American International Journal of Research in Science, Technology, Engineering & Mathematics

Available online at http://www.iasir.net

ISSN (Print): 2328-3491, ISSN (Online): 2328-3580, ISSN (CD-ROM): 2328-3629

AIJRSTEM is a refereed, indexed, peer-reviewed, multidisciplinary and open access journal published by International Association of Scientific Innovation and Research (IASIR), USA
(An Association Unifying the Sciences, Engineering, and Applied Research)

Study and Review of Fuzzy Inference Systems for Decision Making and Control

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Abstract*: The fuzzy inference system with weighted average is computationally efficient and useful for dynamic nonlinear system control while the system that defuzzifies the fuzzy output into crisp is best suited for decision making and control. However in these systems complexity with high order polynomials and a substantial computational burden rises when used separately. Multilayer approach with weighted average and defuzzification set in layers can reduce the cost of defuzzification and lack of output expressivity that causes risk when used as a controller. The adaptive fuzzy system with this approach makes the system exploitable for areas requiring easy interpretation and human reasoning. In this review paper there is the study of fuzzy inference systems and the proposed multilayer system with defuzzification and weighted average is explained.*

Keywords*: Weighted average; defuzzification; decision making; multilayer approach.*

I. Introduction

Fuzzy systems are a part of soft computing that works on the discipline of vagueness and gives results in an interpretable manner. Fuzzy system makes use of fuzzy set theory, fuzzy reasoning and inference mechanism so that such systems can be employed in various applications.

In classical set theory an object can either a member of a given set or not while fuzzy set theory allows an object to belong to a set with a certain degree. Fuzzy system models fuzzy boundaries of linguistic terms by introducing gradual membership. Fuzzy set includes membership function. Membership function maps each element of a set to a membership degree [1].

The fuzzy set (F) is represented by two values, the member x of the fuzzy set(X) and the membership degree (μ_A). The fuzzy set is provided by the membership function (f) to which the member is added to the set [2].

$F= f\{x, \mu_x\}$

$F= \{(x, \mu_A(x))| x \epsilon X\}$.

Fuzzy systems have closeness to human reasoning so solutions obtained using fuzzy systems are easy to apply and understand. There is no need to have formal model of the problem of interest and no training data is required when fuzzy systems are used for solving the problems. Due to this fuzzy system is chosen if linguistic, vague or imprecise information has to be modeled [2].

Fuzzy inference system is a computing framework based on the disciplines of fuzzy set theory, fuzzy if then rules and fuzzy reasoning. The input required to Fuzzy inference system is in fuzzy form or in crisp form but the output it generates is always in fuzzy form. Fuzzy inference system is also called as fuzzy rule based system, fuzzy expert system, fuzzy associative memory, fuzzy controller, fuzzy model or simply fuzzy system on the basis of the target for which the system is designed. For example if the target of a system consist of temperature controlling tasks then the fuzzy system will be called as fuzzy controller and if the target is an expertise in medicine then the designed system is called fuzzy expert system [1].

In this paper authors are studying the fuzzy inference system. Fuzzy inference systems are widely applicable in economic, scientific and engineering application areas due to the intuitive nature of the system and ability to analyze human judgments. Fuzzy inference systems can capture changing environment as an expert knowledge that can be easily integrated with fuzzy systems. Fuzzy inference systems have the output expressive power so one can easily understand the results and control the target. A multilayer approach for fuzzy inference system is proposed by authors. In decision making and control applications use of fuzzy inference systems is attractive.

The rest of the paper is organized as follows. In Section II, literature survey of fuzzy inference system is described which contains the background of the system and fuzzy inference system related work in various applications. Section III explains the proposed work of authors.

II. Literature Survey

Classical control theory is based on the mathematical models which describes physical plant under consideration. But the traditional control systems are not superior to fuzzy logic controller system. Conventional logic systems do not consider the vagueness in the data so they are not closer to human analysis and natural languages. While the fuzzy inference systems have this ability due to which initially fuzzy inference system were used as a controller [3].

The structure of fuzzy inference system is composed of three components rule base, database and reasoning mechanism.

Rule base

In rule base fuzzy rules are selected. Fuzzy rules are built from antecedent and consequent. Fuzzy rules are in 'if then' form [3].

Database

A database defines membership functions used in fuzzy rules. With this membership function membership degree is decided for the objects of the set so that they can be included in fuzzy sets with the membership degree [3].

Fuzzy reasoning

Fuzzy reasoning performs inference procedure which uses the input information and available fuzzy rules to conclude the output of reasoning mechanism [3]. Such inference procedure derives conclusions from a set of fuzzy it-then rules and known facts. Fuzzy reasoning is also known as approximate reasoning. Fuzzy reasoning is made by using basic rules of inference such as two valued logic modus ponens in which the truth value of one proposition can be inferred from the truth value of other proposition given that one proposition implicates other proposition [1].

A. Types of fuzzy inference system

Fuzzy inference system is classified into three types on the basis of the consequent of the fuzzy rules that are required for the inference procedure.

1) Mamdani fuzzy inference system

Mamdani fuzzy inference system was initially developed to control the steam engine and boiler combination by using a set of linguistic variables. The fuzzy rules in such control system are obtained from experienced human operator [4]. The fuzzy rules in Mamdani fuzzy inference system are of the form,

If x is small then y is small.

If x is small then y is medium.

Here antecedent and consequent of the rules are linguistic variables and both are fuzzy. Mamdani fuzzy inference system generates output in fuzzy form so there is a need to convert this fuzzy output into crisp form. For this purpose different defuzzification techniques are used to defuzzify fuzzy output into crisp [1].

2) Takagi Sugeno Kang fuzzy inference system

Takagi Sugeno Kang fuzzy inference system was proposed by Takagi, Sugeno and Kang for developing systematic approach that can generate fuzzy rules from given input output data set [4]. A typical fuzzy rule in this model is of the form,

If x is A and y is B then z=f(x, y).

Where antecedent of the rule is in fuzzy form and consequent of rule is represented by a function in x and y fuzzy input. z=f(x, y) is a crisp function. f(x, y) is a polynomial in x and y. If f(x, y) is a first order polynomial then the inference system is called as first order Sugeno fuzzy model. If f is constant then the inference system is zero order Sugeno fuzzy model which is a special case of Mamdani fuzzy model. The order of TSK fuzzy model changes with the polynomial. The overall output of Takagi sugeno kang fuzzy inference system is obtained by weighted average. Weighted average operation is sometimes replaced by weighted sum operation to avoid unnecessary complications in computations [1].

3) Tsukamoto fuzzy inference system

In Tsukamoto fuzzy inference system the consequent of fuzzy if then rule is represented by a fuzzy set with monotonical membership function. So the output of each rule is defined as a crisp value. The overall output is taken as the weighted average of output of each rule. However Tsukamoto fuzzy inference system is not used often in applications because this system is not much transparent in comparison to Mamdani fuzzy model and Takagi Sugeno fuzzy model. The rules in this inference system are represented as,

If x is small then y is c1.

If x is medium then y is c2.

Here the consequent of the rules are fuzzy sets. The output of Tsukamoto fuzzy inference system is crisp even if the input is fuzzy [1].

B. Related work

Various authors have studied fuzzy inference systems for different applications depending upon the need of the application. Some of the work done by researchers is explained in this section as follows.

A. Kaur et al. [5] used fuzzy system approach for air conditioning system. In this Mamdani type and Sugeno

type of fuzzy inference systems are designed for air conditioning system. These systems take two inputs from temperature and humidity sensors which gives the temperature and humidity of the room. Output is produced in the form of signals that controls the compressor speed. Mamdani type and Sugeno type of fuzzy inference system are compared in this work. Mamdani system is widely accepted due to the intuitive nature. However this system uses defuzzification method for output that entails computational burden. Sugeno type fuzzy inference system is computationally efficient and adaptive with respect to optimization technique. Sugeno fuzzy system is best suited for dynamic nonlinear systems. But the output expressive power and human interpretability of Mamdani output is missing in Sugeno fuzzy system. Sugeno type fuzzy inference system for air conditioning system works to its full capacity while Mamdani type fuzzy inference system does not work to its full capacity. The advantage of Sugeno type fuzzy inference system is that it can be integrated with optimization technique due to this the controller can be used with to individual user, weather and environment.

V. Davidson et al. [6] proposed a fuzzy model to predict consumer ratings. Fuzzy models are developed as a part of automated inspection system to recognize consumer preferences for biscuits based on the physical features extracted from digital images of biscuits. Mamdani fuzzy inference system and Sugeno fuzzy inference system developed to recognize consumer ratings for a product. Fuzzy system is developed in this work because fuzzy methods easily represent the variations and consumer preferences and opinions. In this work the Mamdani fuzzy inference system used centroid of area and mean of maximum method of defuzzification. Sugeno fuzzy inference system used weighted average mechanism to obtain overall output that can be expressed intuitively. Mamdani fuzzy inference system used in this work requires more number of membership functions. For Mamdani fuzzy inference system the root mean square error is more for calibration set and validation set than Takagi Sugeno fuzzy inference system.

D. Delgado et al. [7] proposed fuzzy based controller, as an advisory system that incorporates expert knowledge about the treatment of disease is developed using Mamdani type fuzzy logic controller to regulate blood's glucose level. The control framework is based on feedback structure. With this structure the variations in glucose insulin dynamics of the different patients is avoided. The inner loop decides the amount of long and short acting insulin which is needed three times in a day before meal. The outer loop suggests the maximum amount of insulin required by patient in a time scale of days. The outer loop works as a supervisor for the inner loop. The inner loop controller is designed with Mamdani type fuzzy architecture with fuzzy sets that uses three types of membership functions. The shape of membership function is selected according to the fuzzy classification of input and output values. The output of this controller is evaluated with centroid of area method. Both inner loop and outer loop controllers are structured using Mamdani type fuzzy controllers to incorporate information about patient treatment. This method with two loop controller is robust and effective for blood glucose regulation. But there are some flaws in this system such as there is less flexibility in system design of the Mamdani type fuzzy controller.

I. Elamvazuthi et al. [8] proposed a fuzzy system for auto image zooming. Implementation of supervised learning method based on membership function includes training in the context of Mamdani fuzzy models is done in this work. The autozoom function of digital camera is modeled with Mamdani technique. Triangular membership function, trapezoidal membership function and Gaussian distribution functions are used in this system. The input is taken in the form of distance of object and camera. In fuzzification membership function assigns membership degrees to the input. In inference stage fuzzy rules are inferred from knowledge base. Finally the output is defuzzified so that it is provided for controlling the activity or function of the digital camera.

G. Zang et al. [9] introduced the concept of probabilistic fuzzy logic system. A probabilistic fuzzy system based prediction model is designed for short term prediction. The probabilistic dimension is used for capturing both stochastic and deterministic uncertainties and it gives guarantee to have better prediction in complex stochastic environment. Mamdani inference is used in the probabilistic fuzzy logic system. To convert the fuzzy output into crisp output probabilistic defuzzification is required in this method. Probabilistic center of set defuzzification is used for defuzzifying fuzzy output and the crisp wind speed output is calculated as,

$$\boldsymbol{y}_{\text{PFLS}} = \frac{\sum_{i=1}^{J} y_i \mu_{A^i}}{\sum_{i=1}^{J} \mu_{A^i}}$$

In this equation y_i is centre of probabilistic fuzzy set in rule i. Number of rules are J and the firing level of rule i is μ_{A^i}. The value of $\boldsymbol{y}_{\text{PFLS}}$ is used to calculate expected wind speed $\boldsymbol{y}$ [9].

$\boldsymbol{y}$= E ($\boldsymbol{y}_{\text{PFLS}}$).

III. Proposed System

A multilayer fuzzy inference system is proposed in which the fuzzy inference system with weighted average is used for one layer of data and for other layer fuzzy inference systems that defuzzifies the fuzzy data is planned to use. Number of fuzzy rules required to build a system can be reduced by the use of fuzzy inference system with weighted average. For complex and high dimensional systems a multilayer approach of fuzzy inference system is useful.

Since the fuzzy inference systems with weighted average works well for nonlinear systems and require less

processing time while fuzzy inference systems with defuzzification comprise ability to work with multiple input single output and multiple input multiple output system, the multilayer approach can provide the advantages of both of the systems.

Fuzzy systems with defuzzification have closeness to human reasoning so solutions obtained by using such fuzzy systems are easy to apply and understand. There is no need to have formal model of the problem of interest and no training data is required when fuzzy systems are used for solving the problems. Due to this the multilayer approach of fuzzy systems is planned to design if linguistic, vague or imprecise information has to be modeled.

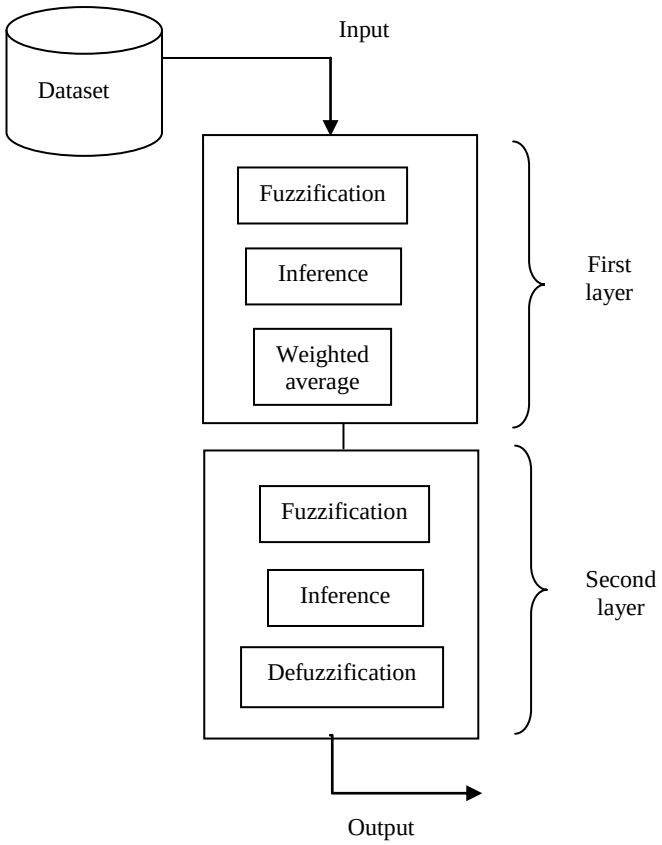

Figure 1: Proposed multilayer fuzzy inference system

Figure 1 shows the design of the proposed system which is a multilayer fuzzy inference approach. The input data is provided for fuzzification. The membership degrees are decided by the membership function and depending upon that the object data belongs to the fuzzy sets. The dataset can be divided into layers and for the first layer of data weighted average scheme is used to obtain crisp output from the fuzzy output. For the second layer of the data defuzzification methods can be applied to get the final output.

There are various repositories of dataset useful in applications that require quick and correct decision making and control. The proposed multilayer fuzzy inference system with weighted average and any of the defuzzification method such as centroid of area, mean of maximum can be used for such application.

IV. Conclusion

In this paper authors have studied the fuzzy inference systems with weighted average and defuzzification for decision making and control applications. There is a presence of certain flaws in both type of fuzzy system when used separately. To overcome these flaws of defuzzification and weighted average, the multilayer fuzzy inference system approach for decision making and control is planned to use. In the future the multilayer fuzzy inference system can be applied to an appropriate application having fuzzy input and that requires accurate decision making.

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V. Acknowledgments

Authors would like to express gratitude to Prof. Dr. Girish K. Patnaik, Head of the Computer Science and Engineering Department for his guidance and support in this work. The authors are also thankful to the Principal, SSBT's College of Engineering and Technology, Jalgaon for being a constant source of inspiration.