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Assessment of PID and Fuzzy logic controllers for process LLC: A performance comparison

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Abstract
There is a mechanism for controlling the level of tanks everywhere. Having a solid grasp of how tank control systems function and how level control issues are resolved is crucial knowledge for control systems engineers. Since the control action for level control in tanks holding various chemicals or mixes is crucial for further control connecting set points, the liquid level is bearing significant weight in industrial control systems.

Since every real-world system is inherently non-linear, traditional controllers aren't always reliable. To get a better answer, we apply Fuzzy Logic Control. Whether you're making a linear or non-linear embedded control system, Fuzzy Logic is a great alternate design process to follow. Reduced development costs, improved final product performance, and enhanced features are all possible thanks to fuzzy logic.

Tank LLC is one example of a successful use of fuzzy control.

Here, we use MATLAB to create a Fuzzy Control based on the water tank's liquid level. We then compare the control effect to that of a PID controller and conduct an analysis based on our findings. When comparing the two, Fuzzy Control is clearly the better option. Time to reaction, steady-state error, and overshoot are a few of the factors that might get extra focus. When we compared the two systems' control responses, we found that the fuzzy logic controller drastically cut down on overshoot and steady-state error.

Keywords: Tank system, PID, Fuzzy logic, control system design

Introduction

Due to its affordable cost, simple control structure, and ease of design, the typical proportional integral-derivative (P1D)-type controller has been the most extensively employed in industry up until now. Over 90% of the control loops were of the PID type, according to a 1988 study of the status of process control systems undertaken by the Japan Electric Measuring Instrument Manufacture's Association [1, 2]. Although PID formulae are easy to adapt to various controlled plants, they will not provide satisfactory control performance in highly ordered or nonlinear systems.

A design theory on fuzzy controllers is lacking, which is a key difficulty in fuzzy control technology. This is despite the fact that several control applications demonstrate that fuzzy logic controllers may enhance control performance, particularly for high-order linear or non-linear systems. Instead of deliberately designing fuzzy controllers, several have been built case by case utilizing designers' expertise with fuzzy control to guide the trial-and-error technique. A few writers have discussed fuzzy control in relation to PID control [3, 4] and conducted stability analyses on the scaling factor of fuzzy PID controllers [5], but their findings are subjective and don't provide any guidance on how to select a fuzzy PID control type or design a fuzzy rule base in accordance with a tuned PID control [6].

Many common techniques and methods are found in control systems; they are used in every industry and field of technology. It turns out that fuzzy logic is often the best method out of the hundreds of methods to govern any system [7, 8]. Speed and cost are the only considerations. For process industries, one of the most fundamental problems is controlling the amount of liquid in tanks as well as the flow between them. The process industries rely on the pumping, storing, and pumping of liquids [9, 10].

Controlling the amount of fluid in the tanks and the movement between them is essential, especially when the liquids undergo chemical or mixing treatment in the tanks. Level interaction occurs often due to the tightly connected nature of the tanks and must likewise be managed [11].

"What does fuzzy logic control do that the conventional cannot do?" was the main question at the time. Here, we zero in on fuzzy logic control, a subset of intelligent control techniques, as a potential replacement for the prevalent proportional-integral-derivative (PID) approach in modern industrial control systems [12, 6].

The core of every chemical engineering system is the regulation of levels and flows in tanks. Some of the most important sectors of the economy that rely on precise regulation of liquid levels and flows are the petrochemical and nuclear power industries.

Enterprises involved in water treatment

You may see an example of a general application for controlling liquid levels in Figure I.

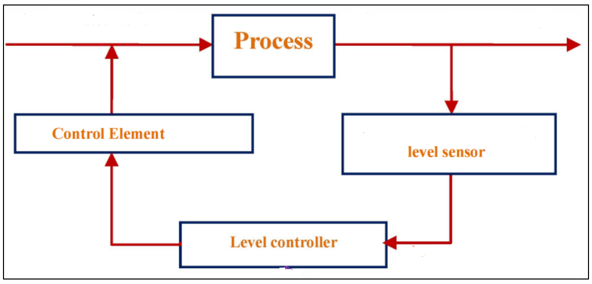

Fig 1: Normal LLC in Industry

Liquid storage tank

We take it as read that the liquid's density will remain constant. R is the exit pipe resistance. There are two possible types of exit flows: turbulent and laminar. In a laminar flow, qo is equal to h divided by R, while in a turbulent flow, it is equal to Kh squared, where K is the coefficient of discharge [4]. Fig 2 depcit the LST.

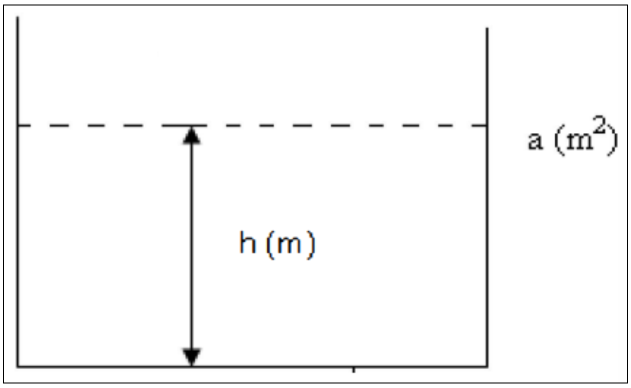

Fig 2: Storage of tank

Characteristics of the Subsystem

Tank for Holding Water

Figure 3 shows the water tank's Simulink diagram.

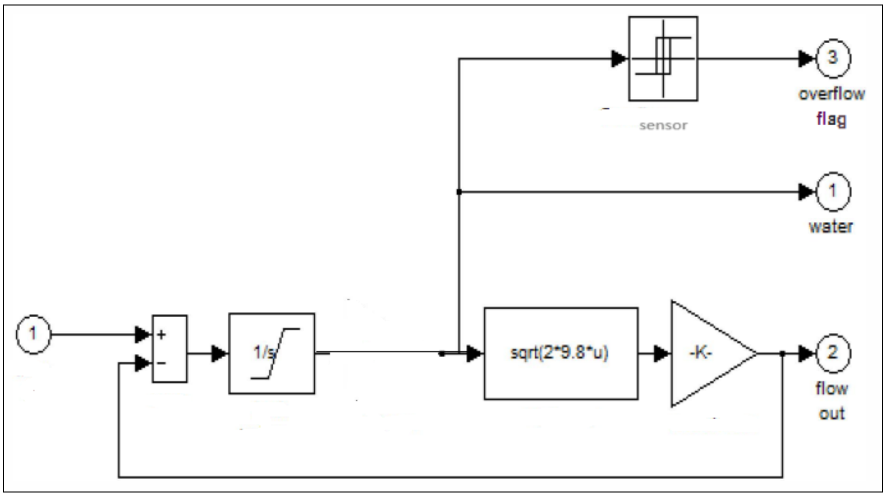

Fig 3: Simulink diagram

Valve As shown in Figure 4, the simulated valve subsystem allows for the regulation of the water flow level via the use of a restricted integrator.

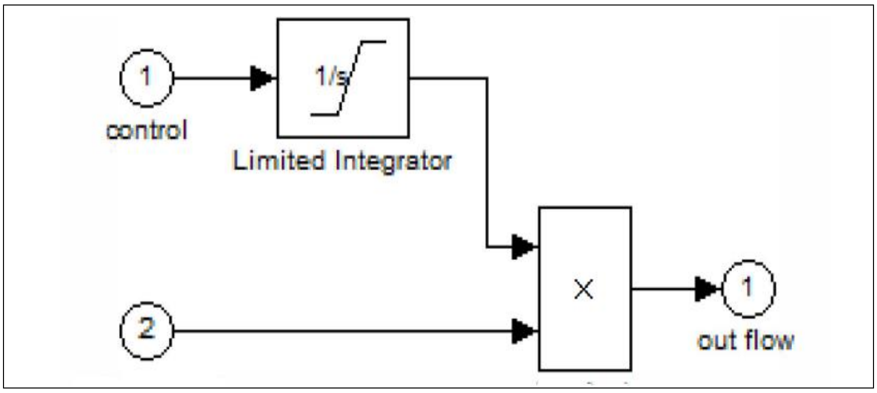

Fig 4: Valve Simulink

Model equation

As seen in Figure 5, water flows into a tank from its top and out through its bottom. The input voltage, V, to the pump determines the water inflow rate. The rate at which water drains from a tank is directly correlated to the square root of the tank's height [5].

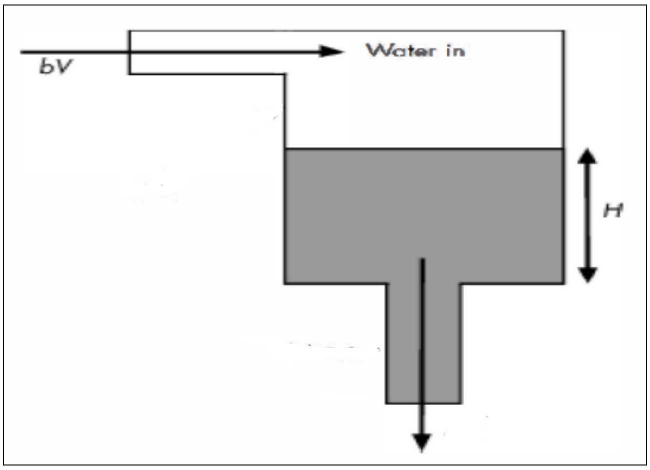

Fig 5: Model of the Liquid-Tank Control System

Equation (I) gives a differential equation for the tank's liquid height.

$$\frac{dV_{at}}{dt} = A\frac{dH}{dt} = bV - \alpha\sqrt{H} \quad (1)$$

A' represents the tank's cross-sectional area, 'b' is a constant that is tied to the flow rate into the tank, and 'a' is a constant that is related to the flow rate out of the tank. Here, Vol is the volume of liquid in the tank. Because there is a difference in the flow rates into and out of the tank, the equation (1) shows the liquid level, H, as a function of time. H is the only state, V is the only input, and H is the only output in Eq. (1). Since it is reliant on the square-root of H, it cannot be considered linear. Simplifying the analysis of this model is achieved by linearizing it using Simulink Control Design. A appropriate sensor detects the level and transforms it into a signal that the controller can understand. The control element is activated when the level signal is compared to the intended set-point by the controller.

To regulate the flow of liquid, the control element modifies the variable being regulated to shift the valve's location. The controller's job is to keep the level as near to the specified point as it can.

The water-tank mechanism fundamentally

- A controller subsystem that allows the user to adjust the voltage provided to the pump in order to manage the tank's water level.
- The target water level is established by a reference signal.
  Here we have a scope block that shows the water level at different times.

To see what's within a block, double-click on it. A basic integral-derivative proportional controller is included in the Controller block.

Water-Tank Control Unit: there is a time gap between the inflow and outflow rates of the tank, the equation (1) shows the water level, H, as a function of time. Assuming a constant 'a' and a constant 'b' that are both connected to the flow rate into and out of the tank, we get the tank's cross-sectional area, A. The parameters' values are provided as a=3 cm25/s, A=22 cm, and b=6cm /(s·V).

Controller block: Figure 6 shows the possible circuitry for the water tank controller. Two inputs are available to the fuzzy controller. Both the current liquid level and the pace at which it is changing are measured in the tank. The controller's output determines whether the valve opens or closes. After liquid level sensors pick up on the level, a saturation non-linearity determines the upper and lower bounds for the rate of change, which is then used to compute the level signal's derivative.

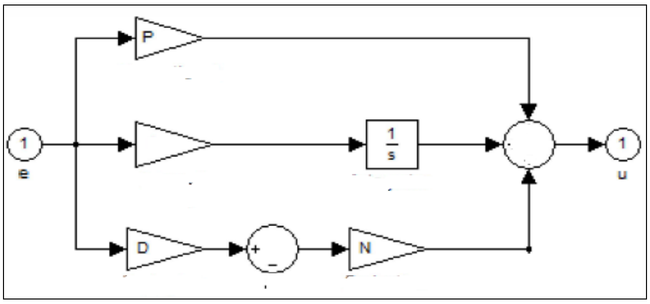

Fig 6: Controller block

FIS Editor

The Fuzzy Controller has two inputs that we have described. Both the level (abbreviated "level") and the pace (abbreviated "rate") of the liquid in the tank are important variables to consider. You may use both of these inputs with the rule editor [8, 9]. The controller opens the valve, which is labeled "valve" as its output, in accordance with the rules set in the Rule Editor. Figure 7 could illustrate it.

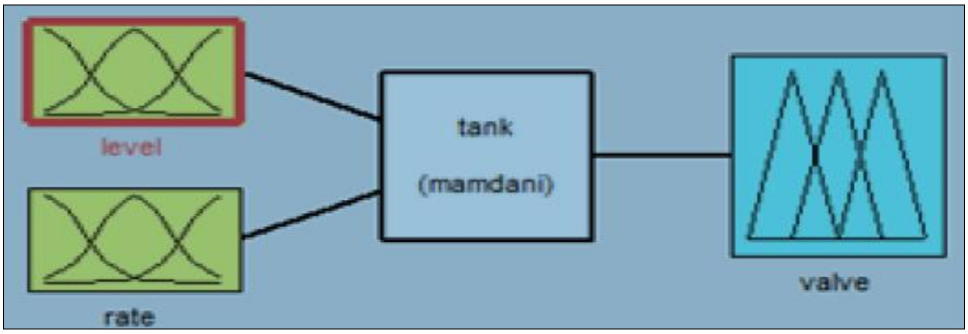

Fig 7: Fuzzy Controller

Simulation Results

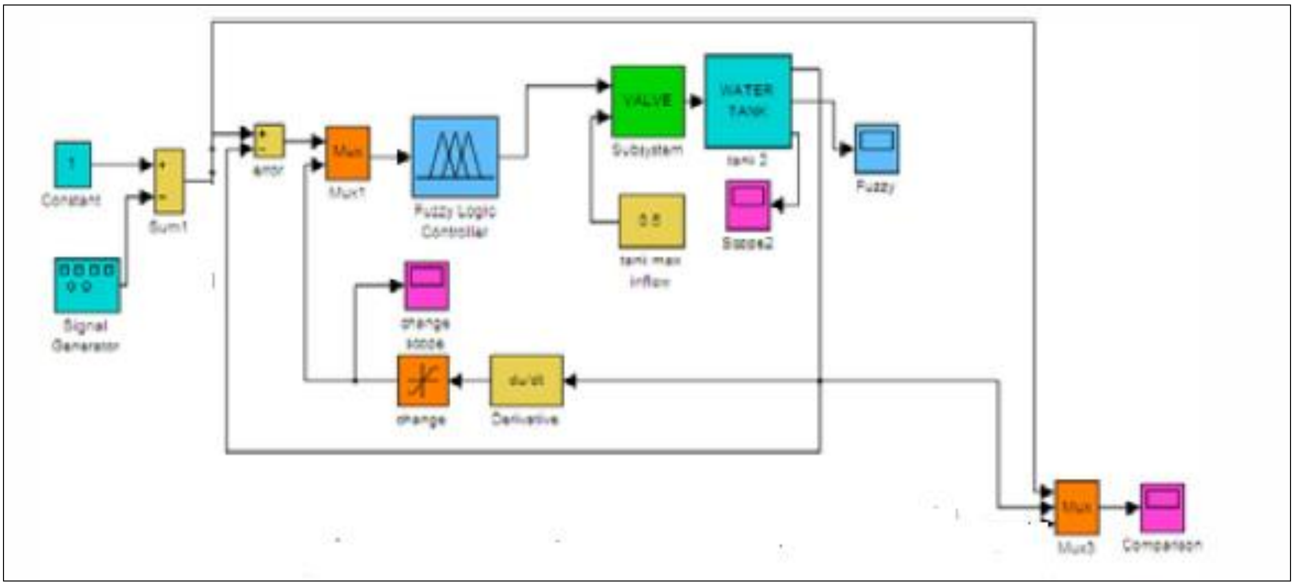

Fig 8: Visual representation in Simulink of the comparison of PID and Fuzzy simulations

Findings from the Simulation: The PID Controller's Reaction to the Liquid Level Controller

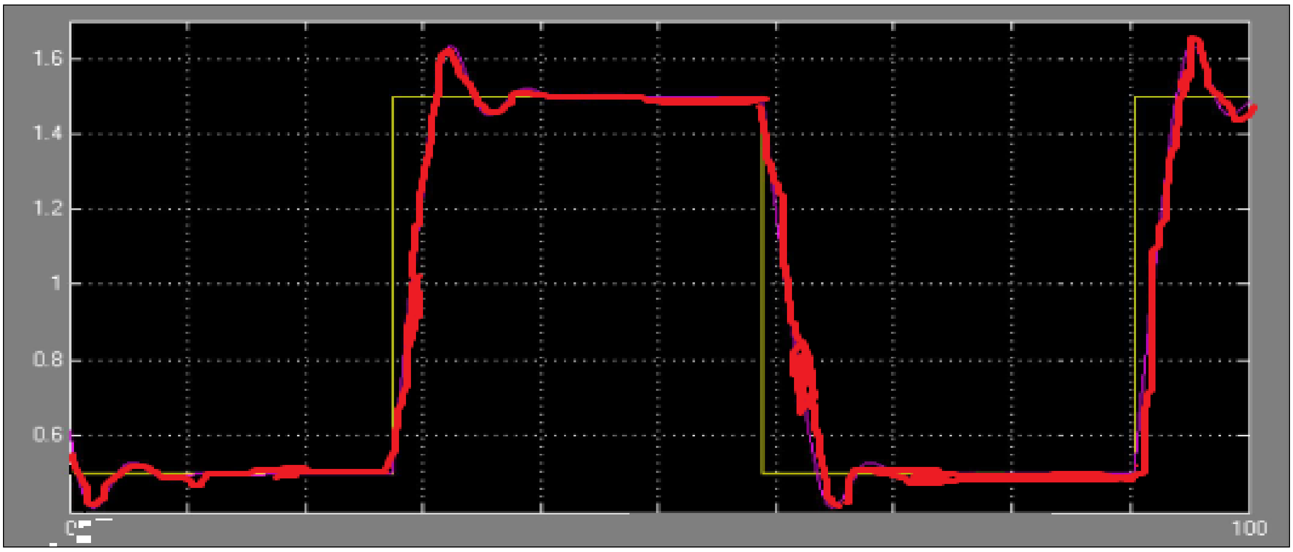

Fig 9: Findings from the PID controller simulation

Figure 9 shows that the system becomes unstable when using PID controllers because of the mismatch error caused by the incorrect time delay value in the plant model.
When controlling the liquid level using a PID controller, you could experience transients and overshoots.

The Fuzzy Logic Controller-Response

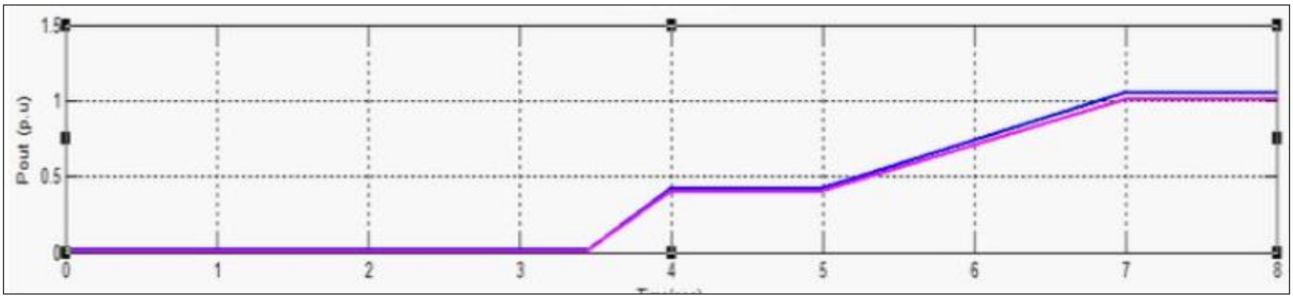

Fig 10: Product of the Fuzzy Logic controller-based simulation

Figure 10 shows that even without a prediction mechanism, FLC perform well with respect to oscillations and overshoot. In the face of extended time delays, the FLC algorithm swiftly adjusts and delivers a consistent Response.

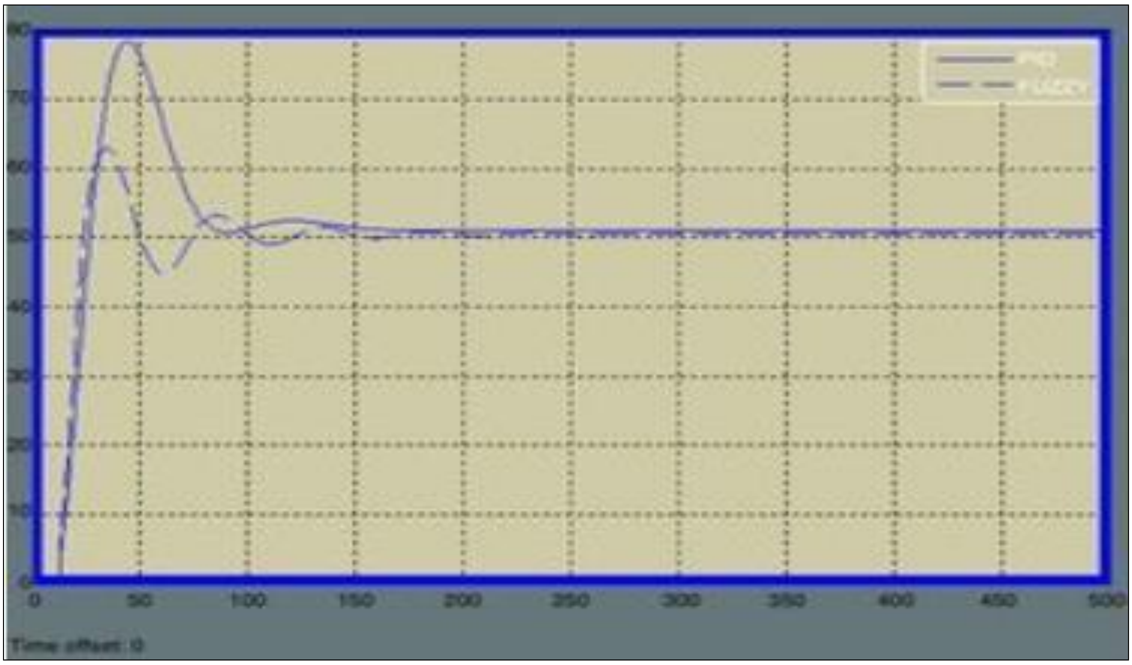

Fig 11: The Intermittent Behavior of PID and Fuzzy Controllers

In Figure 11, we can see the transient responses of fuzzy and PID controllers for a target level of 1 meter. The green line represents the PID response, the pink line represents the fuzzy response, and the yellow line displays the desired level. The graph clearly shows that the PID controller overshoots far more than the fuzzy controller and takes much longer to settle at the target level. In contrast, fuzzy logic offers rapid stabilization, precise level control, and little overshoot and steady-state error. We discover that the benefits and drawbacks of both PID control and fizzy control are about equal. Rapid control (coarse adjustment) is possible with a fuzzy controller, and precise control the findings showed that the fuzzy logic controller greatly decreased steady state error and overshoot compared to the other system. In Table no. 1 below, you can see the results of the comparison between PID and FLC.

Table 1: Combined PID controller and FLC performance metric

PID	FLC	Parameter
Not Present	Not Present	Transient
less	More	Settling
Not Present	More	Overshoot
less	more	Rise time

Conclusion

Apply the FLC that worked on one industrial level control system to another, and you'll see the same promising outcomes. In this case, we apply FLC and PID to the same level control system that has been precisely modelled, and we get simulation results. In comparison to the popular PID design technique, the results demonstrate a considerable increase in sustaining performance with respect to the amount of overshoot and oscillations created. There is reduced rising time using a PID controller, but greater oscillations, overshoot, and settling time, as seen in figures 15-18. However, FLC may be used in situations where process oscillations are intolerable because of its short settling time, overshoot, and oscillations. Even when dealing with plants that display a great deal of dynamic change, the FLC demonstrates strong performance. The goal of the Fuzzy Logic approach is not to comprehend the inner workings of the system but rather what it ought to accomplish. Instead of worrying about whether or not one can mathematically describe the system, one may focus on finding a solution to the issue at hand. This ahnost always results in less expensive and more efficient solutions.

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