Control Presentation

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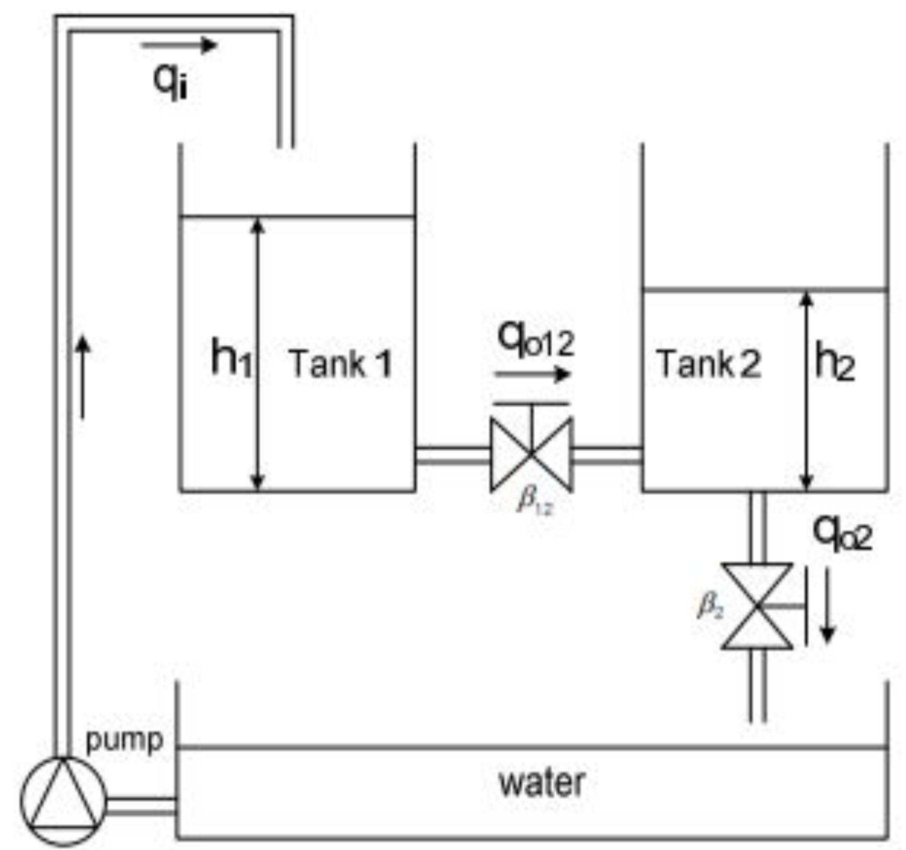
The system



The nonlinear equation can be obtained by mass equivalent equation and Bernury's law is given by.

$$\frac{dh_1(t)}{dt} = -\frac{\beta_{12} a_{12}}{A_1}\sqrt{2g\big(h_1(t) - h_2(t)\big)} + \frac{k}{A_1}u(t)$$

$$\frac{dh_2(t)}{dt} = -\frac{\beta_2 a_2}{A_2}\sqrt{2gh_2(t)} + \frac{\beta_{12} a_{12}}{A_2}\sqrt{2g(h_1(t) - h_2(t))}$$

$$G(s) = \frac{H_2(s)}{U(s)} = \frac{K}{T_{12}T_2 s^2 + (T_{12} + 2T_2)s + 1}$$

$$T_{12} = \frac{A_1}{\beta_{12}a_{12}}\sqrt{\frac{2(\overline{h_1} - \overline{h_2})}{g}}, \quad T_2 = \frac{A_2}{\beta_2 a_2}\sqrt{\frac{2\overline{h_2}}{g}}, \quad K = \frac{kT_2}{A_2}$$

$$G(s) = \frac{19.8617}{2070.8939\,s^2 + 224.2254\,s + 1}$$

where A_1 and A_2 are the cross section area (cm^2) of tank 1 and tank 2, a_2 is the cross section area (cm^2) of outlet of tank 2, a_{12} is the cross section area (cm^2) of jointed pipe between tank 1 and tank 2, β_2 is the value ratio at the outlet of tank 2, β_{12} is the value ratio between tank 1 and tank 2, g is the gravity (cm/s^2) and k is the gain of pump ($cm^3/V \times s$).

A_1, A_2	a_2, a_{12}	β_2	β_{12}	$\overline{h_1}$	$\overline{h_2}$	k
154	0.5	0.682	1.531	30	25	30

Hardware

Pump “Motor”

Tanks “containers”

Sensor “ultrasonic most probably”

Water tap

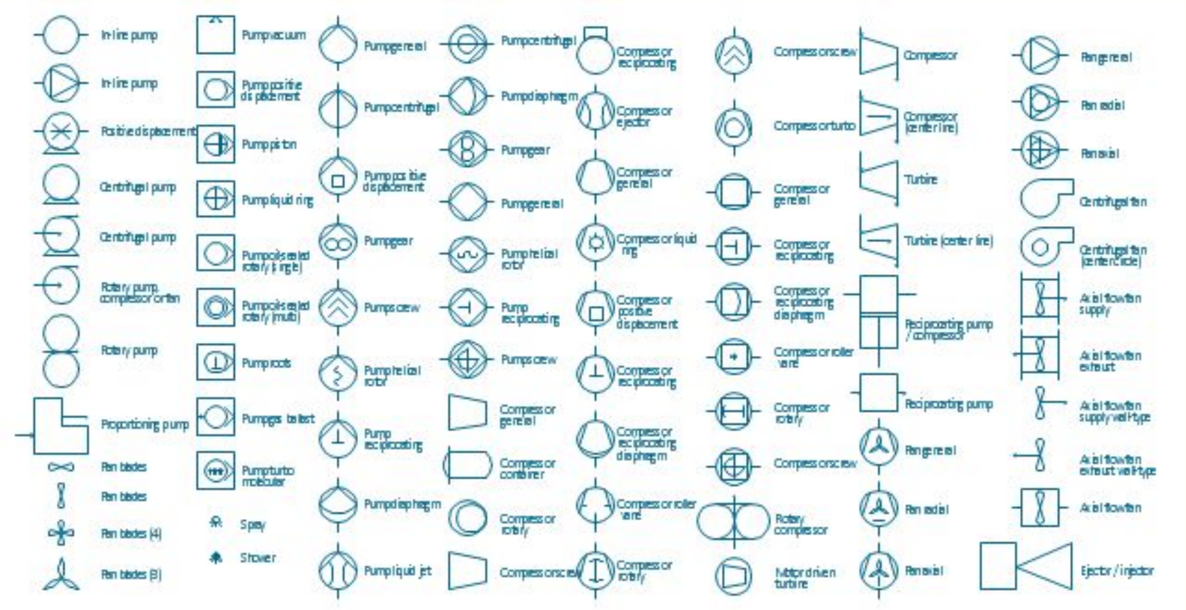
Tubes

Hose

Water valve

PID-Controller

Bread board ,wires



Simulation - Matlab

```
G =

         19.86
  ----------------------
  2071 s^2 + 224.2 s + 1

Continuous-time transfer function.
```

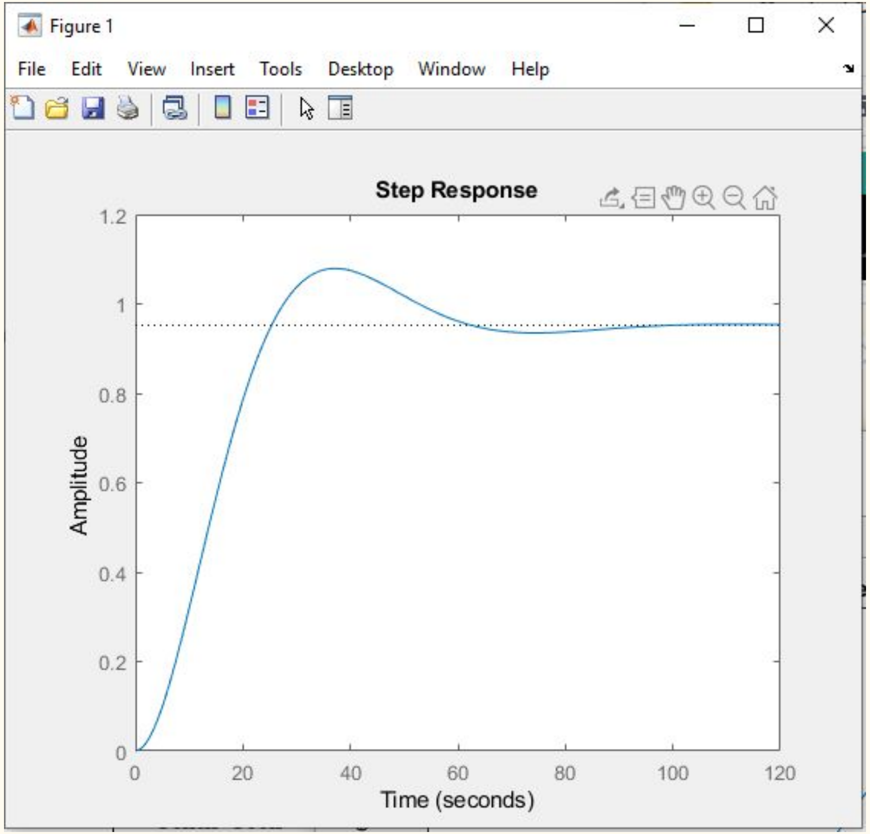
Pole	Damping	Frequency (rad/seconds)	Time Constant (seconds)
-5.41e-02 + 8.45e-02i	5.39e-01	1.00e-01	1.85e+01
-5.41e-02 - 8.45e-02i	5.39e-01	1.00e-01	1.85e+01

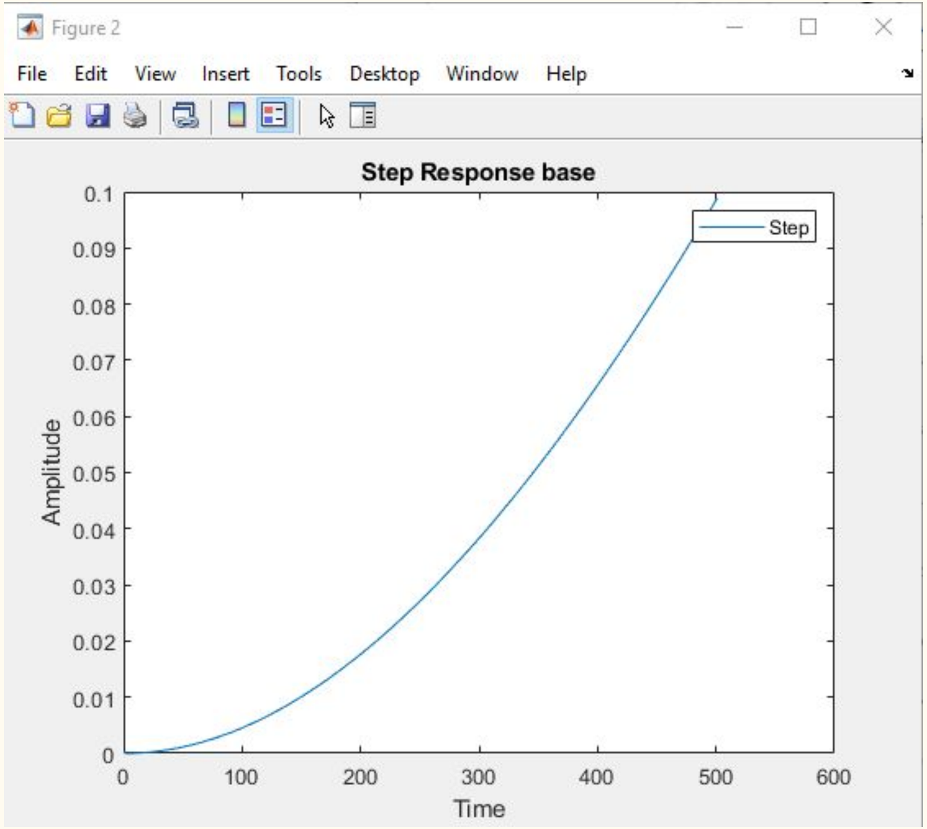
```
    RiseTime: 17.1210
SettlingTime: 57.8193
 SettlingMin: 0.8606
 SettlingMax: 1.0793
   Overshoot: 13.3627
  Undershoot: 0
        Peak: 1.0793
    PeakTime: 37.4284
```

```
ess =

    0.0479
```

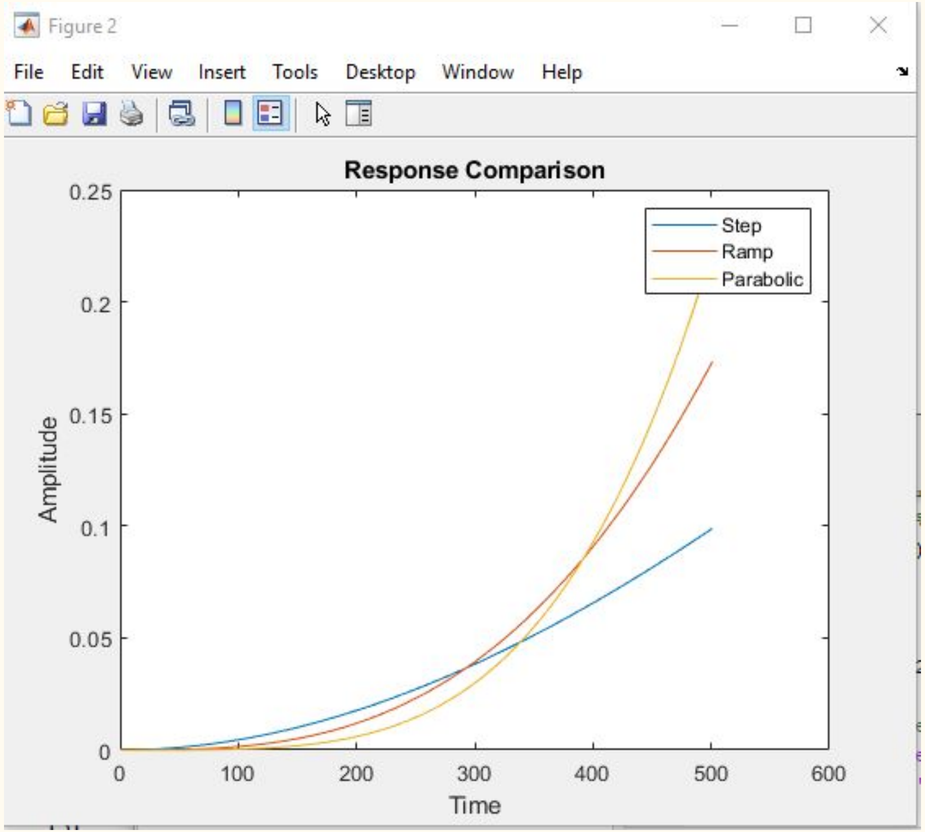
```
clear all; clc; close all;
s=tf('s');
t=0:0.01:5;
%define function
%open loop
G=(19.8617)/(2070.8939*s^2+224.2254*s+1)
%closed loop
T=feedback(G,1);
%obtain damping
damp(T)
%obtain overshoot, undershoot, tr, ts, peak, etc
stepinfo(T)
%obtain ess
%e=1/s*s*1/1+openloopgain
%ess=lim(e)as s->zero
%knowing that the open loop gain is G
E=1/(1+G);
ess=dcgain(E);
ess
%plot step response
step(T)

figure %initialize figure
t = 0:0.01:5; %small time for plot
plot(step(T, t)); %step
hold on
title('Step Response base')
legend('Step','Ramp','Parabolic')
xlabel('Time')
ylabel('Amplitude')
```

Step Response





Response comparison



Comparison of parameters in paper (PSO)

Table 2: Comparison of PID controller parameters

Tuning rules	PID parameters		
	K_p	K_i	K_d
Zeigler-Nichols	1.4928	0.0855	6.5159
Cohen–Coon	1.6712	0.0791	5.2666
IMC	1.0153	0.0046	4.3440
PSO	12.144	0.030	9.349

Table 3: Comparison of time domain specifications for set-point tracking

Transient Characteristic	Z-N	C-C	IMC	PSO
Rise time[s]	11.07	11.33	22.22	3.80
Peak amplitude	32.43	32.13	30.25	31.96
Peak time[s]	29.02	29.42	46.15	9.35
Settling time[s]	111.19	101.58	75.58	40.01

Table 4: Comparison of time domain specifications for disturbance rejection

Transient characteristic	Z-N	C-C	IMC	PSO
Peak amplitude	30.48	30.43	30.05	30.39
Peak time [s]	129.12	129.45	146.25	109.35
Recovery time [s]	211.19	201.55	169.45	140.01

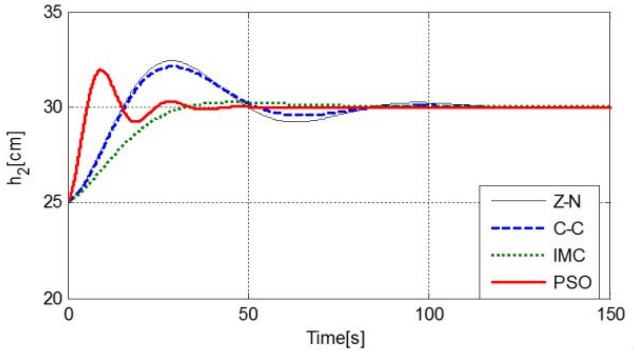


Figure 5: Closed-loop responses for set-point tracking with PID controllers

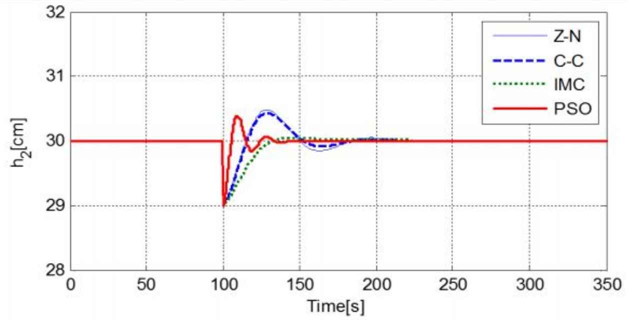


Figure 6: Closed-loop responses for disturbance rejection with PID controllers

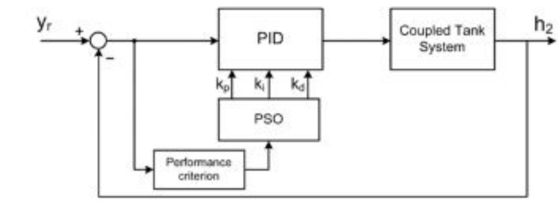


Figure 2: Structure of PSO based PID control system

Reference

1. Lee, Yun-Hyung & Ryu, Ki-Tak & Hur, Jae-Jung & So, Myung-Ok. (2014). PSO based tuning of PID controller for coupled tank system. Journal of the Korean Society of Marine Engineering. 38. 1297-1302. 10.5916/jkosme.2014.38.10.1297.
2. Lee, Yun-Hyung & Jin, Gang-Gyoo & So, Myung-Ok. (2014). Level control of single water tank systems using Fuzzy-PID technique. Journal of the Korean Society of Marine Engineering. 38. 550-556. 10.5916/jkosme.2014.38.5.550.