Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(12):403-410

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Application of fuzzy controllers for flow control processes in chemical industries

Snehal N. Rajguru*, Pritesh Shah, NeelaRayavarapu and PriyankaTupe

Symbiosis International University, Symbiosis Institute of Technology, Lavale, Pune

---

ABSTRACT

Fuzzy logic is a control system, which is able tosimulate the decision making capability of an experienced human being. Using human knowledge it is able to solve complex real world problems, which might require excellent human intelligence. In the industrial world Fuzzy logic applications have been in use since long time. Fuzzy logic's expert high grade decision making ability has allowed it to be used in areas such as flow process plants, power plants, thermal process plants, oil refineries, diagnosing medical problems, etc. Chemical processes are well-known for difficulties such as large variations in output responses and non-linearity. Thus it is difficult to control these processes using the conventional regulating mechanisms. This paper provides an overview on some researches, some pioneering and some path-breaking, which have been conducted in last few decades, in the area of Fuzzy logic controller design and highlights the important characteristics in design of Fuzzy logic controller for chemical industrial applications.

Keywords: Fuzzy Logic, design, implementation, Chemical industries, flow control process.

INTRODUCTION

The relationship between Automation and Control System is commonly widespread in the industrial world. This trend started when the industrial revolution took place in the manufacturing industries. The importance of control systems came into picture when a need aroused to implement better efficient manufacturing process using automated machinery. With so much productivity and large scale manufacturing coming into the picture, the ability of human operators just wasn't enough to be able to the meet the demands of mass manufacturing.

This resulted in increase in importance of Automation and Control systems in the manufacturing or any other process plants [1]. Worker safety and health also led to development of better automated machinery in manufacturing.

One of the applications of automatic control system is process control. Fuzzy logic has been successfully applied to various processes in chemical engineering, especially flow control processes. Any product whether it is a chemical, for e.g. gasoline, gas agents or any consumable, for e.g. a food product, can only be manufactured by passing the raw materials through a process. Chemical engineering largely involves the design, improvement and maintenance of processes involving chemical or biological transformations for large-scale manufacture. Chemical engineers ensure the processes are operated safely, sustainably and economically. Complex industrial processes such as a batch chemical reactors; blast furnaces, cement kilns and basic oxygen steel making are difficult to control automatically [2].

The fundamental structure of a control system for process consists of components such as a control element, sensors, controller, and a process or plant. Each component gives its own contribution in the stability of the control system;

but controller is the only component which can be modified in order to obtain better stability. Thus, it is extremely critical that stability of controller component is good in order to attain system stability.

PID controllers and Fuzzy Logic controller are two controllers used for automatic control systems. PID controller is designed on the basis of manually-tuned conventional control system. PID controllers are extensively useful because of their simple structure and wide range of applications in industry. But Fuzzy Logic controller has the ability to emulate human thinking, knowledge and reasoning into the control system and allows better control performance in the control system [3]. Having so many advantages over conventional PID controller, it is evident that many efforts have been made in order to replace the PID controller or combine both the controller design.

Fluid flow control systems are one of those systems which do not allow them to be controlled using the conventional methods. This is because there is a deficit in numerical data regarding the input-output relations of the flow control system [4]. Fuzzy Logic controllers can be applied to applications of fluid flow control in process plants because of their ability to give better stability, lesser error between output and desired result, and faster responses of the control system.

LITERATURE REVIEW

King. et.al. (1977) [5] illustrated the implementation of fuzzy logic algorithms to the control of dynamic processes in industry. Fuzzy logic can be used with a view to automate those processes where modeling difficulties and poorly-defined processes result in imperative need for manual control. Heuristic approach towards nonlinear time varying process systems was developed. Fuzzy Logic control approach was applied to two industrial applications. One application was the control system for temperature control of a steam boiler and second being as the temperature control of a stirred tank. During the experimentation in the first experiment it was found out that gains and time constants obtained were varying as according to the initial conditions of the control process outputs, also it was found that the process was highly nonlinear. This led to the result that it is not possible to achieve better control responses using the similar controller parameters in a constantly changing dynamic process. In the second experiment it was found out that the process was oscillating about a set point, and the primary cause of the instability of the system was time delay, thus time delay rules were considered in the controller structure. The results in the second experiment show that good control responses in terms of oscillations and settling time can be achieved. The heuristic rules based approach can itself be automated to obtain better results. For further research application of an adaptive-learning scheme to synthesize control rules with performance criterions can be developed.

Lee. et.al. (1990) [6] demonstrated the general methodology for constructing a Fuzzy Logic controller. The responses of the control process were assessed for performance criteria. The basic structure of fuzzy logic control is described by author. It consists of four parts they are Fuzzification unit, Fuzzy Inference System, Rule Evaluation, and Defuzzification. A systematic procedure to develop a Fuzzy logic controller using Mamdani Approach was described. The author explains the importance of probability based rules and possibility models in the design of Fuzzy logic controller. The need for additional rules based strategies whenever degree of membership tends to become some set value, say 0.5, was described. Development of self-adapting Fuzzy logic rules strategy was needed to be researched.

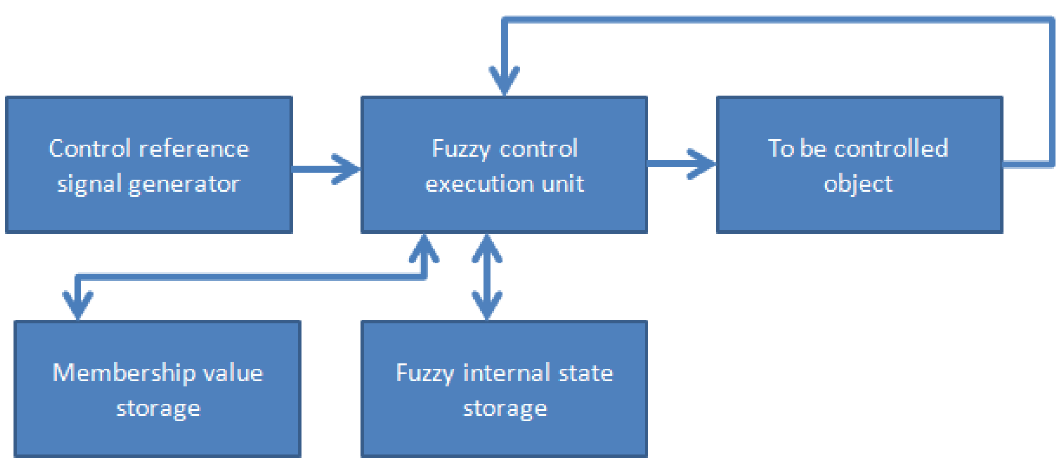

Fig.1. Adaptive fuzzy controller design with fuzzy internal state storage

Endo. (1995) [7] U.S. Patents (No. 5412757) invented the basic structure related to advanced adaptive Fuzzy logic control. The author in the patent discloses a fuzzy logic control system which obtains a membership function related to a control value of a to-be-controlled object using a fuzzy interference operation as according to the input value. The author demonstrates two design structures of advanced adaptive fuzzy logic control systems. Block diagrams and flowcharts related to the design of controller were also demonstrated. The fuzzy control system demonstrated by the author has a plurality of internal states. In the first design of controller the author describes that output control value of the previous state of controller is stored in the internal state storage, while in the second design along with the control output values membership functions are also stored in the internal state storage. In the design when the control performance of the to-be-controlled object gets too low the fuzzy control renews the internal state. The fuzzy logic design is capable of performing control actions reflecting an expert's high-grade judging functions was also found out. The author exerts attention towards the advantages and applications of the invention for future research on Fuzzy logic controllers.

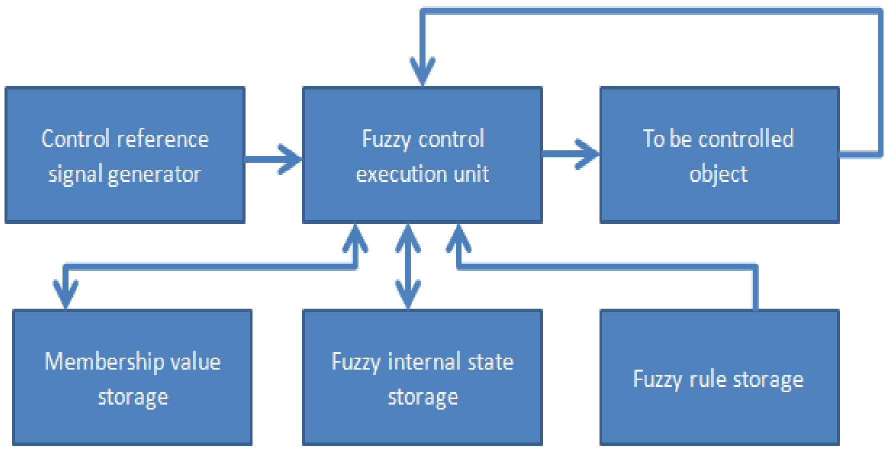

Fig.2. Adaptive fuzzy controller design with fuzzy internal state storage and membership value storage

Reznik. et.al. [3] (2000) designed a structured base for PID plus Fuzzy Logic controller. Controller design was applied to two industrial applications and their performance was assessed. Author exerts importance to the advantages of Fuzzy Logic controllers as being a heuristic approach towards controlling nonlinear processes. A combined PID-FL controller design was derived for aircraft guidance control. In the guidance control system a low-level conventional PID feedback controller was used to control the ailerons and elevators of the aircraft, it also controls the throttle settings of the aircraft. The Fuzzy controller provides reference signals to the PID controller for roll and pitch angles and for throttle settings. Assessment for performance of controller was based on errors in final positioning of the aircraft. The result showed that the PID-FL controller produced positioning errors which had normal distribution and were under acceptable limits. Need for new synergetic controller design using Fuzzy logic approach, for better quality control also was described by the author.

Pathmanathan. et.al (2010) [1] developed a fuzzy logic controller and implemented it for an industrial application. Author describes critical need for better real time control system for industrial applications such as for flow process. Using hardware and software tools a setup for controlling the process plant was created. Using MATLAB tool Fuzzy logic controller was created having set of 81 rules; this resulted in more accurate control and better performance of the controller. The results of the experiment demonstrated that FLC gives improved settling time, reduced integral of the absolute value of error and lesser output value overshoot. The bubble noise effect in the flow process was also reduced using FLC. The author suggests conducting research in other methods of fuzzy control such as sliding mode control, self-tuning control and adaptive PID-FL control in order to achieve better control.

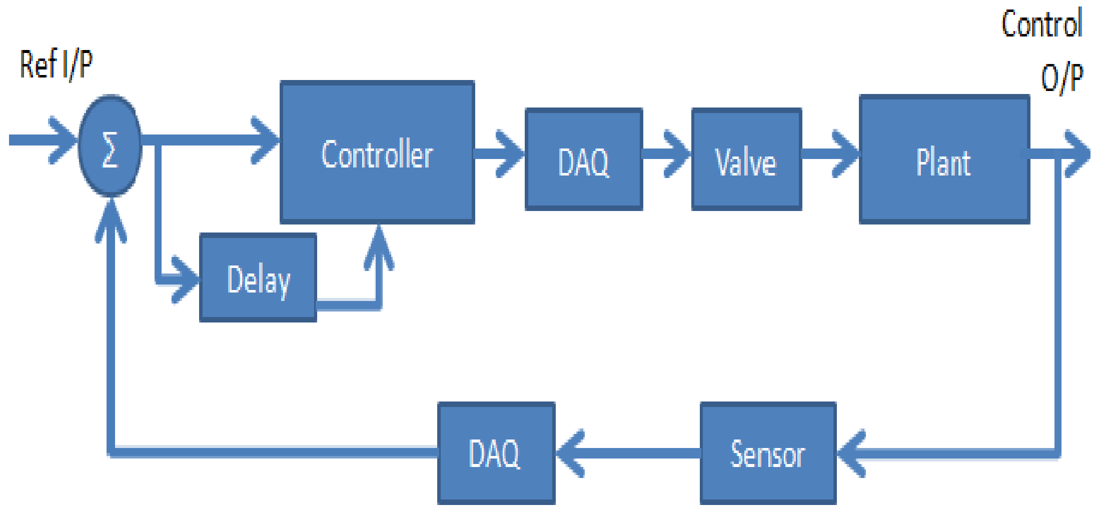

Fig.3. Control Scheme Block diagram

Precup. et.al. (2010) [8] presents a survey on different methods for advanced fuzzy control. Author describes three methods for advanced fuzzy control viz. Mamdani fuzzy control, Takagi-Sugeno fuzzy control, and Adaptive fuzzy control. Mamdani control system is described as a heuristic approach incorporating human skills and experience and is a model-free approach. Types of Mamdani approach are explained, they are: (i) PI-, PD-, and PID- fuzzy logic control, (ii) Sliding mode control and (iii) 2-DOF fuzzy control. Sliding mode control is capable of reducing instability caused due to chattering effect in input conditions. Takagi-Sugeno control is a dynamic model-based approach. Usually Fuzzy model is based on sets of local linear models, so the best approach to design the model is parallel distributed compensation (PDC) which means designing one local controller for each local model of the process. But the main disadvantage of the model is instability in control outputs. Adaptive fuzzy controllers have an extra module in the control process. This module is known as the supervisory control module which has access to modify several parameters of fuzzy controller. It is a hierarchical approach and it aims to achieve overall control of the system instead of localized control. The author describes the need for research in areas such as iterative tuning and learning techniques in fuzzy control, need for low-cost fuzzy controllers from point-of-view of design and various other factors.

Mazlan. et.al. (2012) [9] presented a design and implementation of Adaptive Fuzzy PID controller for industrial processes such as flow process control. The author aims to enhance the performance of PID controller by implementing Fuzzy logic control into it. The combined capabilities of PID and Fuzzy logic control are demonstrated. Author describes that the hybrid system of Adaptive Fuzzy PID controller (AFPIDC) can overcome problems of slower response control and instability of system. The Fuzzy logic control is used to produce three operating signals that make the PID gains to automatically adjust in accordance with the process control. Using the required hardware and software tools the setup for the implementation of control system was developed. The fuzzy logic controller was developed in MATLAB and consisted of 49 rules set to manipulate the conventional PID. The designed controller was implemented and assessed for performance. The performance of AFPIDC was also compared to performance of fuzzy logic controller and conventional PID controller. The result of experimentation showed that AFPIDC provided better performance as compared to fuzzy logic and conventional PID controller; this was due to capabilities of AFPIDC such as better settling time, smaller output overshoot and smaller integral of absolute error. The results also showed better performance of AFPIDC in reducing bubble noise effect. Author exerts his attention towards research in other type of controller types such as Neuro-Fuzzy controller, Model Predictive control (MPC).

Gaurav. et.al. (2012) [4] has demonstrated performance comparison between conventional PID and Fuzzy logic control, and has used MATLAB/Simulink as the method of implementation. Fuzzy logic controllers are more advantageous than conventional PID controllers as they provide a linguistic control strategy based on high-grade judging knowledge of an expert. Author has exhibited the poor capabilities of conventional PID controller to control processes which are nonlinear in nature. PID controller tuning is difficult as knowledge of process parameters is insufficient in case of nonlinear processes. Implementation of fuzzy logic controller was conducted using MATLAB/Simulink and performance of process outputs of each type of controller was assessed. The result shows that PID controller exhibits larger settling time and peak overshoots parameters than compared to fuzzy logic controller, also oscillations in case of fuzzy logic controller were very less. Using different methods of fuzzy logic control more advanced controllers can be designed in order to achieve better process control.

FUZZY LOGIC CONTROLLER

A. Fuzzy Logic

'Fuzzy' word is equivalent to inaccurate, approximate and imprecise in meaning. Fuzzy logic is a form of approximate reasoning rather than fixed or exact. Traditional binary sets have truth value as either 0 or 1 that is true or false, while fuzzy logic have the truth value ranging between 0 and 1 that is it its truth value can take any magnitude range between 0 and 1 or true or false.

Fuzzy logic emulates the human reasoning and logical thinking in a systematic and mathematical way. It provides an instinctive or perspective way to implement decision making, diagnosis and implementation of control system. Fuzzy logic deals with the uncertainty existing in the real world, for example if colors of two apples are to be compared then there exist uncertainty in the degree of color of apples, applying human logical thinking to this we classify the color to be either dark or lighter than the other. Using traditional binary sets it is not possible to exactly classify the color of the apples as completely dark i.e. 0 or false and completely lighter than the other i.e. 1 or true. To deal with this uncertainty or approximation regarding the degree of color of apples, fuzzy comes into the picture. Fuzzy logic gives a particular degree to the intensity of the color, thus making it much easier to classify how dark or light the color of apple is.

The Fuzzy logic is built upon two critical components known as linguistic variables and membership functions. Linguistic variables are entities used to represent qualities spanning a particular spectrum. In the above example "dark" and "light" are the two linguistic variables used to classify the color of the apple. Membership functions are user defined values for the linguistic variables. Thus the human logic reasoning capabilities can be implemented for controlling complex real world systems.

B. Fuzzy Logic controller structure

Fuzzy logic controller is based on expert knowledge which provides means to convert the strategy for linguistic variable control into strategy for automatic control.

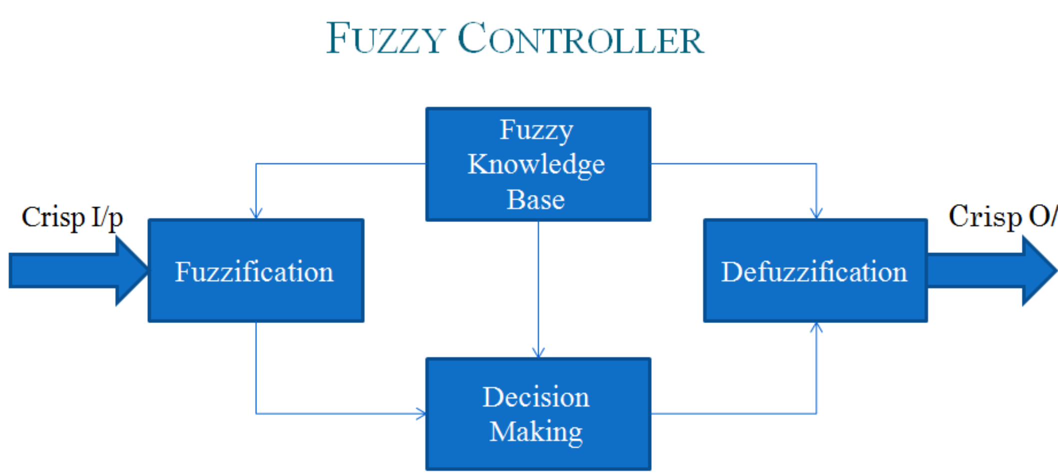

Fig.4. Fuzzy Controller Structure

The fuzzy logic controller encompasses four main components viz. Fuzzification unit, Fuzzy Knowledge Base, Decision making unit, and Defuzzification unit. These are explained briefly below.

i. **Fuzzification**: Fuzzification unit measures the real scalar values of variables inputted into the system. It then performs a scale mapping of the range of scalar values of input variables and then converts it to corresponding fuzzy value. Thus fuzzification simply means converting the crisp input data into fuzzy value with help of suitable linguistic values and defined membership functions. Fuzzification process can be represented mathematically as given below:

$x = \text{fuzzifier}(x_0)$

Where x is the fuzzified value of the crisp input value.

ii. **Fuzzy Knowledge Base**: It consists of a database comprising of the necessary definitions used to describe linguistic variables and fuzzy data manipulation also it consists of a rule base comprising the control goals and control policy defined by the experts by means of linguistic control rules.

iii. **Decision Making Unit:** the Decision making unit is the heart or kernel of a fuzzy logic controller which has the capability of inferring fuzzy control actions employing rules of inference in fuzzy logic. A set of IF-THEN rules are used for inferring a control action based on expert knowledge or designing.

IF (antecedents are satisfied) THEN (consequents are inferred)

IF-THEN rules are accompanied with linguistic variables and are frequently called as fuzzy conditional statements, or fuzzy controlled rules. IF-THEN rules can be also be used with logic operators such as Boolean operators for applying multiple antecedents or multiple consequents. For example:

IF (A AND B are satisfied) THEN (C is the consequent)

Where A & B are inputs and C is the control outputs.

IF (A is satisfied) THEN (B OR C are the consequents)

Where A is the input and B and C are control outputs.

iv. **Defuzzification**: The last unit of the fuzzy logic controller is the defuzzification unit which converts a inferred fuzzy control value from the decision making unit to a non-fuzzy or a crisp control value, which is fed to the process for the controlling action. In defuzzification a scale mapping is done to convert a fuzzy value to a non-fuzzy value. Defuzzification can be done by various methods. The most used method is the Centre of Gravity method to get the most desired control value.

$Z_{\mathbf{0}}$ = defuzzifier (Z)

Where Z_0 is crisp control output Z is fuzzy control output.

C. Methodology or Techniques for Construction of FLC

In the recent past a lot of research scholars are indulging in research in the domain of developing and implementing fuzzy logic controllers for varied applications where there is still scope of improvement or development of new fuzzy logic control systems with better performance and high accuracy. The result of extensive research done by various scholars in the field of fuzzy logic controllers has led to the discovery or invention of three major methods in which fuzzy logic controllers can be implemented. This paper discusses these three methods viz. Mamdani design, Takagi-Sugeno design and the Adaptive or Predictive fuzzy design in brief in the following sub-section.

i. **Mamdani Design**: Mamdani design is usually developed by heuristic means, that is, experienced based techniques for problem solving. Initially, fuzzy logic controllers were developed and implemented using Mamdani design based on experience and expertise of the developer or the process operator. Basically, Mamdani design incorporates human skills and experience to develop the fuzzy logic controller, thus being a model free approach to the design of FLC. This design has its own advantages and disadvantages. The advantage being, it is a model free approach and thus is easy to design and implement based on expert knowledge for non linear systems whose input and output parameters of the process are poorly defined or where there is lack of quantitative data to define the system. The shortcoming of this process is the FLC tuning and the lack of general purpose design. There are some issues regarding the stability, robustness and sensitivity in the FLC design [6]. Therefore in further FLC designs, more emphasis was given to the systems stability and performance.

ii. **Takagi- Sugeno Design**: Unlike the Mamdani design approach, which is model free design of FLC, Takagi-Sugeno design is based on the fuzzy dynamic model. In this design approach, a set of local linear models are combined by the main fuzzy model. In T-S approach, FLC is developed using Parallel Distributed Compensation (PDC), which means, for each sub-process a local model is developed which aims to achieve the goals of only that particular sub-process. Then all the local models are combined to form the main FLC which aims at global goal or the overall goal of the process which is to be controlled. This system design approach overcomes the shortcoming of the Mamdani design, by resulting into better stability and performance of the system in regard of sensitivity and accuracy of the control output. The main disadvantage of this approach is complexity in developing the system model for non linear process due to its model based approach. Being a model based design, there are concerns regarding the stabilization of T-S fuzzy models though the results of stability in T-S model are much higher than the Mamdani design approach. This led the researchers on a track to develop more flexible fuzzy control systems with high efficiency and stable output control using adaptive fuzzy control design.

iii. **Adaptive Fuzzy Design**: The term “Adaptive” generally means to change according the demands of the situation. In Adaptive fuzzy design approach, there is on additional controller named as the supervisory module along with the traditional fuzzy controller. This supervisory controller has access to all inputs as well as outputs of the system to be controlled and has the right to change any parameter of the control system, to achieve the dynamic goals of the global system.

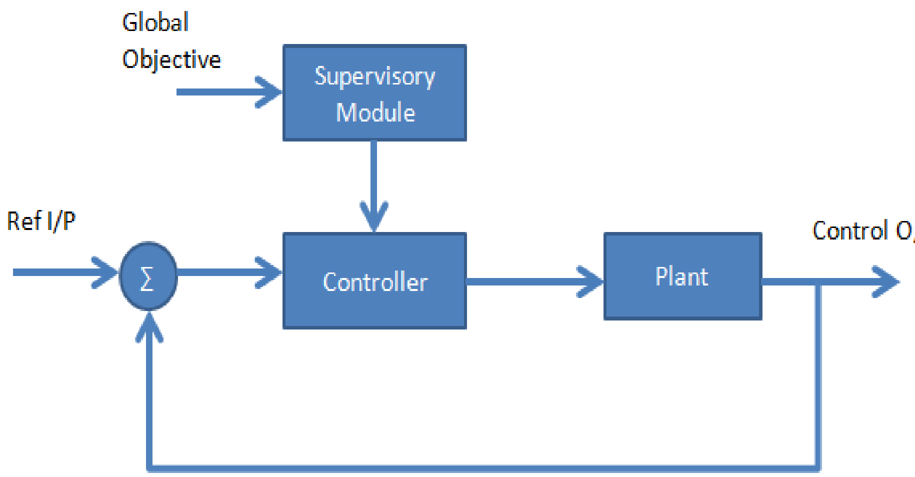

Fig.5. Adaptive Fuzzy Controller

Adaptation can be done in the size of membership functions, position of the membership functions and link values according to the global aim of the system. A predictive FLC design does not change the parameters of the system to be controlled, but chooses the best output control signal based on the performance of described global aim of the system. New technologies are coming into picture such as designing a FLC using Neuro-Fuzzy approach, where human reasoning capabilities of fuzzy logic controller and the learning capabilities of neural networks are combined smoothly resulting in the hybrid intelligent system for controlling the highly advanced and complex non linear systems.

CONCLUSION

In this paper a systematic review of previous research based on different technologies related to Fuzzy logic were discussed. All the technological domains of fuzzy logic controller including Mamdani, Adaptive, and Takagi-Sugeno were covered. Fuzzy Logic is an effective tool for bridging the human thinking and computational logic. Fuzzy logic controller system is an already established control technology in industrial area, but there are still many untouched nonlinear and complex applications which require more advanced technology of Fuzzy control, such as flow processes, medical diagnosis, nuclear technology, etc. Future in-depth research can be done to achieve fuzzy control systems which are self-adapting and have very high-grade judging and decision making capabilities thus being able to take highly accurate decisions such as Neuro-Fuzzy logic controllers.

ACKNOWLEDGEMENT

The authors are greatly indebted to Symbiosis Institute of Technology, Pune for giving an opportunity to conduct in-depth research in this domain. Secondly, we would like to acknowledge the encouragement we received from Director Dr. T.P. Singh, Deputy Director Dr. AkshayMalhotra, and the staff of Department of Electronics & Telecommunication. We would also like to thank all the friends and colleagues who have helped us and given us support in the process of conducting this research.

REFERENCES

[1] E Pathmanathan; R Ibrahim, Development and Implementation of Fuzzy Logic Controller for Flow Control Application, *International Conference on Intelligent and Advanced Systems (ICIAS),* **2010**, 1-6.
[2] M.R.S. Emami, *The Journal of Mathematics and Computer Science,***2010**, 1(4), 339-348.
[3] A Bourmistrov; L Rezinik; O Ghanayem, *Engineering Applications of Artificial Intelligence*, **2000**, 13, 419-430.
[4] A Kaur; Gaurav, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, **2012***,* 1(1), 84-88.
[5] E. H. Mamdani; P. J. King, *Automatica (International Federation of Automatic Control),***1977**, 13, 235-242.
[6] C.C Lee, *IEEE Transactions on Systems, Man, and Cybernetics,* **1990**, 20, 404-418.
[7] T Endo, Fuzzy Control System, *United States Patent,* Patent number: 5412757, **1995**, 1-20.
[8] H Hellendoorn; R.E Precup, *Computers in Industry*, **2010**, 62, 213-226.
[9] R Ibrahim; Z Mazlan, *International Conference on Intelligent and Advanced Systems*, **2012**, 1-6.
[10] J. J Buckley; W Siler. Fuzzy Expert Systems and Fuzzy Reasoning, John Wiley & Sons Publication, **2005**.
[11] K.M Passino; S Yurkovich. Fuzzy Control, Addison Wesley Longman Publication, **1998**.
[12] H Li; M.M Gupta. Fuzzy Logic and Intelligent Systems, Springer Science & Business Media Publications, **1995**.
[13] G Chen; T.T Pham. Introduction to Fuzzy Sets, Fuzzy Logic, and Fuzzy Control Systems, CRC Press, **2000**.
[14] E Kolman; M Margaliot. Knowledge-Based Neurocomputing: A Fuzzy Logic Approach, Springer Science & Business Media Publications, **2009**.
[15] A. Vasickaninová; M. Bakošová, Cascade Fuzzy Logic Control Of A Chemical Reactor, *15th Int. Conference Process Control ,* **2005**, 175-1 – 175-5.
[16] S.Palani; S.Rajendran, *International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS,***2014**, 14(04), 7-13.