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Comparison of Fuzzy PI Controller with Particle Swarm Optimization for a Nonlinear System

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ABSTRACT

In this paper control of the level of a conical tank by using the design of Fuzzy PI controllers and Particle swarm optimization algorithm. In recent days, many process industries have been involved with the conical tank system for easy discharge of process elements. Due to the shape, it is nonlinear in nature which is difficult to control. In many industries, conventional controller is used for controlling the process where the PI controller itself is needed to control the process. An intelligent controller like fuzzy PI controller is used to improve the performance when compared to the conventional controllers. To optimize the value particle swarm optimization technique is used to determine the required performance by reducing the integral square error.

Keywords: Nonlinear process, Fuzzy controller, PSO method, Integral square error.

INTRODUCTION

The control of level in various processes is an imperative component which gives them a major role in larger commercial industries. The raw materials may vary depend on upon the process industry such as slurries, viscous liquids, and solid materials. To make an easy flow of these raw materials, conical tank processes are generally used. Owing its shape in a conical tank the raw resources can be disposed of easily and quickly. The control of level is a necessary factor to avoid the overflow or spillage of an important element. Not only to dispose of the materials but also to provide a hygienic and fast cleaning is easy in using a conical tank system, which will avoid the rusting of materials. Due to the control of level spillage of elements, overcapacity of tanks can be avoided. In the highly industrialized countries, to improve the process safety and efficiently utilize resources can be made by controlling the level. In the developing countries, the main venture is the production of products should be fast for developing process automation. The furthest requirement in the process automation is used in many industries like the petrochemical industry, chemical industry, Pharmaceutical industry and power generating engineering. The centrality of mechanization information gives an enormous to increment in the process commercial enterprises. The level control in tanks is a vital issue in the development of process commercial industries without providing wastage to the materials utilized. However, the automation gives more challenges because of the nonlinearity behavior of the conical tank system. The nonlinearity is due to its shape because the area of cross-section is nonuniform. A controller can be designed for a nonlinear process but it is difficult and terribly hard to realize it. The principle assignment of the controller design is to accomplish the ideal working conditions and to design the controller to attain its most favorable execution performance.

A nonlinear process, whose process variable changes the parameters which are considered for conical tank level process. The desired setpoint level is maintained with a fixed and controlled outlet flow rate. The process gain and time constant are the important precipitates which vary as a function of level in the chosen

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process. There is a need to control a Level for the reason that if the level becomes very high which may disturb the reaction stability of the total process in which it may spoil the apparatus, or cause in wastage of expensive or perilous substance from the process (Ravi et al., 2011). If the level is very low, it might provide dreadful consequences for the chronological function carried out by the process (Anandanatarajan et al., 2005), done work on the nonlinearity which is due to its change in shape. Their shape assures optimal stirring and mixing of ingredients and provides a fast and hygienic cleaning (Nithya et al, 2010).

MATERIALS AND METHODS

Mathematical Modeling: The mathematical model of the conical tank can be determined, by considering the assumptions (i) control variable (level) (ii) the manipulated variable (Tank inflow). This is accomplished by controlling the inflow of the tank. The Figure shows the schematic diagram of the conical tank system.

Operating Parameters are

F_1 - Inflow rate of tank

F_2 - Outflow rate of tank

H - Total height of the tank.

R –Tank Top radius

h – Nominal tank level

r - Radius of the nominal level of the tank

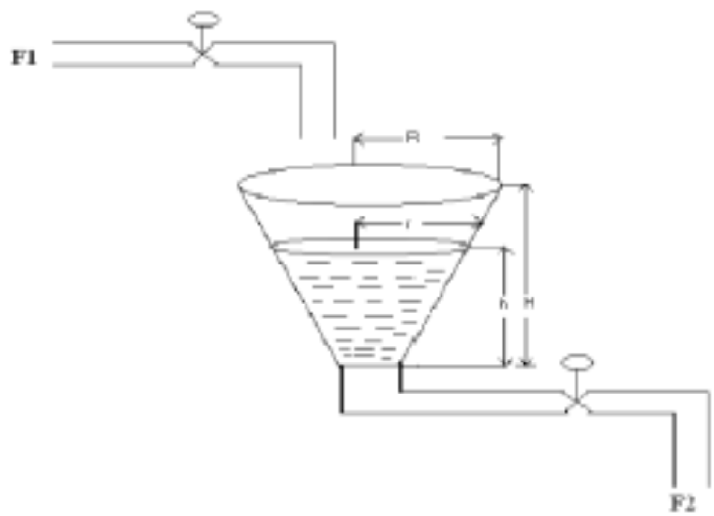


Figure 1: Schematic diagram of the Conical Tank system

Mass balance Equation is given by

$$F_1 - F_2 = A_1 \frac{dh}{dt} \tag{1}$$

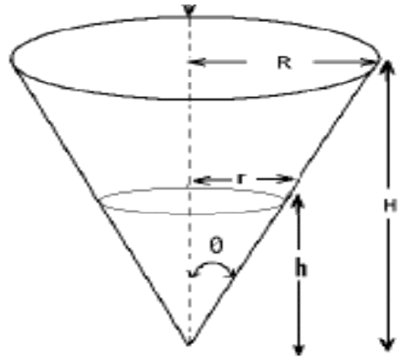
$$F_2 = b\sqrt{h} \tag{2}$$

Where b = a√(2g)

Where a- Outlet area of the tank

g- Acceleration due to gravity

By substituting the equation and considering the cross-sectional area of the tank at level h



$$\tan\theta = r/h = R/H$$

$$A = \pi r^2 \tag{3}$$

$$A = \pi R^2 h^2/H^2$$

$$\text{Where } r = R^2h^2/H^2$$

The transfer function (TF) is given by taking the partial differentiation of the linear equation and its corresponding Laplace transform.

$$\frac{h(s)}{F1(s)} = \frac{k}{\tau s + 1}$$

Where $\tau = \frac{2A\sqrt{h}}{b}$ *and* $K = \frac{2\sqrt{h}}{b}$

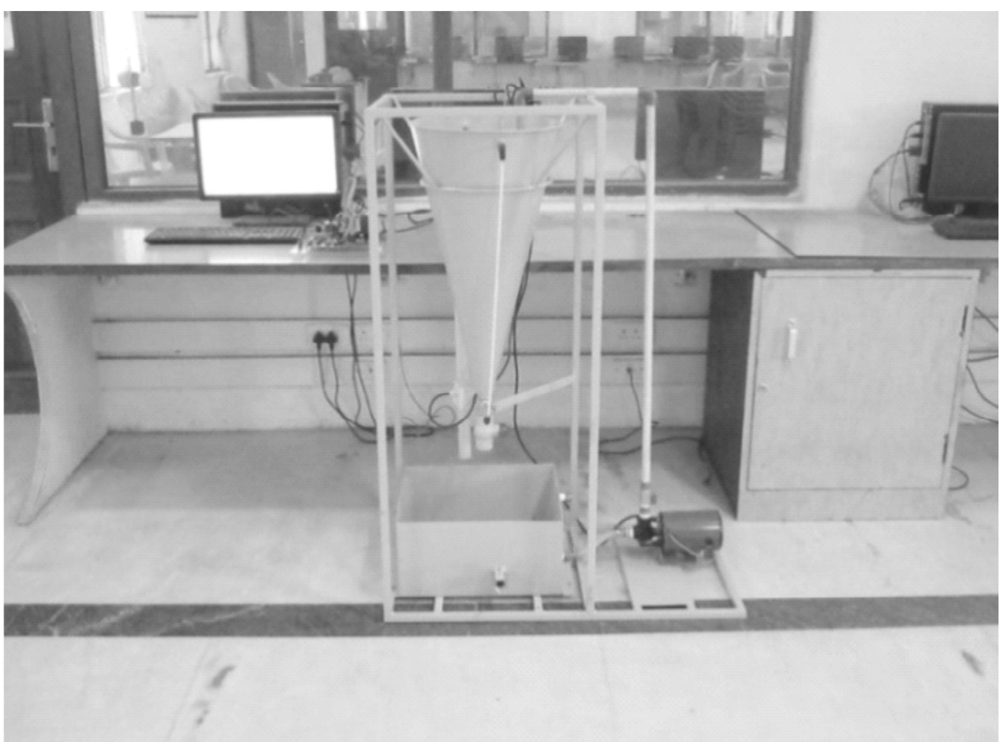


Figure 2: The experimental setup of the conical tank system

Table 1
Specification Details of Conical tank System

Specification Details	
Reservoir Tank Capacity	35 litres
Conical Tank Capacity	22 litre
Conical Tank Height	700 mm
Conical Tank Top diameter	350mm
Conical Tank Bottom diameter	25mm
Level Transmitter Type	Piezoelectric type
Measuring range	700 mm

Based on the specification the transfer function is given by

$$G(S) = \frac{1.23}{313.198S + 1}$$

Fuzzy PI controller

Fuzzy PI controller is designed for the process where the controller design is difficult to accomplish without knowing the design of the process and also the application of the controller design. Fuzzy logic procedures are applied above it using Mamdani Model fuzzy logic controller. Fuzzy logic systems are based on logical thinking along with capability to fuzzify any system which helps in simple realization. In many engineering processes, Fuzzy Logic Controllers is used because it can able to take the control deed like human and the controlling process is very simple once it designed. Mainly FLC is implemented on non-linear systems which give up to improved results. For designing, the number of controller parameters has to be selected and then it's Membership Function and rules are framed based on heuristic knowledge. The block diagram of a fuzzy controller is shown in Figure 3.

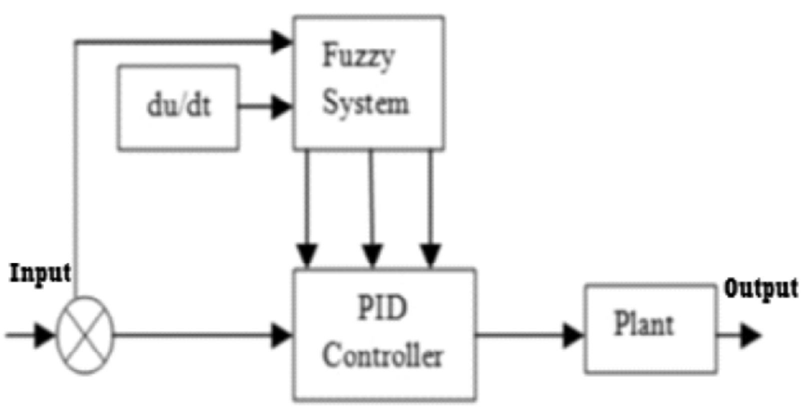


Figure 3: Fuzzy Logic Block Diagram

To control the level of conical tank process, input and output membership functions are designed depending on both inputs and output consist of 5 functions for error and 7 functions for change in error. The output functions are used to decide the values of K_p and K_I with 5 functions. The membership function considered for controlling the level of the conical tank is triangular and centroid method. The input membership function is shown in figure 4 and figure 5. The output membership function is shown in figure 6 and figure 7.

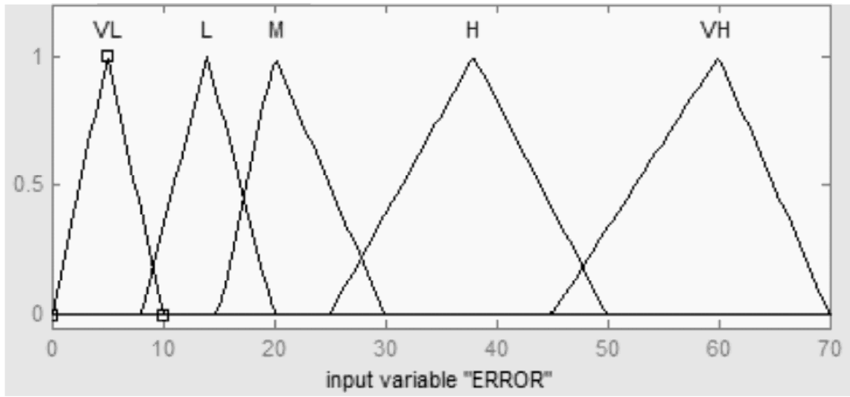


Figure 4: Error Input Membership function

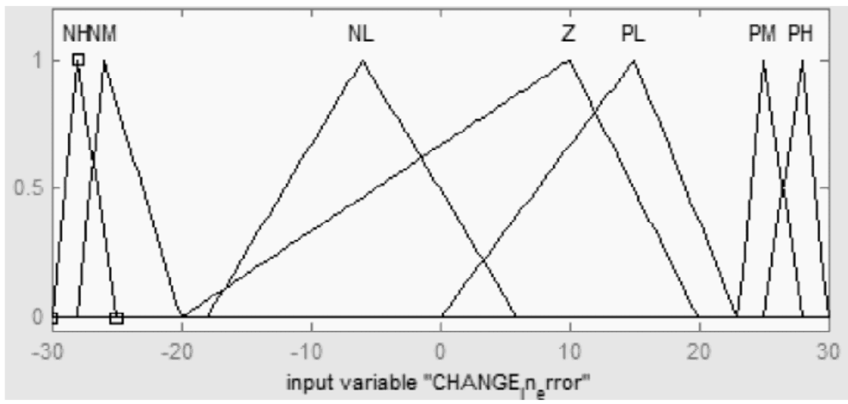


Figure 5: Change in Error Input Membership function

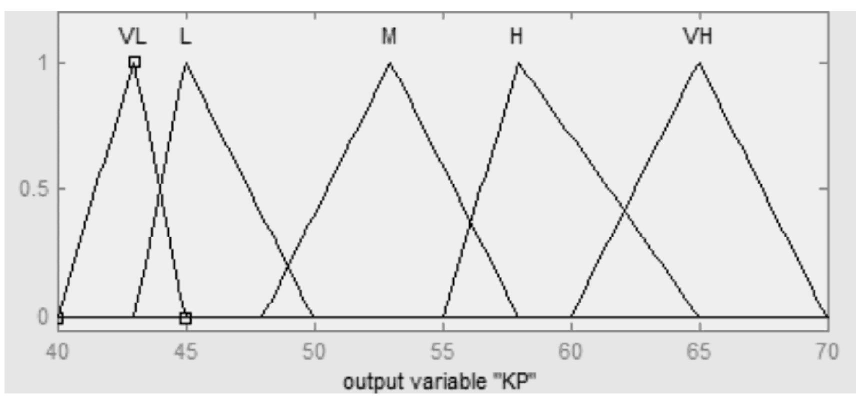


Figure 6: Output membership functions for K_p

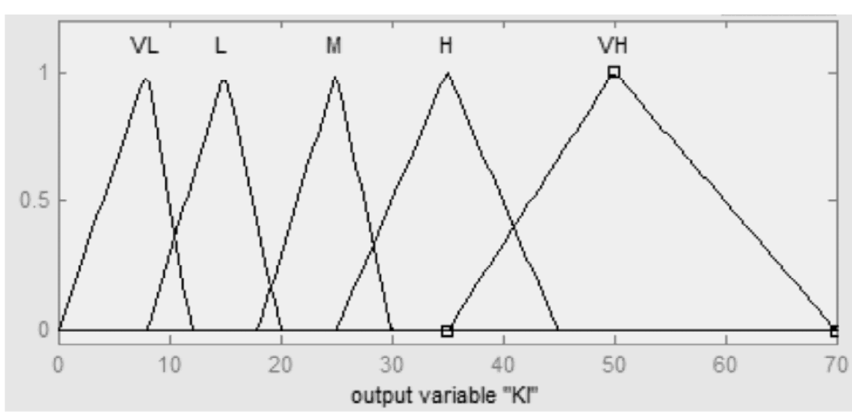


Figure 7: Output membership functions for K_i

Error Input range is considered from 0 to 70 and change in error input range is considered from -30 to 30. The rule base is usually developed based on skilled knowledge. The rule base is developed by an understanding of the system and some trial and error manipulations. The rules designed for its function is given in Table 2 and Table3

Table 2
Fuzzy Logic Rules for Proportional controller

E \CE	*NH*	*NM*	*NL*	*Z*	*PL*	*PM*	*PH*
VL	VL	VL	VL	M	M	H	VH
L	L	M	M	M	M	H	VH
M	H	H	M	H	M	H	VH
H	VL	M	H	H	H	H	VH
VH	VH	H	H	H	VH	VH	VH

* VL-Very Low, L-Low, M-Medium, H- High, VH-Very high, NH- Negative High, NM-Negative Medium, NL-Negative low, Z-Zero, PL-Positive Low, PM-Positive Medium, PH-Positive High.

Table 3
Fuzzy logic rules for Integral Controller

E \CE	*NH*	*NM*	*NL*	*Z*	*PL*	*PM*	*PH*
VL	VL	VL	M	VL	M	H	H
L	VL	VL	L	M	M	M	H
M	L	L	M	M	M	M	H
H	VH	VH	L	H	H	H	VH
VH	VH	VH	H	H	H	H	VH

Surface Viewer is a GUI tool which is used to represent the two-dimensional curve that represents input and output systems that can generate three-dimensional plots in MATLAB. It can be used to plot the output graph. In this fuzzy logic depending on the rules, the K_p and K_I values can be analyzed for the control of nonlinear conical tank system. Figure 8 and Figure 9 represent the fuzzy system output surface for K_p and K_I

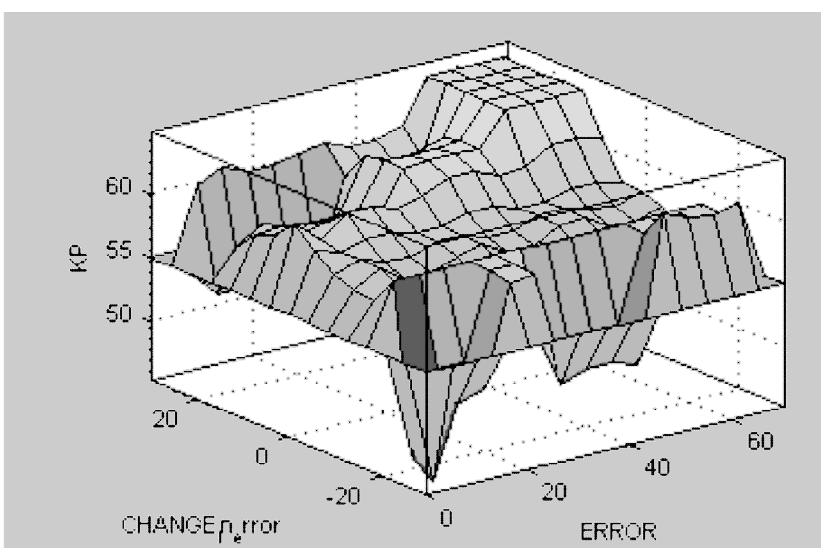


Figure 8: Fuzzy system Output surface for K_p

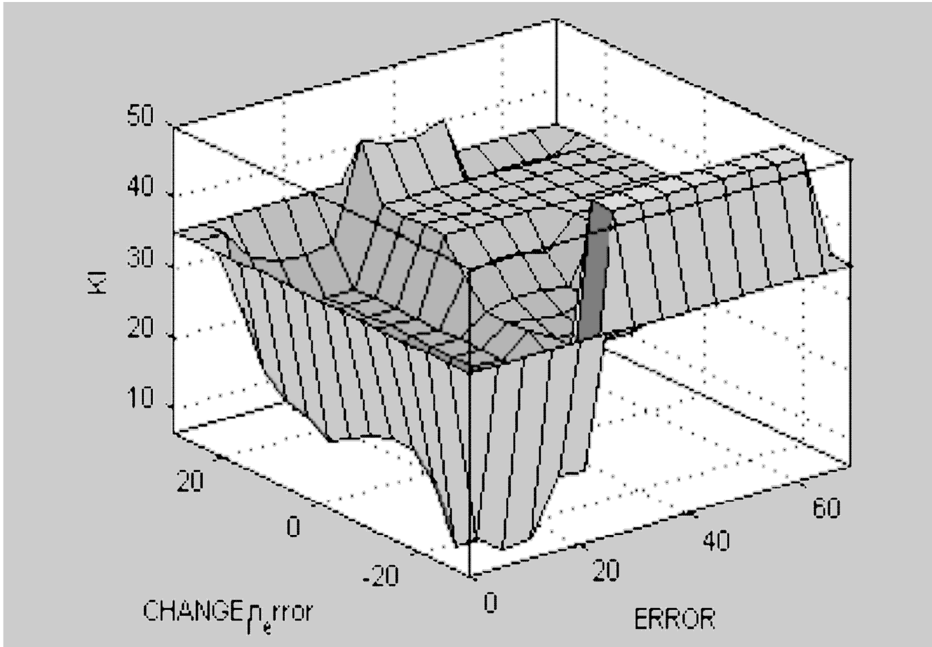


Figure 9: Fuzzy system Output surface forK_I

Particle Swarm optimization (PSO) Algorithm

Particle Swarm Optimization (PSO) is a optimization technique to improve the quality of candidate solution by iteratively trying using the computational method. The problem can be solved using the swarm movement and its move around the search space by having a population of candidate solutions, based on simple mathematical formulae over the particle's position and velocity. Each particle's movement is subjective by its local best-known position which is updated as better positions are found by other particles. It is expected that the swarm can move to best solutions. Parameters that are considered for the design of PSO optimization technique is

Size of the Swarm (No. of Birds) =50

Maximumly no. of birds steps =50

Dimension of the Problem (K_p , K_I) = 2

PSO parameters C_1=0.12 and C_2=1.2

PSO momentum of inertia=0.9

RESULTS AND DISCUSSION

In this section, the response of a conical tank system is determined by comparing Fuzzy PI controller method with the Particle swarm optimization techniques using MATLAB and tested for various nominal height of tank. Performance indices and time domain analysis are determined to find out the better performance of different methods which are implemented.

A nominal height of 25 cm is applied to the process setup and also tested with various values of its level. Figure 10 shows the comparison output for fuzzy PI controller and PSO

Table 4 represents the performance indices analysis like ISE (Integral of squared error), ITAE (Integral of the time-weighted absolute error) and time domain analysis Rise Time and settling Time of Fuzzy PI controller and particle swarm optimization technique.

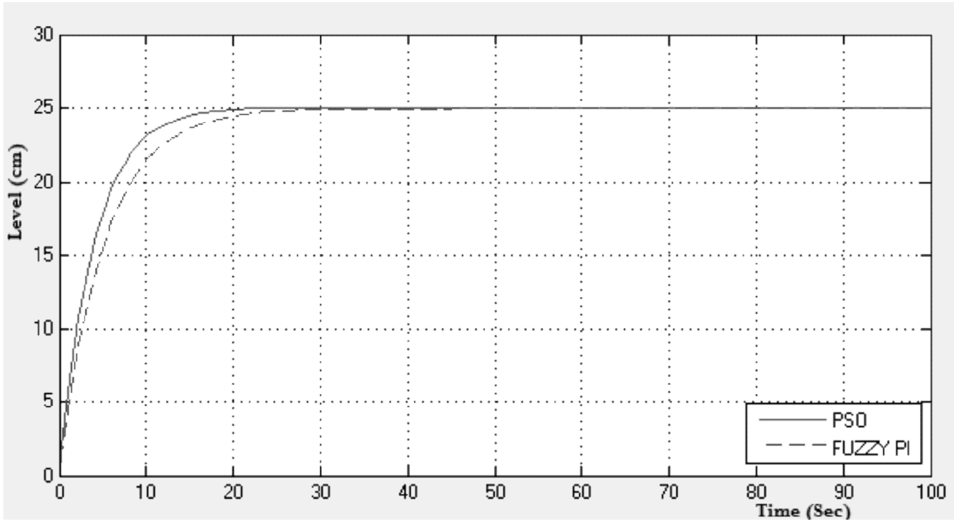


Figure 10: Comparison output for fuzzy PI controller and PSO

Table 4
Performances Indices and Time domain analysis

Methods	*Rise Time (sec)*	*Settling Time (sec)*	*ISE*	*ITAE*
Fuzzy PI	30.0440	40.9941	1598	831.3
PSO	23.1221	31.6661	1226	357.7

CONCLUSION

In this paper, Fuzzy PI controller technique is implemented to control the level of a conical tank system. Fuzzy is an intelligent controller which can able to provide a better output when compared with other conventional controllers. The performances are measured to compare with the particle swarm optimization technique for various setpoint values. The values of proportional and integral are calculated using PSO and implemented in the experimental setup for its analysis. From the table above it is determined that PSO algorithm can provide the best optimization value for the control of level.

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