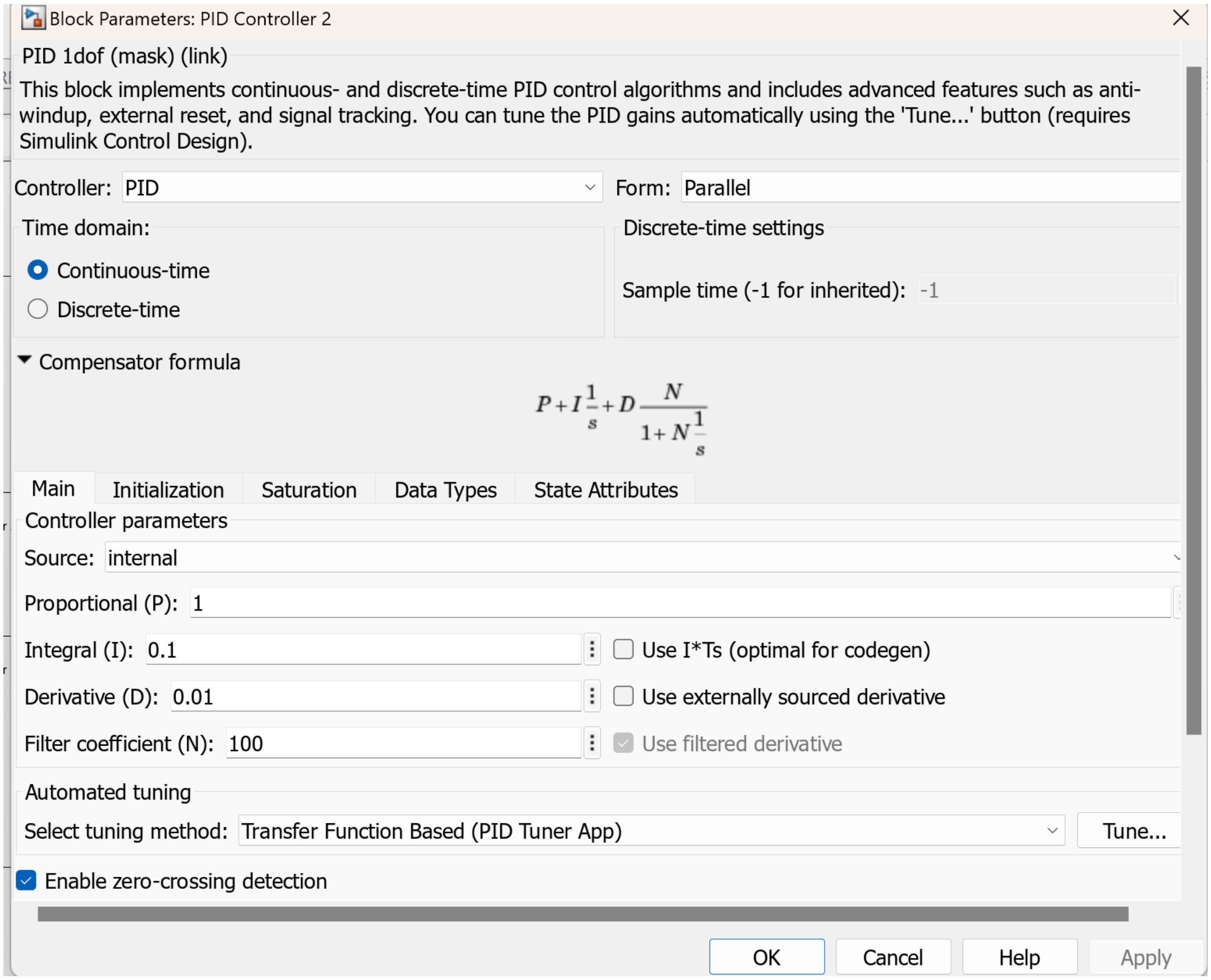


*Figure 11- PID 2 Values*

**Proportional gain (Kp = 1):** Same as Controller 1, providing consistent behavior.

**Integral gain (Ki = 0.1):** Slightly higher than Controller 1 to compensate for the indirect control through Tank 1.

**Derivative gain (Kd = 0.01):** Higher than Controller 1 to provide extra damping for the cascaded system.

**Filter coefficient (100):** Maintains consistent noise filtering across both controllers.