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Comparison of Mamdani-type and Sugeno-type FIS for Water Flow Rate Control in a Rawmill

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Abstract—Fuzzy inference systems (FIS) are developed for water flow rate control in a rawmill of cement industry using Mamdani-type and Sugeno-type fuzzy models. This concept is taken from ambuja cement plant. It is essential to control water flow rate efficiently to produce high quality cement. Rawmill is a mill which is used to grind the raw materials which are used to manufacture cement. Water flow rate control system is two input and one output system. In this paper, both the models are simulated using MATLAB Fuzzy logic Toolbox and the results of the two fuzzy inference systems are compared. This paper outlines the basic difference between the Mamdani-type FIS and Sugeno-type FIS.

Index Terms— FIS, flow rate control, mamdani, process value, rawmill, setpoint, sugeno.

1 INTRODUCTION

The term "fuzzy logic" was introduced by Lotfi A. Zadeh in 1965. Fuzzy logic is a form of many-valued logic. It deals with reasoning that is approximate rather than fixed and exact. In contrast with traditional logic they can have varying values, where binary sets have two-valued logic, true or false, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. [1] This is a methodology to represent and implement human's knowledge about how to control a system. FLC is a non-linear controller that can be viewed as an artificial decision maker that operates in a closed loop system in real time. To design the FLC, information must be gathered on how the artificial decision maker should control the system. This information can either be collected from a human decision maker who performs the control task or by directly understanding the plant dynamics then formulate a set of rules about how to control the system. Fuzzy systems have been in a wide variety of applications in engineering, science, business, medicine, psychology, and other fields [2]. Mamdani is given by Ebrahim Mamdani 1n 1975 [3].

The cement production is one of the most fundamental industries. The cement can be found almost everywhere in the everyday life and the industrial society cannot be imagined without it. Cement is typically made from limestone and clay or shale. The cement manufacturing process consists of broadly of mining, crushing and grinding, burning, and grinding with gypsum as shown in fig. 1. Two basic processes, the wet process and the dry process, are used for cement manufacturing [4].

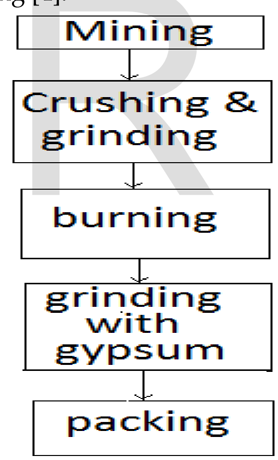

Fig. 1 Plant Process Flow Diagram[4]

Nowadays dry process is used to decrease energy consumption. The quality of the produced cement depends on the raw materials and also on the processing operations. The control system of the cement production controls these operations to produce the maximum quantity of the cement with prescribed quality and minimum cost. Due to increasing population, various constructional activities are increasing day by day. As a result the market demand of cement is also increasing continuously [5]. Our interest is to control raw grinding systems. Fuzzy logic system is flexible in terms of the number of inputs that would map fuzzy inputs into a crisp value.

The rest of the paper is organized as follows: Section II gives the difference between Mamdani-type and Sugeno-type FIS. Section III shows the development of Mamdani-type FIS. Section IV shows the development of Sugeno-type FIS. Section V gives results and discussions and section VI conclusions.

2 MAMDANI-TYPE FIS vs. SUGENO-TYPE FIS

Mamdani method is widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more human-like manner. However, Mamdani-type FIS entails a substantial computational burden. On the other hand, Sugeno method is computationally efficient and works well with optimization and adaptive techniques, which makes it very attractive in control problems, particularly for dynamic non linear systems. These adaptive techniques can be used to customize the membership functions so that fuzzy system best models the data. The most fundamental difference between Mamdani type FIS and Sugeno type FIS is the way the crisp output is generated from the fuzzy inputs. While Mamdani FIS uses the technique of defuzzification of a fuzzy output, Sugeno FIS uses weighted average to compute the crisp output. Therefore in Sugeno FIS the defuzzification process is bypassed [6]. The expressive power and interpretability of Mamdani output is lost in the Sugeno FIS since the consequents of the rules are not fuzzy. But Sugeno has better processing time since the weighted average replace the time consuming defuzzification process. Due to the interpretable and intuitive nature of the rule base, Mamdani-type FIS is widely used in particular for decision support application. Other differences are that Mamdani FIS has output membership functions whereas Sugeno FIS has no output membership functions. Mamdani FIS is less flexible in system design in comparison to Sugeno FIS as latter can be integrated with ANFIS tool to optimize the outputs [6].

Table 1 – Comparison between Mamdani FIS and Sugeno FIS [6]

Mamdani	Sugeno
Output membership function	No output membership function
Crisp result obtained through defuzzification of rules' consequent	No defuzzification: crisp result is obtained using weighted average of the rules' consequent
Non-continuous output surface	Continuous output surface
MISO (Multiple Input Single Output) and MIMO (Multiple Input Multiple Output) systems	Only MISO systems
Expressive power and interpretable rule consequents	Loss of interpretability
Less flexibility in system design	More flexibility in system design

3 DEVELOPMENT OF MAMDANI-TYPE FIS

Water flow control system in a rawmill is first developed using mamdani fuzzy model. It consists of two inputs and one output. First input is variation in required temperature i.e. difference between present and previous setpoint and denoted by 'dSP'. Its units are ˚C. Second input is difference between actual and required temperature i.e. difference between process value and setpoint and denoted by 'dT'. Its units are also ˚C. Output is flow rate of water measured in m^3/h and denoted by 'FlowRate'.

The two inputs and output each have four triangular membership functions. The membership functions of dSP and dT range from -4˚C - 6˚C and 0˚C - 2˚C respectively as shown in Fig. 2 and Fig. 3. FlowRate is taken in range of 4 m^3/h - 15 m^3/h as shown in Fig. 4.

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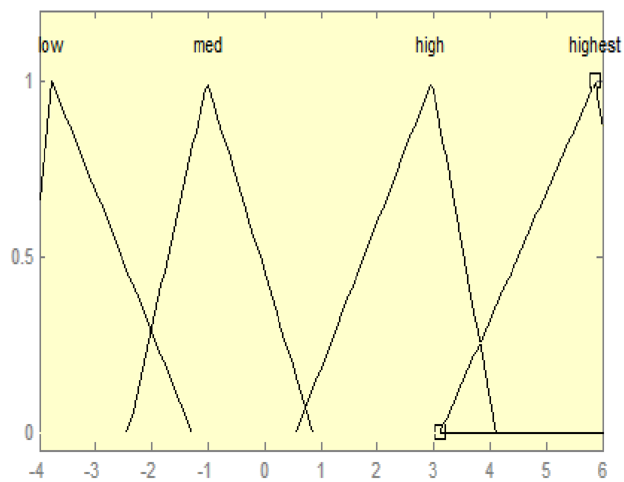

Fig. 2 Diff. between present and previous setpoint membership functions

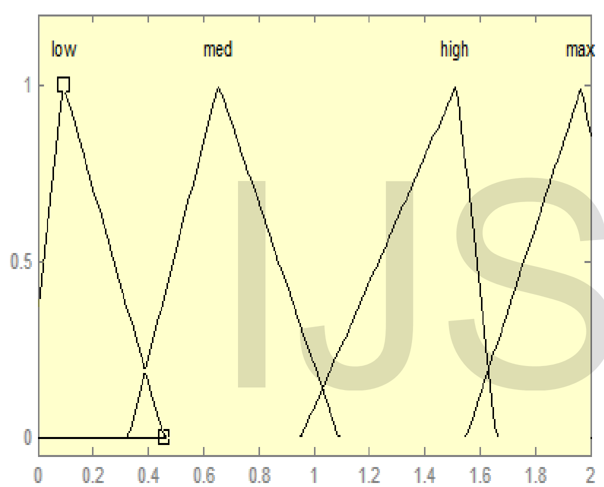

Fig. 3 Diff between process value and setpoint membership functions

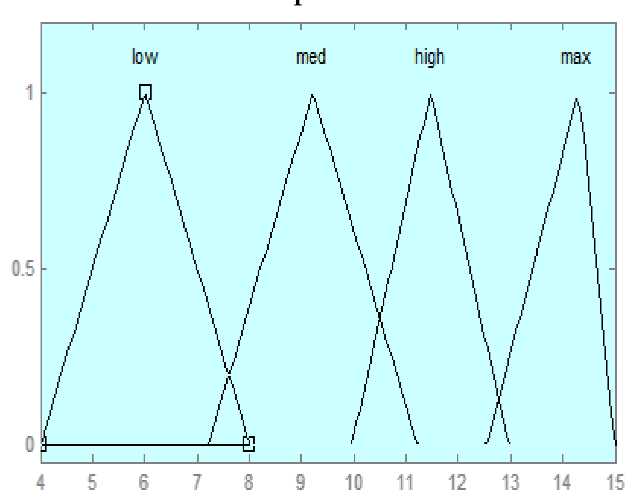

Fig. 4 Water flow rate membership functions

The rule base of the neuro-fuzzy controller is given in Table 2.

Table 2 Rule base

S. No.	dSP	dT	FlowRate
1	highest	low	low
2	high	low	low
3	highest	low	low
4	Low	max	max
5	high	med	med
6	med	high	max
7	Low	high	high
8	med	max	max

4 DEVELOPMENT OF SUGENO-TYPE FIS

For development of air conditioning system using Sugeno-type model, the initial steps are same as Mamdani-type model. It also takes same inputs and produces an output signal that controls the water flow rate. The two inputs each have four triangular membership functions. The membership functions of dSP and dT range from -4˚C - 6˚C and 0˚C - 2˚C respectively (as already shown in Fig. 2 and Fig. 3). The output flow rate can only be either constant or linear in this FIS, so four membership functions for the output are "low", "med", "high" and "max" which are constant and are shown in Table 3. The output in Sugeno-type FIS can only be in range of 0-1. The rule base for Sugeno-type FIS is same as for Mamdani-type FIS as shown in Table 2.

Table 3 Water flow rate membership functions

Flow rate	Constant value
low	0.25
med	0.4
high	0.66
max	1

5 RESULTS AND DISCUSSIONS

The model is simulated using MATLAB Fuzzy logic Toolbox. The plots obtained after simulating Mamdani-type of FIS for water flow control system are shown in Figs.5, 6 and 7.

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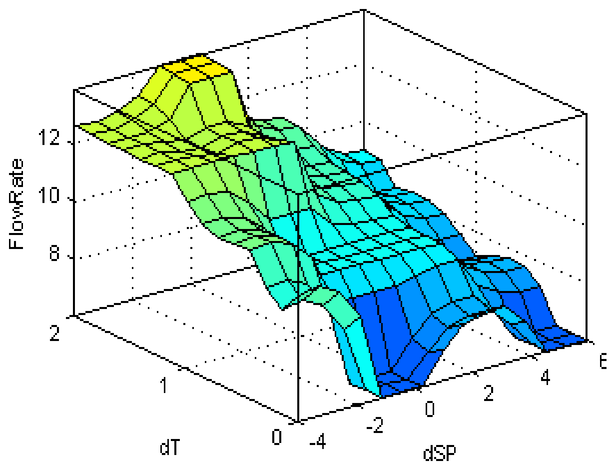

Fig. 5 Surface view of Mamdani-type FIS

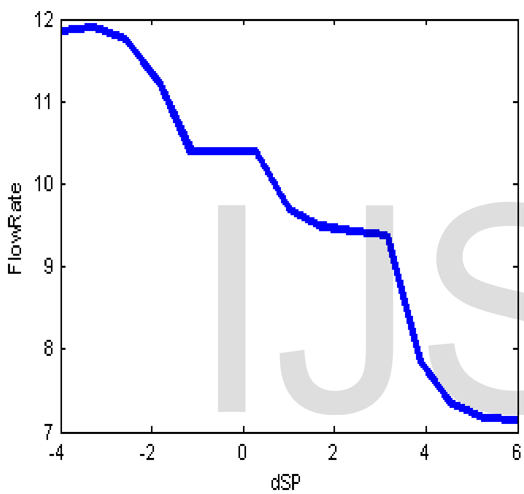

Fig. 6 FlowRate with dSP (Input 1)

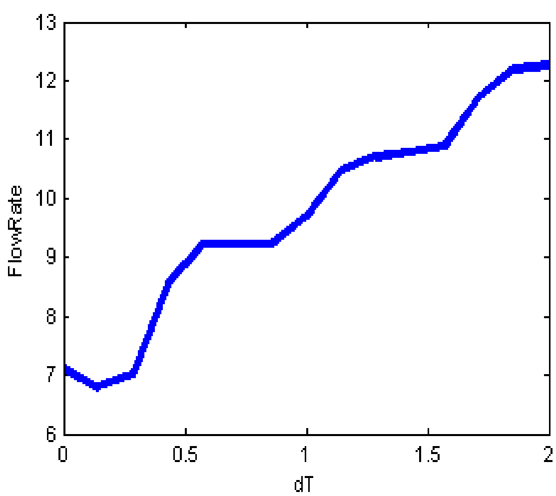

Fig. 7 FlowRate with dT (Input 2)

Following are the plots obtained after simulating the Sugeno-type FIS for water flow control system (as shown in Fig. 8, 9 and 10):

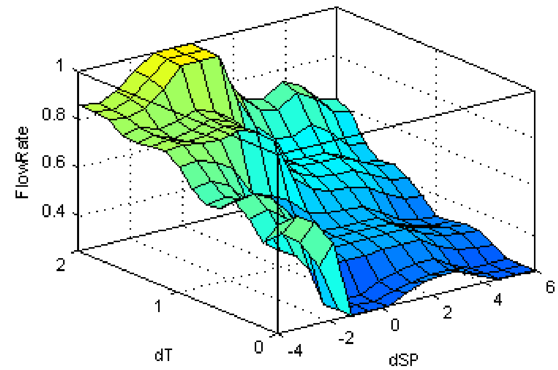

Fig. 8 Surface view of Sugeno-type FIS

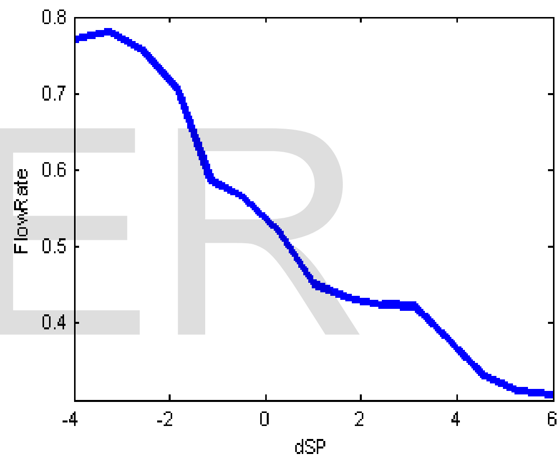

Fig. 9 FlowRate with dSP (Input 1)

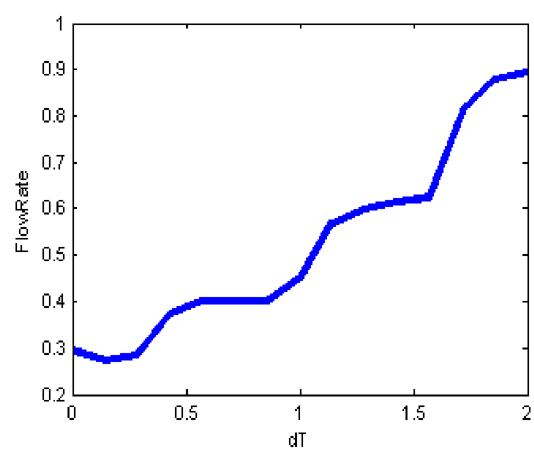

Fig. 10 FlowRate with dT (Input 2)

The results obtained show that for the given application of water flow control system Mamdani-type FIS and Sugeno-type FIS work similarly. It is observed output is inversely proportional to input 1 and directly proportional to input 2. The only difference noticed is that in Sugeno-type FIS water flow control system provides slightly better results than Mamdani-type FIS.

6 CONCLUSION

It can be concluded from this paper that to control water flow rate in a rawmill Mamdani-type FIS and Sugeno-type FIS performs similarly but by using Sugeno-type FIS model it allows the system to work at its full capacity. Although the designing of both the FIS is same but the output membership functions of Sugeno-type can only be either constant or linear and also the crisp output is generated in different ways for both the FIS. Sugeno-type FIS has an advantage that it can integrated with neural networks and genetic algorithm or other optimization techniques so that the controller can adapt to environment. We will adopt only one system. Most likely we are going to utilize the Sugeno FIS due to its accuracy and because we can use certain features in MATLAB such as the ANFIS tool which optimizes the inputs.

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