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Fuzzy Logic Controller Design for Tank Level Control

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Abstract

In this paper, a fuzzy controller is designed based on operating mode knowledge and it is implemented in a tank level control system. The mathematical model of the plant is experimentally obtained. An important feature of the plant is its nonlinearity. To control the level of water in the tank over the whole range, one must use three tuning parameters pairs for the PI controller that work around three different operating points. The design of a fuzzy controller that uses the plant information works within the whole range, making it more suitable for this level control.

Key words: *Fuzzy controller; Level control; PI controller*

Introduction

Recently considerable research interest has been paid to the implementation of advanced controllers [2, 6, 7, 8]. PID controllers are still being used in the majority of industrial processes because the PID control schemes have a simple structure which can be easily understood and operated by field personnel. But in most of the cases, the tuning of conventional PID remains a difficult task due to lack of insufficient knowledge of the process. Many classical PID control loops have poor tuning due to the nonlinear and time-varying nature of industrial processes, usually operating in manual mode (open loop). In such cases, one cannot assure real good performances for control loop behaviour in case of disturbances and varying set points, in the presence of uncertainties. Fuzzy logic control technique has proved to be a good alternative to the classical controllers [3, 4, 5]. The fuzzy PID control technique was widely studied in the last two decades because it provided a smooth transition from classical PID controllers to fuzzy controllers.

In this paper, a fuzzy controller is designed based on prior knowledge of the process and tested on a tank level control system. The proposed fuzzy controller has good performances on the entire control range.

Fuzzy Controller Design

The water tank is part from a laboratory plant (figure 1). There are two vessels (one on top of the other) that communicate through an opening valve (gravitational leakage). The top vessel has an immersion type level transducer with 4.20mAcc output. The level is controlled in the top vessel, the vessel below being used as buffer tank (the water is recycled using a centrifugal pump that empties the bottom vessel). For the top vessel, the outflow rate depends on the hydraulic resistance of the outflow valve (which usually is set constant) and the pressure in the tank (which varies with the water level). The system has nonlinear characteristics.

Fig. 1. The laboratory plant for tank level control.

The fixed part of the control loop is formed from the level transducer for the top vessel, the tank process and the control valve for the water that flows in the tank. The controller used for the experiment is a PLC from Siemens Simatic Step 7 S 300 (fig. 2).

Fig. 2. PLC connections to the laboratory plant.

The human machine interface is built in WinCC and allows the change of control valve position in manual mode (fig. 3). The fixed part of the level control loop can be identified using an analytical-experimental identification. Usually the water level process with pump evacuation is an integral type process, but in this case the presence of the buffer tank and the gravitational leakage makes the process response more like proportional first order lag with saturation (see fig. 4).

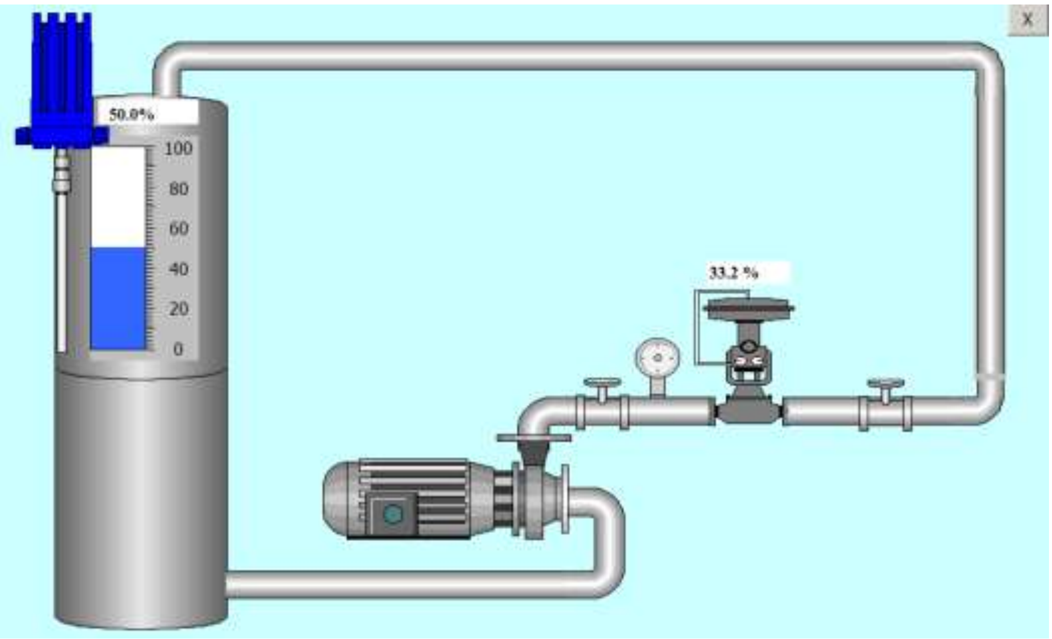
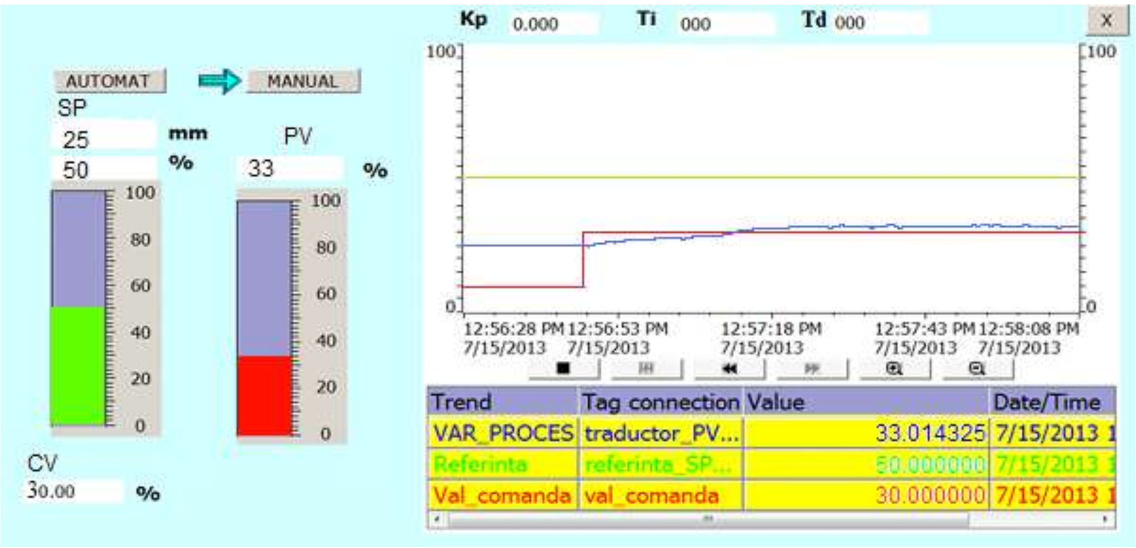


Fig. 3. Control level synoptic scheme.



Kp 0.000 Ti 000 Td 000

SP
25 mm
50 %

PV
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CV
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Trend	Tag connection	Value	Date/Time
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Fig. 4. Process identification.

The process identification leads to the conclusion that the process range can be split into three zones corresponding to three operating points. Within this zones the parameters for process identification can be considered constants (namely process gain $k_{process}$ and transient time T_{tr}).

In Table 1, there are summarized the process characteristics and the proposed PI controller tuning parameters according to the Cîrtoaje's tuning method of [1].

Table 1. Control ranges and associated tuning parameters.

Control range [0-100%]	Process gain $k_{process}$	Transient time T_{tr} [sec]	Proposed Controller gain K_c	Proposed controller reset time T_i [sec]
0-30	0.41	50	2.2	17
30-70	0.52	40	1.7	13
70-100	0.39	60	2.3	20

The fuzzy controller should benefit from the PI controller experience. As shown in Table 1, the PI controller have 3 pairs of tuning parameters (controller gain K_c, reset time T_i) that are suited to the specified control range. A fuzzy controller can work on the entire range with good performances. The design procedure starts from the assumption that the fuzzy controller has one input (the level error) and one output (the rate at which the control valve is opening/closing). The design is made using MATLAB fuzzy control toolbox. The control valve is normally closed so the controller should have reverse action (error is the difference between set point and process value). So the controller should perform no change for control valve if the level is okay and fast opening/closing of control valve if level is low/high (fig. 5).

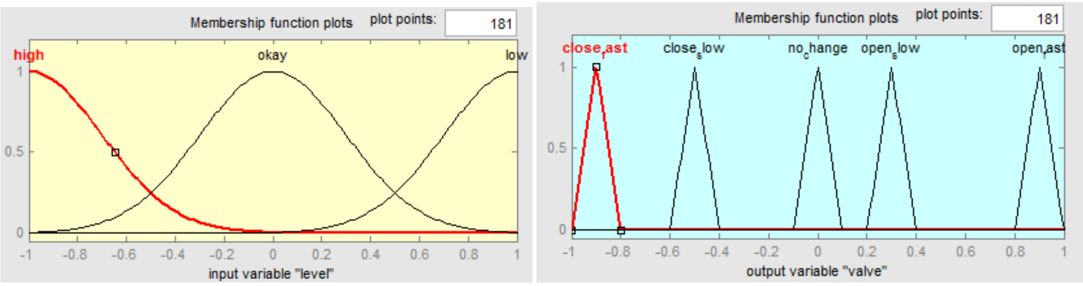

Fig. 5. Membership functions for the input and output of fuzzy controller.

Nevertheless a fuzzy controller with only three rules can be further improved by adding the information about level's rate of change (a second input to fuzzy controller – figure 6). This information is important because the fast closing/opening of the control valve means great energy consumption and can lead to early failure on the travel block associated with control valve. So the control valve movement is slowed down when level gets close to the set point value.

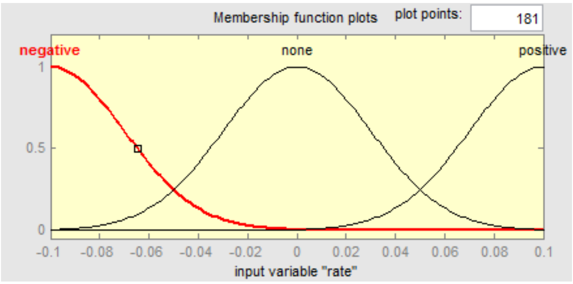

Fig. 6. Membership functions for additional input.

The resulted fuzzy controller is based on the following rules

1. *If* (level *is* okay) *then* (valve *is* no_change);
2. *If* (level *is* low) *then* (valve *is* open_fast);
3. *If* (level *is* high) *then* (valve *is* close_fast);
4. *If* (level *is* good) *and* (rate *is* negative), *then* (valve *is* close_slow);
5. *If* (level *is* good) *and* (rate *is* positive), *then* (valve *is* open_slow).

The resulted rule base satisfies the properties of continuity, consistency and completeness.

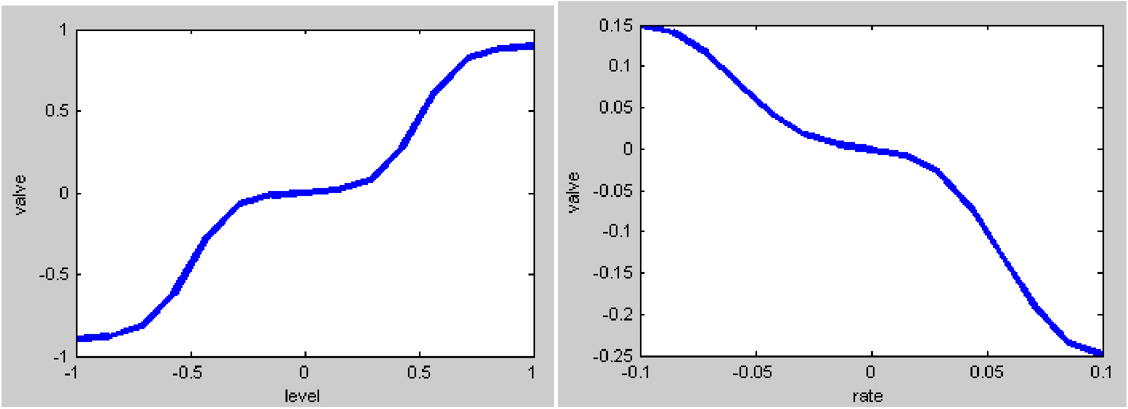

Fig. 7. Controller input-output characteristics.

The obtained surface shows a nonlinear character of controller gain according to process nonlinearity. The tank empties slower than it fills up due to the outflow valve diameter. The plot from figure 7 is asymmetric because the open_slow valve membership is designed to compensate this nonlinear behaviour. The closed loop simulations lead to the results presented in figure 8.

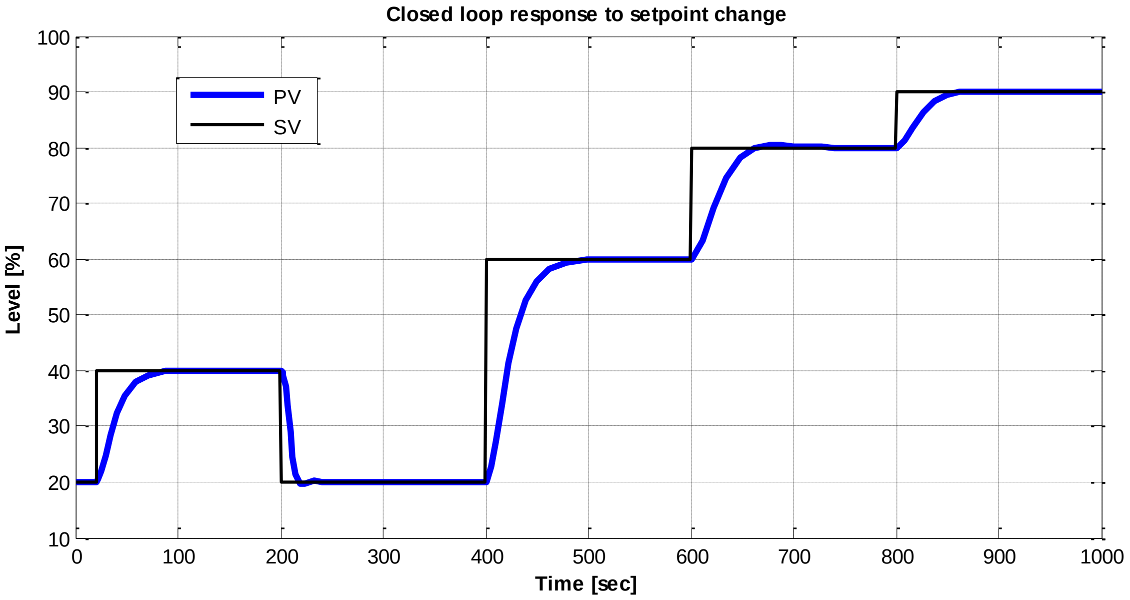

Fig. 8. Closed loop simulations for fuzzy level control.

Conclusion

The PI controllers cannot deal with the nonlinearities of the process. The fuzzy controller design allows taking into account those nonlinearities making it more suitable for this process. Also the fuzzy controller has the advantage that works very well for the entire control range and does not need different tuning for different control ranges as PI controllers. The simulation results look very promising, the next step being the fuzzy controller implementation on Fuzzy Control++ environment dedicated to SIMATIC S7 and SIMATIC WinCC.

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Proiectarea unui regulator fuzzy pentru reglarea nivelului într-un rezervor

Rezumat

În această lucrare este proiectat un regulator fuzzy bazat pe cunoştinţele apriori de operare şi este testat într-un sistem de reglare a nivelului într-un rezervor. Modelul matematic al instalaţiei este obţinut experimental. O caracteristică importantă a instalaţiei este neliniaritatea acesteia. Pentru a regla nivelul apei din rezervor pentru întregul domeniu al sistemului de reglare automată trebuie utilizate trei perechi de parametri de acordare pentru regulatorul PI care se potrivesc în jurul a trei puncte de operare diferite. Proiectarea unui regulator fuzzy bazat pe cunoştinţele modului de operare a procesului conduce la un regulator care funcţionează optim pe întregul domeniu, făcându-l mai potrivit pentru acest exemplu de reglare a nivelului.