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Comparison Study between Fuzzy Logic Controller (FLC) and Proportional-Integral-Derivative (PID) in Controlling of Liquid Flow

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***Abstract*— To surmount the difficulties innate in controlling a system that is both nonlinear and time varying, a controller based on fuzzy logic was implemented. The fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. It has better stability, small overshoot, and fast response. In this Paper, performance analysis of proportional-integral-derivative (PID) controller and fuzzy logic controller in the Control of liquid flow has been done by the use of MATLAB and SIMULINK, and at the end comparison of various time domain parameters is done to prove that the fuzzy logic controller has small overshoot and fast response as compared to proportional-integral-derivative (PID) controller.**

***Index Terms*— Fuzzy, PID, SIMULINK, Liquid, Control**

I. INTRODUCTION

Conventional PID controller can be designed to maintain the level of liquid flow, but the weakness is its feedback type controller that is after the output is affected by error that the controller will take control action. Secondly, it doesn’t accept the unexpected change in the set point and also, the transient behavior of the system is oscillatory. One reason for this lack of a satisfactory performance in PID is the fact that linearization of a non-linear system might be valid only as an approximation to the real system around a determined operating point [1].

To overcome the lapses innate in conventional PID controller, a controller based on fuzzy logic was implemented. Fuzzy controllers are non-linear, and effective enough to provide the desired non linear control actions by carefully adjusting their parameters [2].

Fuzzy logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. It is a means of controlling with sentences rather than equations. It can be applied for the control of liquid flow and level in any processes [3].

Fuzzy logic is a form of knowledge representation suitable for notions that cannot be defined precisely, but which depend upon their contexts. It is a means of computing with words rather than numbers. It enables computerized devices to reason more like humans, and emulates the ability to reason and use approximate data to find solutions. It also enables control engineers to efficiently develop control strategies in application areas marked by low order dynamics with weak nonlinearities. Fuzzy Logic provides a completely different, unconventional way to approach a control problem. This method focuses on what the system should do rather than trying to understand how it works. One can focus on solving the problem rather trying to model the system mathematically [4]. This almost invariably leads to quicker, cheaper solutions. Other advantages of fuzzy logic systems include: robustness, since it does not require precise, noise-free inputs and degrade gradually when system components fail like if a feedback sensor quits or is destroyed. It can be easily combined with conventional and allied control techniques, it can be modified easily to add, improve or alter system performance. Because of the rule-based operation, system can be easily designed for any reasonable number of inputs and outputs. It can also model non-linear functions of arbitrary complexity.

Therefore, by using fuzzy logic, designers can realize lower development costs, superior features, and better end product performance.

II. BRIEF HISTORICAL BACKGROUND

In 1965, the concept of Fuzzy Logic was conceived by Prof. Lotfi Zadeh at the University of California Berkley. He presented fuzzy set theory not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time. Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control. If feedback controllers could be programmed to accept noisy, imprecise input, they would be much more effective and perhaps easier to implement [5]. Likewise, neural networks are also capable of representing the precise information from existing data sets. These intelligent control techniques like neural networks, fuzzy logic and genetic algorithms have been used in liquid level control for the last two decades.

In 1997, Park and Seong [6] investigated self-organizing fuzzy logic controller for water level control of steam generators. Wu *et al.* [7] built a prototype of water level control system implementing both fuzzy logic and neural network control algorithm and embedded the control algorithms into a standalone DSP-based micro controller and compared their performances. Sugeno model was used for fuzzy logic control system and Model Reference Adaptive

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neural Network Control based on back propagation algorithm was applied in neural network. Galzina *et al.* [8] presented applied fuzzy logic for water level control in boiler drum and combustion quality control.

Fuzzy control rules were extracted from operator knowledge based on relative ruling criteria for existing boiler room. Taoyan *et al.* [9] proposed a novel interval type-2 fuzzy control system by extending the membership functions to interval type-2 membership function without increasing the design complexity. The control system can efficiently reduce the uncertain disturbances from real environment. Recently, Shome and Ashok [10] described an intelligent controller using fuzzy logic to meet the nonlinearity of the system for accurate control of the boiler steam temperature and water level. Fuzzy Logic control has been rapidly gaining popularity among practicing engineers. This increased popularity can be attributed to the fact that fuzzy logic provides a powerful vehicle that allows engineers to incorporate human reasoning in the control algorithm.

III. FUZZY LOGIC SYSTEMS

Fig. 1 depicts a fuzzy logic system that is widely used in fuzzy logic controllers and signal processing applications. A fuzzy logic system maps crisp inputs into crisp outputs. It contains four major components; fuzzifier, rules, inference engine and defuzzifier.

A. Fuzzification

Fuzzification is the process of making a crisp quantity fuzzy. The fuzzification interface involves the following functions:

i) Measures the value of input variables;

(ii) Performs a scale mapping that transfers the range of values of input variables into corresponding universes of discourse; and

iii) Performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as labels of fuzzy sets.

B. Fuzzy rules

A fuzzy system is characterized by a set of linguistic statements based on expert knowledge. The knowledge base comprises knowledge of the application domain and the attendant control goals. It consists of a ‘database’ and a ’rule base’. The database provides necessary definitions which are used to define linguistic control rules and fuzzy data manipulation. Generally the design of fuzzy controllers is based on the operator’s understanding of the behavior of the process instead of its detailed mathematical model. The main advantage of this approach is that it is easy to implement ‘rule of thumb ‘experiences and heuristics. These rules are often expressed using syntax of the form: If <fuzzyproposition>, then <fuzzy proposition >, where the fuzzy propositions are of the form, *‘x is Y’* or *‘x is* not *Y‘, x* being a scalar variable and *Y* being a fuzzy set associated with that variable. This rule establishes a relationship or association between the two propositions.

Fuzzy logic systems store rules as fuzzy associations; i.e. for the rule IFA THEN 5, where A and B are fuzzy sets, a fuzzy logic system stores the association (A,@ in a matrix M). The fuzzy associative matrix M maps fuzzy set *A* to fuzzy set *B.* This fuzzy association or fuzzy rules is called a fuzzy associative memory (FAM).

C. Fuzzy Inference

Fuzzy inference is the kernel in a fuzzy logic system. It has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic. In the fuzzy inference engine, fuzzy logic principles are used to combine fuzzy 'IF-THEN' rules from the fuzzy rulebase into a mapping from fuzzy input sets to fuzzy output sets.

D. Defuzzification

The defuzzification interface performs the following functions:

(i) Scale mapping which converts the range of values of output variables into corresponding universes of discourse; and

(ii) Defuzzification, which yields a nonfuzzy control action from an inferred fuzzy control action.

Defuzzifier produces a crisp output for our fuzzy logic system from the fuzzy set that is the output of the inference block.

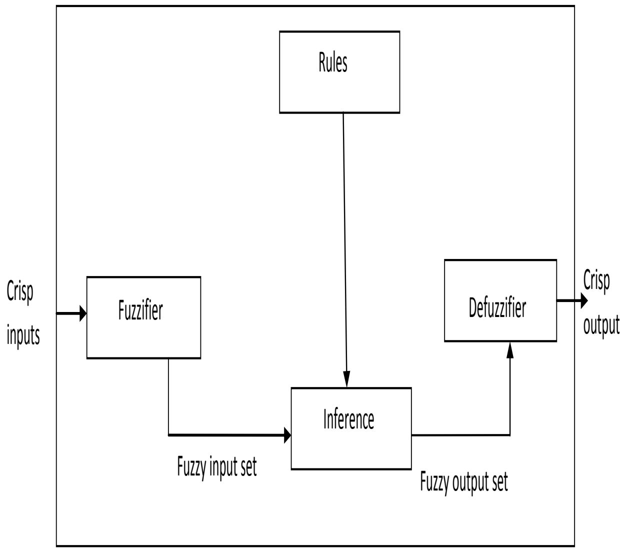

Figure 1: A Fuzzy Logic System.

IV. FUZZY CONTROL CONTROLLER

Applying an inference rule, Assilian and Mamdani developed the concept of fuzzy control in the early 1970s [11], [12]. Fuzzy control can be described as a means of control working with sentences rather than equations. In many cases, it is more natural to use sentences, or rules, (for instance, in operator-controlled systems) with the control strategy written in terms of if-then clauses. If the controller further adjusts the control strategy without human intervention, it is adaptive. The adaptive fuzzy controller, invented by Assilian and Mamdani, is known as the self organizing fuzzy controller. In other words, fuzzy control is based on an I/O function that maps each very low-resolution quantization interval of the input domain into a very low-low resolution quantization interval of the output domain. As there are a few fuzzy quantization intervals covering the input domains, the mapping relationship can be very easily expressed by using the IF-THEN formalism. (In some applications this leads to a simpler solution in less designing time.) The overlapping of these fuzzy domains and their usually linear membership functions will eventually allow a rather high-resolution I/O function between crisp input and output variables to be achieved. Mamdani's development of fuzzy controllers in 1974 [12] gave rise to the utilization of these fuzzy controllers in ever-expanding capacities [13].

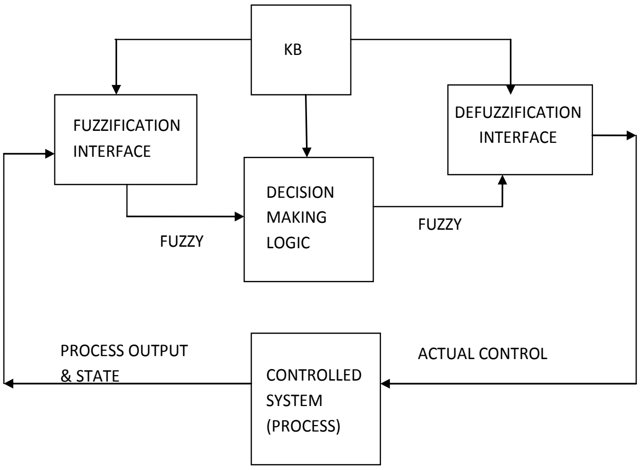

Figure2: Basic configuration of fuzzy logic controller

4.1 Classification of Liquid Level Controllers:
There are several types of level controllers. Some of these are:
(A) Level Controllers: Level controllers are devices that operate automatically to regulate liquid or dry material level values. There are three basic types of control functions that level controllers can use, limit control, linear control and advanced or nonlinear control [14].
(B) Integrated motion controllers: Integrated motion control systems contain matched components such as controllers, motor drives, motors, encoders, user interfaces and software. The manufacturer optimally matches components in these systems. They are frequently customized for specific applications.
(C) Pump Controllers: Pump controllers manage pump flow and pressure output.
(D) Flow controllers: Flow controllers allow metered flow of fluid in one or both directions. Many of them allow for free flow in one direction and reduced or metered flow in the reverse direction

V. DESIGN METHODOLOGY

In this research, we are going to design and develop flow control conventional PID controller and Fuzzy logic controller in MATLAB/Simulink Environment.
The performance of the fuzzy logic controller is compared with a well known existing PID controller. Figure3 shows the development and implementation of liquid flows using MATLAB/Simulink.

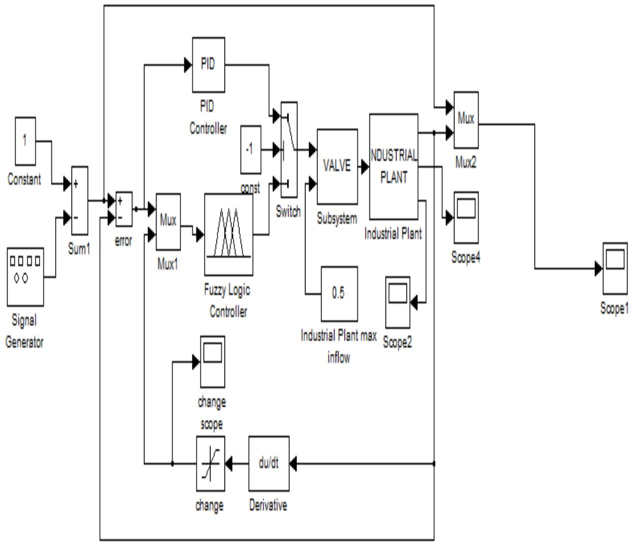

Figure3: Development and implementation of liquid flows using MATLAB/Simulink.

VI. RESULT ANALYSIS

The simulink results of the PID controller and the FuzzyLogic Controller is shown in the below graphs.
Figure 4 shows the response of fuzzy controller on simulation. The controller stabilizes at the desired water level very quickly. Figure 5 shows the response of the PID controller when simulated with the given parameters. The graph shows that the controller has an overshoot and takes time to stabilize to the desired value of 1m. Figure 6 shows the comparison of fuzzy and PID controller transient response for 1m desired level (pink line shows PID and yellow one indicates fuzzy). It is clear from the graph that the PID controller has a large overshoot compared to the fuzzy controller and also takes a lot of time to stabilize at the desired level. Fuzzy logic on the other hand, has little overshoot and steady state error and stabilizes quickly providing accurate level control.

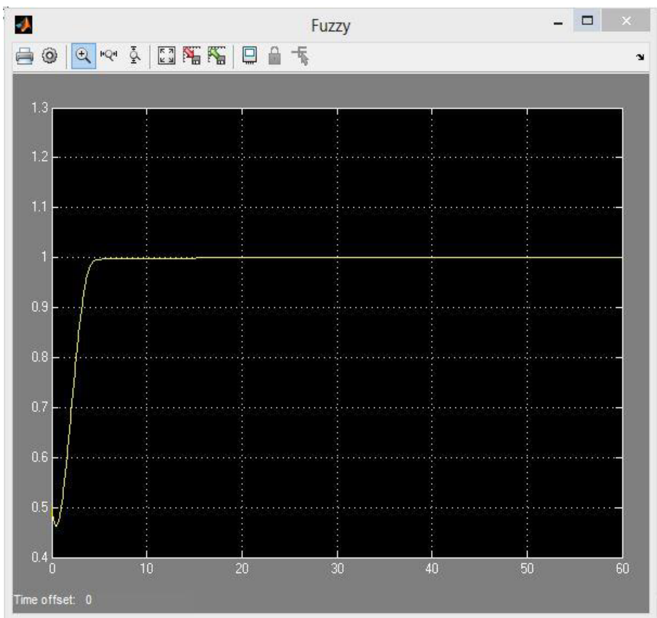

Figure4: Fuzzy controller response

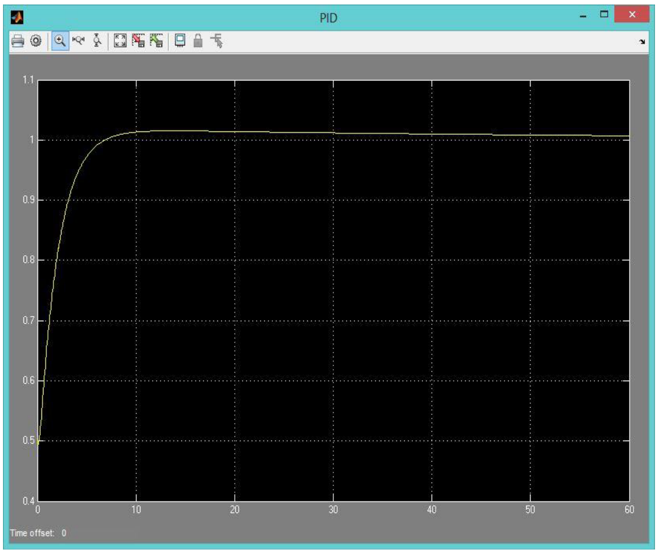

Figure5: PID response

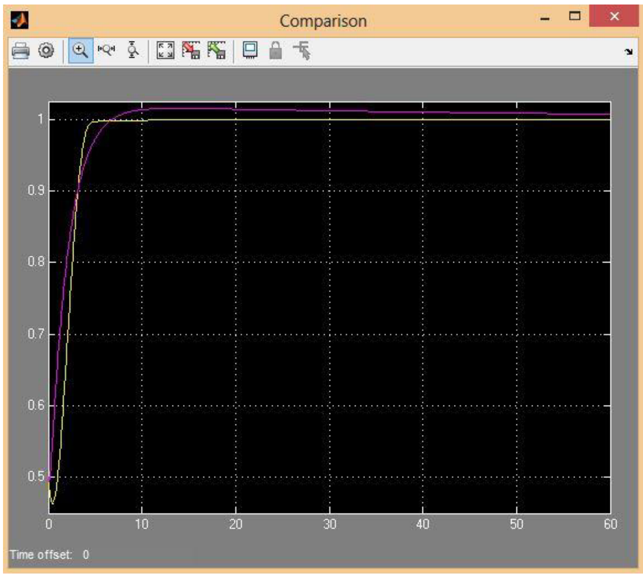

Figure 6: Transient Response of Fuzzy and PID controllers

VII. COMPARISON

Comparison results of PID and FLC are shown Table I below. The overall performance may be summarized as:

Parameter	PID	FLC
Overshoot	More	Less
Settling Time	More	Less
Transient	Present	Not Present
Rise Time	Less	More

VIII. CONCLUSION

In this research, we have studied and simulated two methods of controlling liquid using SIMULINK. As a result of comparing, Fuzzy Logic Controller is found to be better as compared to PID controller. Fuzzy controllers have better stability, small overshoot, and fast response. Hence, it is suggested for controlling fluid levels.

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