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Takagi Sugeno Inference for Single Slope Single Basin Solar Still

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ABSTRACT

Solar energy is renewable source of energy. It has been used for thousand of years in many ways by people all over the world. It is also used for heating,cooking and drying.Presently it is used to make electricity where other energy sources are absent. Water is the most common part on earth it covers about 71.4 percent of the earth. Pure water has no smell, taste, or colour. Water is very important for life some studies suggest that by 2025 more than half of people around the world will not get enough water.To resolve the water problem a device system "Single Slope Single Basin Solar Still" developed for solar desalination process. This device can be constructed easily with locally available material.Solar still is widely used for converting available brine water into potable water. In this paper we apply Takagi Sugeno Model to predict the effect of solar radiation and water temperature (as input) for Distillate Yield and Instantaneous Efficiency (as output). In this study we will examine the outcomes from designing intelligent controllers of Takagi Sugeno and Mamdani type in similar conditions. Then, based on these results and comparing them, we will identify the most appropriate controller for solar still.

Keywords: Fuzzy logic, Takagi Sugeno Model, MATLAB.

1. INTRODUCTION

The first solar still plant was built in 1872 by the Swedish engineer Charles Wilson, this still was large basin type sill used for supplying fresh water, solar still is used in area where water in unavailable. Solar still is a device to desalinate impure water like brackish water or saline water. It is a simple device to get potable / fresh distilled water from impure water, single basin solar still has a top cover made of glass, with an interior surface made of a waterproof membrane. This interior surface uses a blackened material to improve absorption of the sun's rays. Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The base also radiates energy in the infra-red region which is reflected into the still by the glass cover, trapping the solar energy inside the still. The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. The still is filled each morning or evening, and the total water production for the day is collected at that time. The still will continue to produce distillate after sundown until the water temperature cools down. Feedwater should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process.

Solar Stills have got major advantages over other conventional Distillation / water purification /de-mineralisation systems as follows:

1. Produces pure water
2. No prime movers required
3. No conventional energy required
4. No skilled operator required
5. Local manufacturing/repairing
6. Low investment
7. Can purify highly saline water (even sea water)

Fausto Cavallaro[1] present his work on “A Takagi-Sugeno Fuzzy Inference System for Developing a Sustainability Index of Biomass” in this research article Takagi-Sugeno fuzzy inference modelling to build a synthetic index to assess the sustainability of production of the biomass for energy purposes.

Qasem Abdollah Nezhad *et al.,*[2] “An Investigation on fuzzy logic controllers (Takagi -Sugeno & Mamdani) In Inverse Pendulum System” heintroduced Takagi Sugeno model and comparing the most appropriate controller, which can hold the pendulum in vertical position on cart with more sensitivity and accuracy. These results are consequences of system response to sinusoidal and square inputs.

Tomohiro Takagi *et al*.,[3] “Fuzzy Identification of Systems and Its Applications to Modelling and Control” in this paper authors show that two applications for industrial process, one is water cleaning process where an operator controls where an operator's control actions are fuzzily modelled to design a fuzzy controller. The other is a converter in the steel-making process where the conversion process is fuzzily modelled, and model-based fuzzy control is considered. The fuzzy model proposed by Takagi and Sugeno is described by fuzzy IF-THEN rules which represents local input-output relations of a nonlinear system. The main feature of a Takagi-Sugeno fuzzy model is to express the local dynamics of each fuzzy implication (rule) by a linear system model. The overall fuzzy model of the system is achieved by fuzzy "blending" of the linear system models.

Plamen Angelov *et al*.,[5] "On-line Design of Takagi-Sugeno Models" This paper presents an approach to on-line design of TS models, which can have evolving structure and can learn recursively in real-time from the data. The on-line design of TS model can be decomposed into two sub-problems one is on-line recursive clustering responsible for the rule base learning, and another is on-line recursive estimation of the consequent part parameters.

In this paper we use previous observations of Vivek *et al*.,[4] to predict distillate output and Instantaneous Efficiency with the help of Takagi Sugeno Model. Here we present Takagi Sugeno Model and comparing the most appropriate controller. Section 2. Material and Methods the fuzzy cruise controller and rule base with basic concepts used in this paper. Section 3. Results and Discussion explain the solution of problem taken by Vivek *et al*.,4.

2. MATERIALS AND METHOD

2.1 Fuzzy set: A fuzzy set is a pair (X, m) where X is a set and m: X → [0, 1] a membership function. X is called universe of discourse and for each $x \in X$, the value of X(x) is called the grade membership of x in (X, m). Thefunction m = $u_{\tilde{A}}(x)$ is called the membership function of the fuzzy set A = (X, m).in other words

If χ is a collection of objects universe of discourse,then fuzzy set denoted by$\tilde{A}$ is a set of ordered pairs$(x, u_{\tilde{A}}(x)|\forall x \in X\}$ where$u_{\tilde{A}}(x)$ is called the membership function or grade belongingness of x in $\tilde{A}$.

2.2 Fuzzy Logic: Fuzzy logic is a form of many-valued logic in which the truth values of variables may be [0,1]. It is employed to handle the concept of partial truth, where the truth value may range between completely true and false. By contrast, in crisp logic, the truth values of variables may be the either true or false

Fuzzy logic is a logic operations method based on many-valued logic rather than binary logic. Two-valued logic often considers 0 to be false and 1 to be true. However, fuzzy logic deals with truth values between 0 and 1, and these values are considered as degrees of truth.Fuzzy logic may be applied to many fields, including control systems, neural networks and artificial intelligence (AI).

2.3 Fuzzy Rule Based System: Fuzzy linguistic description is formal representation of system model through IF – THAN rules. They encode knowledge about system in statement of the form.

IF (set of conditions) are satisfied THEN (a set of subsequent) can be inferred.

Fuzzy rules are linguistic IF-THEN- constructions that have the general form "IF A THEN B" where A and B are (collections of) propositions containing linguistic variables. A is called the premise and B is the consequence of the rule. In effect, the use of linguistic variables and fuzzy IF-THEN- rules exploits the tolerance for imprecision and uncertainty. In this respect, fuzzy logic mimics the crucial ability of the human mind to summarize data and focus on decision-relevant information. In a more explicit form, if there are I rules each with K premises in a system, the i[th] rule has the following form.

$$If \quad a_1 \; is \; A_{i,1} \; \Theta \; a_2 \; is \; A_{i,2} \; \Theta \ldots \Theta \; a_k \; is \; A_{i,k} \quad then \quad B_i$$

In the above equation *a* represents the crisp inputs to the rule and *A* and *B* are linguistic variables. The operator 1 can be AND or OR or XOR.Example: If a HIGH flood is expected and the reservoir level is MEDIUM, then water release is HIGH.

2.4 Fuzzification and Defuzzification: Fuzzification is process of making a quantity fuzzy by membership function and defuzzification is the reverse process of fuzzification i.e. Conversion of fuzzy quantity into single crisp value. There are following methods used for defuzzification.

a) Center of sums Method
b) Mean of Maxima Method
c) Center of Maxima Method
d) Weighted Average Method
e) Center of Gravity Method is one of the popular method which used widely for defuzzification

2.5 Takagi Sugeno Model: The Sugeno Fuzzy model was proposed by Takagi, Sugeno, and Kangan effort to develop a systematic approach to generating fuzzy rules from a given input-output dataset.it is also known as the TSK model A typical fuzzy rule in a Sugeno fuzzy model has the form:

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

where A and B are fuzzy sets in the antecedent, while Z =f(x,y) is a crisp function in the consequent. Usually f (x, y) is a polynomial in the input variables x and y. It can appropriately describe the output of the model within the fuzzy region specified by the antecedent of the rule. When f(x, y) is a first-order polynomial, the resulting fuzzy inference system is called a first-order Sugeno fuzzy model. When f is a constant, we then have a zero-order Sugeno fuzzy model.

If x is A & y is B, then Z = K.

The main difference between Mamdani type interference and Sugeno type is that the output membership functions are only linear or constant for Sugeno type fuzzy inference and typical fuzzy rule in a zero order Sugeno. The output of a zero-order Sugeno model is a smooth function.A typical rule in a Sugeno fuzzy model has the form: If input A is x and input B is y, then output is z = ax + by +c for a zero order Sugeno model, the output is z is a constant when a= b= 0
For a zero-order Sugeno model, the output level *z* is a constant (*a* = *b* = 0).

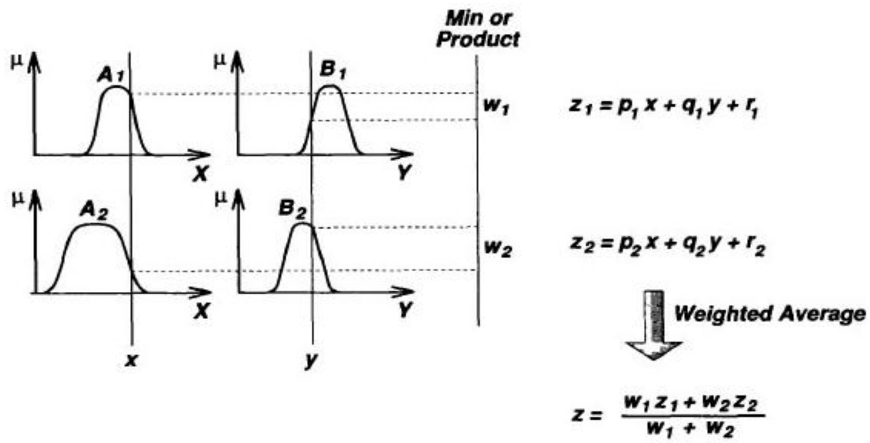


Figure 1: 1st order Sugeno Fuzzy Model

Figure 1 shows the fuzzy reasoning procedure for a first-order Sugeno fuzzy model. Since each rule has a crisp output, the overall output is obtained via weighted average, thus avoiding the time-consuming process of defuzzification required in a Mamdani model.

A Sugeno rule operates as shown in the following diagram.

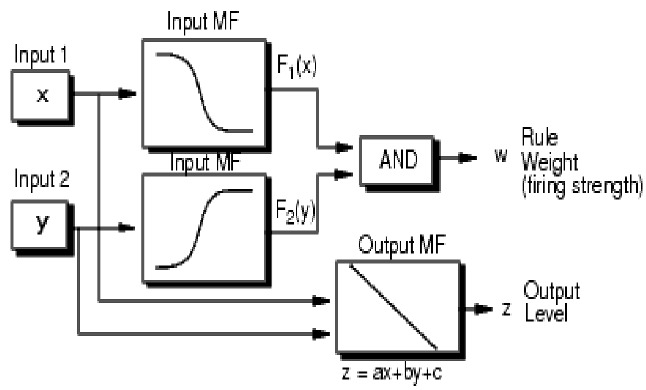


Figure 2: rule operators

After that fuzzy variables and membership functions have been described, the if-then fuzzy rule base can be defined. The number of fuzzy rules defined depends on the possible combination of membership functions. Then according to rule viewer, we aggregate and defuzzify.

3. RESULTS AND DISCUSSION

To predict the amount of distillate output and instantaneous efficiency, using Takagi Sugeno Model, by considering problem by Vivek[4] Solar Radiation and Water Temperature as fuzzy input and Distilled Yield, Instantaneous Efficiency as fuzzyoutput as shown in fig 3.1(a), 3.2 (b) respectively.

Table 3.1: Experimental Observations on 9 th May 2012.

Basin Temp. (⁰C)	Water Temp (⁰C)	Glass Temp (⁰C)	Solar Radiation (W/m²)	Distilled water yield	Instantaneous Efficiency (%)
				Experimental	Experimental
43	41	37	426	0.058	16.87
45	44	41	467	0.082	23.14
51	46	44	627	0.124	30.16
52	48	46	784	0.254	41.23
55	50	49	844	0.280	42.36
60	54	49	892	0.340	47.81
62	59	53	997	0.384	52.35
67	59	58	1076	0.476	59.48
71	65	63	1089	0.570	69.74
76	70	67	1089	0.610	74.85
72	65	64	1010	0.512	69.74
67	62	58	974	0.490	63.14
63	56	53	855	0.420	56.57
60	53	49	839	0.374	51.26
53	46	44	724	0.314	46.54
51	46	43	611	0.276	42.65
47	44	39	499	0.252	39.87

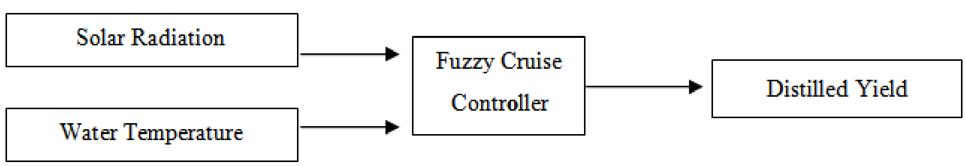


Fig. 3.1(a)

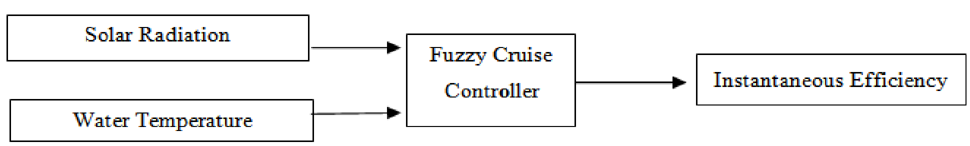


Fig. 3.1(b)

In observation table 3.1 we divide input variable in three linguistic terms Low Normal and High as given table 3.2.

Table 3.2

S. No	Linguistic Terms	Input Range		Output Range	
		I (t)	T_w	D	I(e)
1	Low	426 – 757.5	41-55.5	0.058-0.334	16.87-45.86
2	Normal	591.75-923.25	48.25-62.75	0.196-0.472	31.365-60.355
3	High	757.5 -1089	55.5-70	0.334-0.610	45.86-74.85

Denoting membership function μ_L, μ_N, μ_H to linguistic terms Low Normal and High, for input and output are given in table 3.3(a), (b), (c), (d) respectively.

3.3(a) Input Solar Radiation I(t)

The first variable used in this study as input solar radiation I(t). The value of solar radiation is lies between 426 to 1089 W/m^2.

$$\mu_L(x) = \begin{cases} 0 & \text{when } x \le 426 \\ \frac{(x-426)}{165.75} & \text{when } 426 \le x \le 591.75 \\ \frac{757.5-x}{165.75} & \text{when } 591.75 \le x \le 757.5 \\ 1 & x = 591.75 \end{cases}$$

$$\mu_N(x) = \begin{cases} 0 & \text{when } x \le 591.75 \\ \frac{(x-591.75)}{165.75} & \text{when } 591.75 \le x \le 757.5 \\ \frac{923.25-x}{165.75} & \text{when} 757.75 \le x \le 923.25 \\ 1 & x = 757.5 \end{cases}$$

$$\mu_H(x) = \begin{cases} 0 & \text{when } x \le 757.5 \\ \frac{(x-757.5)}{165.75} & \text{when } 757.5 \le x \le 923.25 \\ \frac{(1089-x)}{165.75} & \text{when } 923.25 \le x \le 1089 \\ 1 & x = 923.25 \end{cases}$$

3.3(b) Input Water Temperature: (T_w)

The second variable used in this study as input water temperature (T_w). The value of water temperature is lies between 41 to70^{0}C.

$$\mu_L(x) = \begin{cases} 0 & \text{when } x \le 41 \\ \frac{(x-41)}{7.25} & \text{when } 41 \le x \le 48.25 \\ \frac{(55.5-x)}{7.25} & \text{when } 48.25 \le x \le 55.5 \\ 1 & x = 48.25 \end{cases}$$

$$\mu_N(x) = \begin{cases} 0 & \text{when } x \le 48.25 \\ \frac{(x-48.25)}{7.25} & \text{when } 48.25 \le x \le 55.5 \\ \frac{(62.75-x)}{7.25} & \text{when } 55.5 \le x \le 62.75 \\ 1 & x = 55.5 \end{cases}$$

$$\mu_H(x) = \begin{cases} 0 & \text{when } x \le 55.5 \\ \frac{(x-55.5)}{7.25} & \text{when } 55.5 \le x \le 62.75 \\ \frac{(70-x)}{7.25} & \text{when } 62.75 \le x \le 70 \\ 1 & x = 62.75 \end{cases}$$

3.3(c) Output Distilled Water Yield: (D)

The third variable used in this study as output Distilled water yield (D). the value of distillate water yield is lies between 0.058 to0.610^{0}C.

$$\mu_L(x)=\begin{cases} 0 & \text{when } x \leq 0.058 \\ \frac{(x-0.058)}{0.138} & \text{when } 0.058 \leq x \leq 0.196 \\ \frac{(0.334-x)}{0.138} & \text{when } 0.0196 \leq x \leq 0.334 \\ 1 & x = 0.196 \end{cases}$$

$$\mu_N(x)=\begin{cases} 0 & \text{when } x \leq 0.196 \\ \frac{(x-0.196)}{0.138} & \text{when } 0.196 \leq x \leq 0.334 \\ \frac{(0.472-x)}{0.138} & \text{when } 0.334 \leq x \leq 0.472 \\ 1 & x = 0.334 \end{cases}$$

$$\mu_H(x) = \begin{cases} 0 & \text{when } x \leq 0.334 \\ \frac{(x-0.334)}{0.138} & \text{when } 0.334 \leq x \leq 0.472 \\ \frac{(0.610-x)}{0.138} & \text{when } 0.472 \leq x \leq 0.610 \\ 1 & x = 0.472 \end{cases}$$

3.3(d) Output Instantaneous efficiency: I(e)

The fourth variable used in this study as output Instantaneous efficiency I (e). The value of instantaneous efficiency is lies between 16.87 to 74.85.

$$\mu_L(x)=\begin{cases} 0 & \text{when } x \leq 16.87 \\ \frac{(x-16.87)}{14.495} & \text{when } 16.87 \leq x \leq 31.365 \\ \frac{(45.86-x)}{14.495} & \text{when } 31.365 \leq x \leq 45.86 \\ 1 & x = 31.365 \end{cases}$$

$$\mu_N(x)=\begin{cases} 0 & \text{when } x \leq 31.365 \\ \frac{(x-31.365)}{14.495} & \text{when } 31.365 \leq x \leq 45.86 \\ \frac{(60.355-x)}{14.495} & \text{when } 45.86 \leq x \leq 60.355 \\ 1 & x = 45.86 \end{cases}$$

$$\mu_H(x)=\begin{cases} 0 & \text{when } x \leq 45.86 \\ \frac{(x-45.8)}{14.495} & \text{when } 45.86 \leq x \leq 60.355 \\ \frac{(74.85-x)}{144.95} & \text{when } 60.355 \leq x \leq 74.85 \\ 1 & x = 60.355 \end{cases}$$

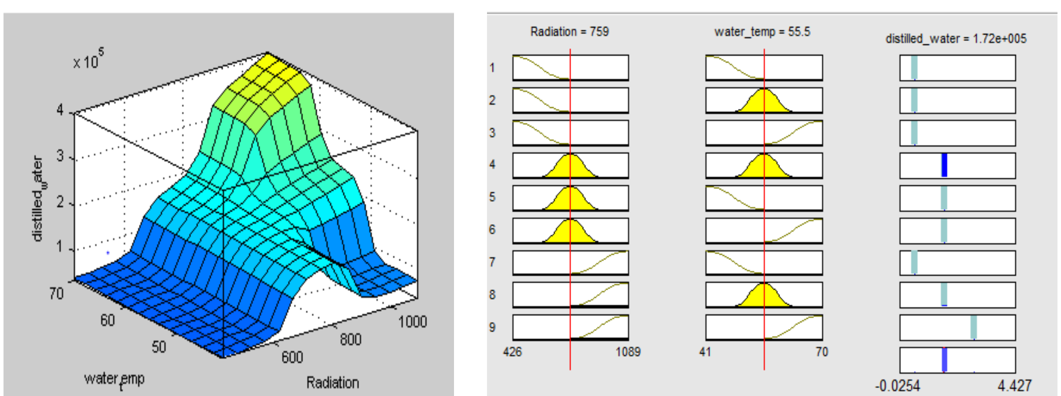
if-then rules have been defined; in the following table some of these are reported as examples.

(a) Fuzzy Rules for distillate yield (D)

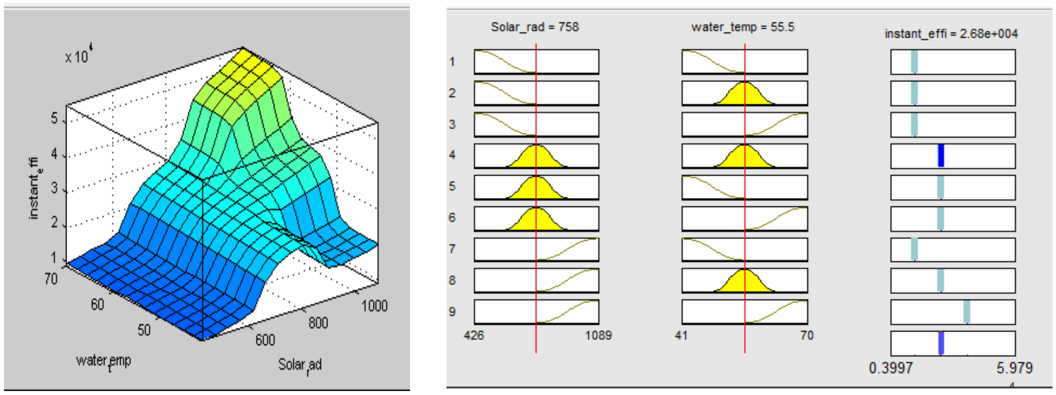
Rule 1	IF (Solar radiation is Low) AND (Water temperature is Low) THEN (Distillated Yield is Low)
Rule 2	IF (Solar radiation is Low) AND (Water temperature is Normal) THEN (Distillated Yield is Low)
Rule 3	IF (Solar radiation is Low) AND (Water temperature is High) THEN (Distillated Yield is Low)
Rule 4	IF (Solar radiation is Normal) AND (Water temperature is Normal) THEN (Distillated Yield is Normal)
Rule 5	IF (Solar radiation is Normal) AND (Water temperature is Low) THEN (Distillated Yield is Normal)
Rule 6	IF (Solar radiation is Normal) AND (Water temperature is High) THEN (Distillated Yield is Normal)
Rule 7	IF (Solar radiation is High) AND (Water temperature is Low) THEN (Distillated Yield is Low)
Rule 8	IF (Solar radiation is High) AND (Water temperature is Normal) THEN (Distillated Yield is Normal)
Rule 9	IF (Solar radiation is High) AND (Water temperature is High) THEN (Distillated Yield is High)

(b)Fuzzy Rules for Instantaneous efficiency I (e)

Rule 1	IF (Solar radiation is Low) AND (Water temperature is Low) THEN (instantaneous efficiency is Low)
Rule 2	IF (Solar radiation is Low) AND (Water temperature is Normal) THEN (instantaneous efficiency is Low)
Rule 3	IF (Solar radiation is Low) AND (Water temperature is High) THEN (instantaneousefficiency is Low)
Rule 4	IF (Solar radiation is Normal) AND (Water temperature is Normal) THEN (Instantaneous efficiency is Normal)
Rule 5	radiation is Normal) AND (Water temperature is Low) THEN (Instantaneous efficiency is Normal)
Rule 6	IF (Solar radiation is Normal) AND (Water temperature is High) THEN (Instantaneous efficiency is Normal)
Rule 7	IF (Solar radiation is High) AND (Water temperature is Low) THEN (Instantaneous efficiency is Low)
Rule 8	IF (Solar radiation is High) AND (Water temperature is Normal) THEN (Instantaneous efficiency is Normal)
Rule 9	IF (Solar radiation is High) AND (Water temperature is High) THEN (Instantaneous efficiency is High)



(c) Surface area and rule viewer for distillate yield (D)



(d) Surface area and rule viewer for instantaneous efficiencyI(e)

CONCLUSION

In this paper we introduced model Takagi Sugeno model for single slope basin solar still. Here we calculate output distilled water yield and instantaneous efficiency by using two input variable solar radiation and instantaneous efficiency. The papers offer a way finding distillate yield using solar still device. Here we made fuzzy sets and using control rule. Which is suitable for approximate result and decision making where uncertainty occurs. Here Takagi Sugeno inference in used once reading carried out, the we obtained best output

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