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Comparison of PID Controller with a Sliding Mode Controller for a Coupled Tank System

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Abstract.-Controlling the level of the liquids is a critical need in many industrial processes. Often the tanks are so coupled together that the levels interact and exhibits a nonlinear behavior. The sliding mode control (SMC) is used to control the level of the coupled tank system. Initially we develop the mathematical model for a non-linear single-input single-output (SISO). A simulation is carried out using MATLAB/SIMULINK to control the non-linear model of coupled-tank system. The step input signals is fed to the system to test the tracking performance of SMC. The tracking performance of SMC is also compared with conventional PID controller in terms of performance index ITAE. The SMC showed excellent tracking results than PID controller.

Keywords: *SMC, PID, Sliding surface, Switching function, Chattering .*

1. INTRODUCTION:

The control of liquid level in tanks is a basic problem in the process industries. The process industries require liquid to be pumped and stored in the tanks, then pumped to another tank. Many times the liquids will be processed by chemical or mixing treatment in the tanks, but always the level of fluid in the tanks must be controlled, and the flow between tanks must be regulated. Often the tanks are so coupled together that the levels interact and this must also be controlled. Vital industries where liquid level control is essential include are paper industries, pharmaceutical industries, petrochemical industries etc…

2. SYSTEM DESCRIPTION:

2.1 Coupled tank system:

Two tanks are connected in interactive manner. Both tanks are identical in cross section. The cross sectional area is represented as A (cm_2). The inlet flow F_{in} is given to the tank 1 and the outlet flow F_{out} is from tank 2. A manual valve is available between the tank1 and tank2 can be used to change the interaction between the tanks. The change in water level h1 (cm) in tank1 affects the water level h_2(cm) in tank 2. The water level variation in tank1 and tank2 depends on the inlet and outlet flows. The control variable is level in tank2 that is h_2 (cm). Manipulated variable is input flow rate F_{in}

Figure 1: Experimental Setup of a Coupled Tank level system

The main objective of the dual-tank system is to reach a reference height of the second tank. This is done by controlling the inflow of the first tank.

2.2 Block diagram:

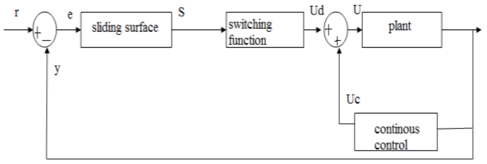

Figure 2: Block diagram of proposed method

In control theory, sliding mode control, or SMC, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to slide along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. The motion of the system as it slides along these boundaries is called a sliding mode. And the geometrical locus consisting of the boundaries is called the sliding (hyper) surface. For designing the SMC, a sliding surface has been selected at first, and then a suitable control law is designed so that the control variable is being driven to its reference value.The structure of SMC law U(t) is based on two main parts; a continuous part U_C (t) and a discontinuous part U_D(t).

2.3 Process model

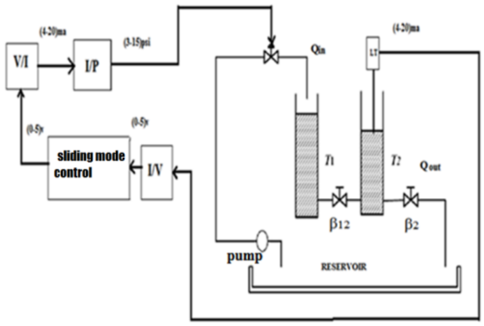

Figure 3: Process model of proposed system

LT :Level transmitter.
I/V :Current to voltage converter.
V/I :Voltage to current converter.
I/P :Current to pressure converter.

3. MATHEMATICAL MODELING:

The conical tank is the process considered which is given in figure 4.

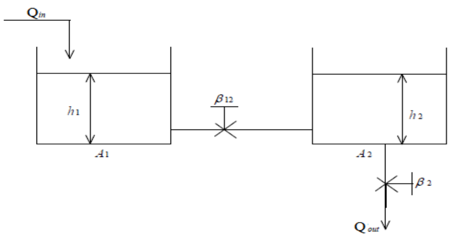

Figure 4: coupled tank

A_1 cross sectional area of tank1

A_2: cross sectional area of tank 2

a_2 : cross sectional area of output pipe in tank 2

a_1: cross sectional area of interaction pipe between tank 1 and tank 2

h_1,h_2: water level of tank 1 and tank 2

Q_{in}: inflow (Lph)

Q_{out}:outflow (Lph)

β_{12} : valve ratio of interaction pipe between tank 1and tank 2

β_2 :valve ratio at the outlet of tank 2

k : gain of the pump

g : gravity (m/s^2)

u : input voltage(v)

Mass balance equation :
Rate of change of mass in the tank = Mass flow in - Mass flow out

A dh/dt = Q_{in} - Q_{out}

The mass balance equation for tank 1 and tank 2 is given as,

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

Expand the above equations using Taylor's series.We can get,

$$\frac{dh_1(t)}{dt} = \frac{-\beta_{12}a_{12}}{A_1}\sqrt{\frac{g}{2(h_1(t)-h_2(t))}}H_1(t) - H_2(t) + \frac{Q}{A_1}$$

$$\frac{dh_2(t)}{dt} = \frac{-\beta_2 a_2}{A_2}\sqrt{\frac{g}{2h_2(t)}}H_2(t) + \frac{\beta_{12}a_{12}}{A_2}\sqrt{\frac{g}{2(h_1(t)-h_2(t))}}H_1(t) - H_2(t)$$

Taking Laplace transform and simplifying, the transfer function of a coupled tank process is obtained from the linear equations

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

4. CONTROLLER DESIGN:

The structure of SMC law U(t) is based on two main parts; a continuous part U_C (t) and a discontinuous part U_D(t) . That is

$$U(t) = U_c(t) + U_D(t)$$

The continuous part of SMC is given by,

$$U_c(t) = f(R(t)\ Y(t))$$

In SMC, the objective is to make the error and derivative of error equal to zero. As the system error is defined as the difference between actual height and desired height, mathematically

$$e(t)=H_D(t)- H_2(t)$$

H_D(t) is desired height while H(t) is the actual height in 2nd tank. The expression for the nth order sliding function is given by

$$S(t)=(d/dt+\lambda)^{n-1}e$$

Then for a 2nd order system

$$S=\dot{e}+\lambda e$$

Where $\lambda > 0$ is the slope of sliding surface. Here $\lambda=1$.For stability condition consider a Lyapunov function:

$$V=1/2S^2$$

From Lyapunov theorem it is known that if $\dot{V}$ is negative definite, the system trajectory will be driven and attracted toward the sliding surface and remain sliding on it until the origin is reached asymptotically.A sufficient condition for the stability of the system is

$$\tfrac{1}{2}\ d/dt\ S^2 \leq -|S|$$

Where S is a positive constant. This equation is called reaching condition or sliding condition. The basic discontinuous control law of SMC is given b

$$U_D=Ksgn(S)$$

Where the parameter K is the constant manual tuning parameter and is responsible for the reaching mode. The main disadvantage of SMC is the Chattering phenomena. Chattering is a high-frequency oscillation around the desired equilibrium point. The chattering problem could be solved satisfactorily if the control U_D is designed according to

$$Ud = \frac{s}{|s|+\delta}$$

The parameter δ is chattering suppression factor and is manually adjusted to eliminate the unwanted chattering. When system remains on sliding surface that means *e (t)* is zero all time. Hence it is desired to make

$$\frac{dS(t)}{dt} = 0$$

The continuous part of the control law will be

$$\frac{1}{b} * (a1 - \lambda) * \frac{dH2(t)}{dt} + a0H2(t) = Uc(t)$$

This procedure in which the continuous part of the controller derived is known in the SMC theory and the equivalent control procedure. The parameters b, a0 and a1 are calculated from the approximated model of the system and these values are b=0.006989, a0= 0.02785 and a1=5.753 respectively.
Then, the complete SMC law can be represented as follows

$$\frac{1}{b} * (a1 - \lambda) * \frac{dH2(t)}{dt} + a0H2(t) + k * \frac{s}{|s|+\delta} = U(t)$$

5. RESULTS AND DISCUSSION:

PID (proportional integral derivative) control is one of the earlier control strategies. It has a simple control structure which was understood by plant operators. Ziegler Nicholas open loop tuning is employed for coupled tank system which is shown in Figure 5 and the response of PID controller as shown in Figure 6

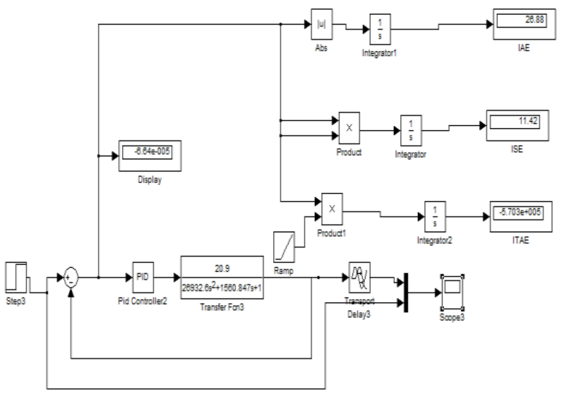

Figure 5: Block diagram of PID controller

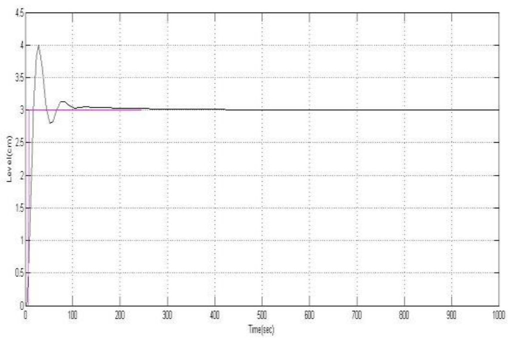

Figure 6 Response graph for PID control

The saturation is used in the simulation to ensure that the control signal always remain within the bound. The value of tuning parameters used in the simulation results is k= 1200 and δ=0.15.The sliding mode control for coupled tank system is shown in figure7 and the response of sliding mode controller is shown in figure 8.

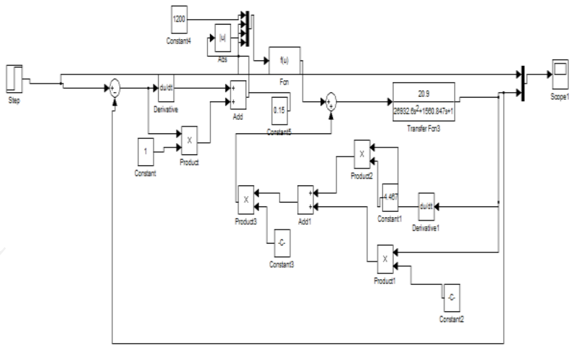

Figure7 Block diagram of sliding mode control

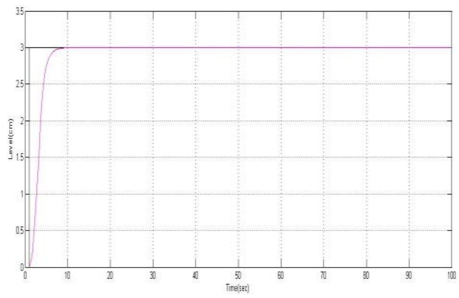

Figure 8 Response of sliding mode control

5.1 Comparison

PARAMETERS	PID	SMC
Settling time	560	7.6
Peak Overshoot	0.03	0
ISE	76.68	14.87
IATE	2.96e+003	1.23e+004
IAE	59.64	6.96

Table 1: comparison of performance measures

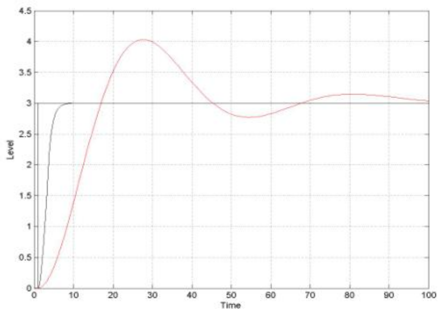

Figure 9 Comparison of PID and Sliding mode control

6. CONCLUSION AND FUTURE WORK:

The validation of this technique can be done by implementing in real time using LabVIEW. The response of sliding mode controller is obtained for various adjustment parameter values. The result is analyzed by adjusting various parameter values of sliding mode controller gives better response with no overshoot and reduced settling time.This project can be extended by the terminal sliding mode controller using evolutionary algorithms and other optimization techniques

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