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Fuzzy Inference System for Bio-Mathematical Modelling

Subrata Kumar Biswas[1], Prosenjit Sen[2]
[1]*Department of Applied Mathematics, Maulana Abul Kalam Azad University of Technology, West Bengal, Nadia 741249, West Bengal, India*
[2]*Department of Mathematics, OmDayal Group of Institutions, Uluberia, Howrah 711316, West Bengal, India*

Abstract: ***In this paper, the soft computational process, namely the fuzzy inference scheme, is illustrated to solve a bio-mathematical model. The development of the fuzzy inference scheme helps to understand the complex bio- dynamical situation where all inputs are in linguistic mode. Fuzzy logic is the main component of this artificial intelligence system. This rule-based process generates a fuzzy or crisp value to predict the model's situation. In the area of bio-mathematical modelling, Fuzzy Inference systems help to predict and make policies to control diseases in epidemiology and ecoepidemiology. Qualitative as well as quantitative aspects of modelling are discussed through these processes. The Mamdani-type inference system is used worldwide for qualitative analysis of bio-mathematical modelling. Takagi Sugeno Kang and Tsukumoto type inference system are used for quantitative analysis of mathematical modelling. This manuscript reviews and presents the Fuzzy Inference Schemes and its application on the decision-making purposes in bio-mathematical modelling.***
Keywords: Fuzzy inference scheme, Bio-mathematical model, Artificial Intelligence, Mamdani, Sugeno and Tsukumoto method.

I. INTRODUCTION

A. *Fuzzy set theory*

Lotfi A. Zadeh [1], pioneer of fuzzy set theory, first presented the concept of the fuzzy set, an extension of traditional or classical set theory. Our cantor sets involve into the crisp data cases. But fuzzy set [1] includes crisp as well as vague, imprecise situational data cases. The elements that are on the broader line of any crisp set are not considered as the set's members. The membership function of any element of a fuzzy set is the speciality of this set. Partial grade or membership value varies between 0 to 1. Zero means the element does not belong to the set. One is the full membership of an element. A fuzzy set is the collection of all elements of a crisp set with its membership grades [2].

B. *Bio-mathematical modelling*

When the real biological happenings expressed in a set of mathematical and computational codes [3] are called a bio-mathematical modelling. Mathematical tools and techniques are used to solve for revealing about the model's physical interpretation and inner biological dynamics. To solve a model, different schemes are used in different environments, fuzzy or crisp. Among the different types of modelling, the one that is very close to our real problem is selected for future applications. Again, different types of solution procedures may be followed for the same modelling. But it has selected only the better accuracy generating scheme. A linear bio-mathematical model represents the simple biological facts. On the other hand, the complex interactions are explored through the nonlinear bio-mathematical model [4]. Stochastic modelling [5] is used to express the random events of biology. All of the above models are used only with precise data in a crisp environment. But another different type of model is imagined to handle the biological situations where both the inputs and outputs are vague and imprecise. These new types of models are known as fuzzy models.

C. *Motivation and novelties*

Our paper is relevant to understanding the solution procedure for a model in a situation where only uncertain data are available. In a developing country like India, the testing facilities, health workers, etc., are unavailable. Data collection about different diseases at the proper time is not always possible. For time delay cases, the data loses its accuracy. To get better results, a large number of tests are conducted, resulting in a significant cost. To avoid these cost issues, fuzzy models are selected in biological cases. These models are very practical in real-life situations.

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II. FUZZY INFERENCE SYSTEM

Nowadays, many artificial intelligence-based techniques [8] are being popular for solving complex biological modelling. Fuzzy Inference Scheme [7] is one of the most popular methods widely used. Any linear or nonlinear complex problem can be expressed through the Fuzzy Inference Scheme. In 1965, Lotfi A. Zadeh first introduced the fuzzy set theory to handle the data which is imprecise and of a vague type of uncertainty. The practical application of fuzzy set theory is in the fuzzy inference scheme (FIS). There are three types of FIS. One well-known scheme is the Mamdani type FIS and another scheme is Takagi- Sugeno Kang (TSK) or Sugeno type FIS. In 1975, Ebrahim Mamdani invented this method, which is widely used in control systems. This method is also known as the Max-Min method. It basically works on the predefined rules which involved with "IF- THEN" format. These rules are the main source of Fuzzy Logic. To handle a fuzzy inference system, one need not higher mathematical knowledge but only a certain level of expertise knowledge in the fuzzy schemes. FIS are applied using Mamdani-type and Sugeno-type fuzzy logic toolboxes. Only outputs can differ between these two methods.

A. Mamdani Type Fuzzy Inference Scheme

Mamdani type FIS [7] is well known for its simple representation and design. It's easier to use this property, which helps many researchers to utilise this scheme in their research papers. To solve the complex models in the case of decision- making problems, Mamdani-type FIS is a very powerful tool in a fuzzy environment. The main components of this model can be classified into five categories. These components provide fuzzification, "IF-THEN" rule evaluation, implication, aggregation and defuzzification. Min is used for "AND" operations in rule evaluation steps. Max is used for "OR" operations in the aggregation part. The number of rules depends on the selection of input variables. Every input variable (temperature) can be categorised into three linguistic variables, such as HIGH, MEDIUM and LOW. In the case of the output variable (speed of fan), we also get three linguistic variables like FAST, MODERATE and SLOW. In the fuzzification steps, we convert the crisp value into a fuzzy value using the membership function. In the rule evaluation step, each "IF-THEN" rule is applied and the firing strength of each rule is found. With the help of each firing strength, we determine the output firing strength in the fuzzy set using the min operation. Max operation is used in the aggregation steps to convert only one fuzzy set. Lastly, defuzzification changes into the fuzzy output into the crisp output. Commonly used in a control system. Fuzzy rule base is the sum of all "IF-THEN" rules. Rules surface, rules viewer, etc., depend on the fuzzy rule base. Mamdani rule base consists of $(\text{number of linguistic variables})^{\text{number of input fuzzy variables}}$ rules mainly depends upon our expert system.

Mamdani Inference rule may be illustrated as:

IF (Fuzzy set) THEN (Fuzzy set) i.e.,

IF [input variables (x_i)] is [linquistic variables (high, medium, low)] THEN [output variable (y)] is [linquistic variable] i.e.,

IF [input variables (x_i)] is [membership functions (μ_i) THEN [output variable (y)] is [membership function (μ)]

i.e.,

IF x_1 is μ_1 and x_2 is μ_2 THEN y is μ where $\mu = min\{\mu_1 \, and \, \mu_2\}$.

Key features of the Mamdani method:

i). Fuzzy sets are used in both input and output.

ii) IF-THEN rule development depends on expert knowledge.

iii). Mamdani FIS is very intuitive, human-like in reasoning and suitable for an expert system

iv) Before defuzzification, the output is a fuzzy set.

v). It is good for control systems, especially for steam engines and boilers, decision support and prediction in modelling.

vi). It has a global acceptance.

vii) It is a collection of "IF -THEN" mappings from a fuzzy set to a fuzzy set.

Example 1: In the heart disease detection cases

IF Age is Old and Blood Pressure is very high, THEN Diagnosis Heart diseases is Strongly Positive.

Example 2: In the environmental or industrial cases, where benefits and cost types criteria are applied in a fuzzy Mamdani-based integrated system, as explained in the following diagram. Where P represents the performance Productivity, OH represents

Operating Hours, UL denotes Utilization Level, tCO_2A means Total CO_2 Avoidance. These are called benefit-type because their higher value is highly expectation. In the case of cost level criteria, IR represents the Investment Required, IP denotes the Installation Price and O&MC denotes Operation and Maximum Cost. These low-level criteria involve a minimum expectation level. The following diagram describes the benefit-type and cost-type fuzzy inference integrated system.

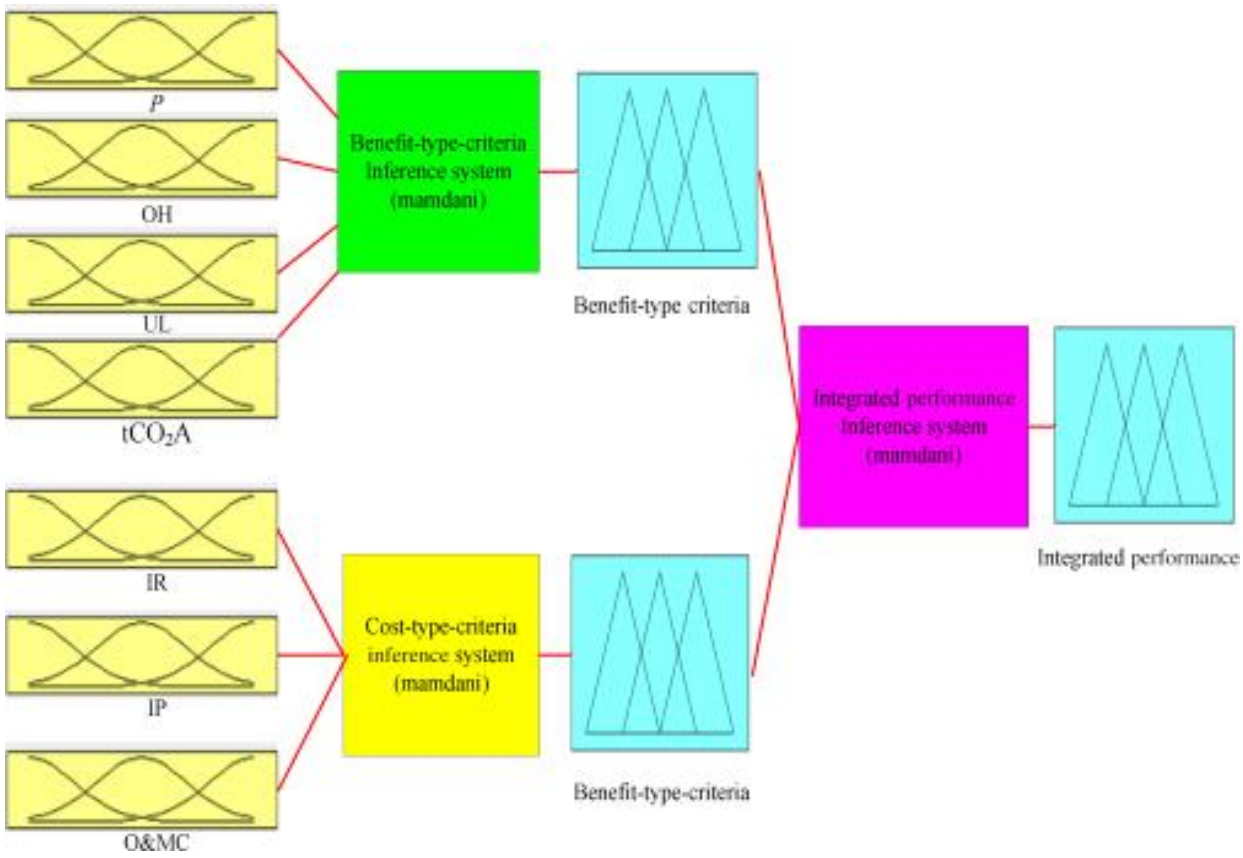


Fig. 1. Example of benefit and cost type criteria-based inference system

Through the above Fig. 1. the application of Mamdani type fuzzy inference system are shown in the benefit criteria and cost criteria based integrated performance process.

B. Sugeno type FIS

The Sugeno type Fuzzy inference scheme is also known as the Takagi–Sugeno Kang method [8, 9, 10]. Michio Sugeno, Takashi Takagi, and Kang in 1985 were the pioneers of this method. According to their name, the method is known as the Takagi-Sugeno method. The method consists of fuzzification, interface, rule base and inference engine. The consequent function is a weighted average of output consequences. This method is also a Mamdani-type FIS model. If the output function is constant, then it is a zero-order type Sugeno method and a linear order type is called when the output is a linear function. Depending on the order of the polynomial, the order of the Sugeno model may change [11]. Mostly, it is used in optimization and control problems.

Sugeno Inference rule may be illustrated as:

IF (Fuzzy set) THEN (a crisp function, usually a polynomial) i.e.,

IF [input variables (x_i)] is [linquistic variables (high, medium, low)] THEN [output variable (y)] is [any real polynomial] i.e.,

IF [input variables (x_i)] is [membership functions (μ_i) THEN [output variable (y) is a polynomial]

i.e., IF x_1 is μ_1 and x_2 is μ_2 THEN $y = f(x_1, x_2)$ is a crisp function.

IF x_1 is μ_1 and x_2 is μ_2 THEN $y = rx_1 + sx_2 + t$.

Key Features of Sugeno model:

i) Its output is a mathematical function.
ii) There are no defuzzification steps.
iii) Faster and computationally advanced.
iv) Its main use is in controlling, optimisation, system identification, especially for nonlinear dynamical problems and in ANFIS (Adaptive Neuro-Fuzzy Inference System)
v) It is very suitable for mathematical analysis using numerical data.
vi) Its function is better for linear techniques.

Example 3: In the case of autopilot aircraft movement during a perturbation.
IF heading Error (x_1) is Small and yaw Rate (x_2) is Medium THEN rudder Angle = $r.\text{Error}\ (x_1)+s.\text{Rate}\ (x_2)$ + t

C. Tsukamoto fuzzy inference system [11]:

In 1979 Katsutoshi Tsukamoto was first introduced an alternative inference system of widely spread fuzzy Mamdani method. This method is less popular than Mamdani and Sugeno method. Its output variable is directly related to crisp value though the "IF-THEN" rule with the consequent membership function is monotonically increasing or decreasing. The fuzzy logic that is the core and acts like human-reasoning used in the fuzzy inference scheme is given as follows:
IF x_1 is medium THEN z_1 is k_1.
IF x_1 is high THEN z_1 is k_2.
Here consequents have fuzzy sets and the antecedent parts have monotonic membership functions
IF (Fuzzy set) THEN (monotonic Fuzzy set) i.e.,
IF [input variables (x_i)] is [linquistic variables (high, medium, low)] THEN [output variable (y)] is [linquistic variable] i.e.,
IF [input variables (x_i)] is [membership functions (μ_i) THEN [output variable (y)] is [membership function (μ)]
i.e.,
IF x_1 is μ_1 and x_2 is μ_2 THEN y is μ where $\mu = f(x_i)$ is monotonic function.
Key features of Tsukamoto fuzzy inference:

i) The consequent or THEN part is crisp, though the antecedent or IF part is a fuzzy set.
ii) Its need monotonic membership function
iii) It is well fit for controlling systems and decision-making.
iv) Defuzzification is not required for getting a crisp value.

Example 4: In the case of automatic fan speed control
Rule 1: IF Temperature is Low THEN fan's Speed is Slow.
Rule 2: IF Temperature is Medium THEN fan's Speed is Fast.

III. STRUCTURE OF FUZZY INFERENCE SYSTEM

We can summarise the inference system in the following diagram

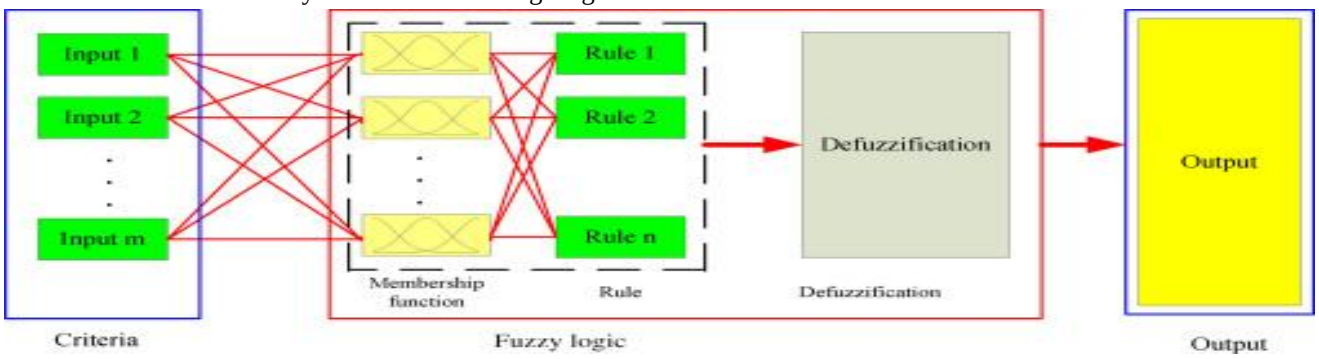


Fig. 2. Diagram of Fuzzy Inference Scheme

The above-mentioned Fig. 2. shows the process of fuzzy inference system passing through the different steps like input criteria, fuzzy logic and output.

In [12], K. Pujaru et al. develop their paper on an economic approach to predict the biomass level of the Bangladesh Sundarbans region. The two-input and two-output fuzzy logic -based model is included for maintaining the sustainable level of fisheries biomass after harvesting and keeping up the reasonable level of revenue collection. Fishing and Tourism are considered as input parameters. Revenue and Fisheries biomass are thought of as output parameters. The fuzzy rule base is consisting of 20 "IF-THEN" rules. Trapezoidal-type fuzzy numbers in normalised form are taken as input variables. Membership function for the input variable "Fishing" is divided into five levels, such as "Low", "Medium", "MSY", "High" and "Overhigh". Another input variable "Tourism" is classified into four categories, such as "Low", "Medium", "High" and "Overhigh". In this way, the output variables can be divided into four categories, like "Low", "Medium", "High" and "Overhigh". Each of these is considered a fuzzy trapezoidal number. In defuzzification steps, the Centre of Gravity method is applied to get a crisp value. The authors explored different results on the revenue and biomass of fish using the FIS model.

They also mentioned that

a) A low level of harvesting as well as a low level of tourism, generates a high level of biomass.
b) A high level of harvesting and tourism produces a high level of revenue.
c) Bio-mass level is minimum when fishing and tourism reach an over-high level.
d) Fishing is done at a small or medium scale and the tourism level is over-high, then the biomass is at a lower level.

The authors, S. Adak and S. Jana [13] proposed an artificial intelligence-based system, i.e., a type-2 fuzzy Inference System in which the Mamdani type of fuzzy logic was used. They combine three inference systems at a time for analysing the chances of the occurrence of dengue fever in type-2 FIS. In the first Inference System, "Temperature" and "Rainfall" are input variables, "Rainfall" and "Relative Humidity" are input variables in the second inference system and "Temperature" and "Relative Humidity" are input variables in the third inference system. "The chance of dengue fever" is the same as the output variable. In the fuzzification step, they applied a Gaussian type-2 membership function. As a result, they found that maximum dengue fever occurs due to high humidity and rainfall ranges between 200 mm – 300 mm.

In [14], Khatua, A. et al. presented a fuzzy logic-based model in the Indian fisheries production. They used a Mamdani-type fuzzy inference system with a trapezoidal-type membership function. Their five input variables were Fish Seed, Export, Post Harvesting, Released Fund and Temperature and their output variable was the Production of Fisheries. The fuzzy logic toolbox consisted of 243 rules in the "IF-THEN" format. Their main aims were to present the Mamdani-type model, find the applicable area and to validate the model with real data. The rule base, the data base and a reasoning mechanism were their mentioned three components of a fuzzy inference system. The rule base consisted with "IF-THEN" rules, The database was formed with a user defined membership function of input and output variables. In the reasoning mechanism, inference procedures were applied. Mamdani and Sugeno types were considered for the classification of an inference system based on the fuzzy rule's consequent part. If the consequent part is a constant function, then it is a Mamdani type and if the consequent part is a linear type function, then it is a Sugeno type. Out of 243 rules built in MATLAB fuzzy environment, they considered only seven rules randomly to make their decision on fisheries production. One of them was given as follows: If (Fish Seed is High) AND (Export is High) AND (Post Harvesting is High) AND (Released Fund is Medium) AND (Temperature is Medium) THEN (Production is Over high).

In [15], the authors Das D. K. et al. proposed a Mamdani-type fuzzy inference system based on bio-mathematical modelling in which a trapezoidal-type membership function was applied on the identification of Covid-19 positive due to some influential environmental factors such as body temperature, body immunity level and efficiency of vaccine. Using this system, they made a decision that IF (Body Temperature is High) AND (Body Immunity Level is Low) AND (Efficiency of Vaccine is Low) THEN (Chance of Occurrence of Covid-19 is High).

In [8], D. Turimoy Mustapoevich et al. presented a model applied to the problem of cattle diseases diagnosing using a Sugeno-type fuzzy inference system with a triangular-type membership function. The results of this model helped to make a decision in the intelligence system for cattle diseases. The outcomes of the Sugeno fuzzy logic model can be applied in the area of veterinary medicine for problem solving cases of cattle disease diagnosis and for the improvement of farmers' economic conditions. They used 17 traits of diseases of cattle specially cow as input variables, such as Temperature, Pulse, Breath, Rumination, Number of erythrocytes, Total Protein, Haemoglobin, Total calcium, Organic phosphorus, Glucose, Reserve alkali, Copper, Cobalt, Manganese, Zinc, The number of ciliates in the rumen 1000/m, Condition of cicatricial fluid (Rameter). Dividing each input variable into High, Medium and Low fuzzy variables, they predict the cattle being infected by the Etiology of secondary osteodystrophy.

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Table 1: This table describes the application of the Fuzzy Inference System

Sl. No	Author details	Model used	Results
1	Pujaru, K., et al. [12]	Mamdani type FIS method into a fisheries-oriented mathematical model in the coastal region	This model helps to maintain harvesting and ecotourism policies at a level such that the coastal region, especially the Sundarbans region, will always be a source of revenue.
2	Adak, S. et al. [13]	Mamdani-type through type-2 Fuzzy Inference Scheme on Dengue disease model. A Gaussian type-2 membership function is considered.	i). No rainfall, with whatever the temperature (High, Medium or Low), the chance of occurrence is Low. ii). Temperature between 20 ◦C–30◦C and more than 200 mm rainfall, the dengue occurrence is medium to high. iii). Maximum Dengue Occurrence is due to high humidity and rainfall range 200mm -300mm.
3	Khatua, A et al. [14]	Mamdani-type Fuzzy Inference System with a trapezoidal membership function followed.	This fuzzy mathematical modelling shows that the fish production is highest when the temperature is medium and the fish seed is high. When export and released funds are both low, then production is lowest.
4	Das, D. K et al. [15]	Mamdani-type fuzzy inference system with trapezoidal-type membership function applied to the detection of COVID-19 positive cases.	This model presented that when the crucial factors Body temperature, Body immunity level and Efficiency of vaccine were low, then the occurrence of Covid-19 is medium.
5	Turimov Mustapoevich, D et al. [8]	A Sugeno-type Fuzzy Inference System with a triangular membership function is selected for diagnosing cattle diseases, which have 17 traits.	The result obtained using the Sugeno method gave a 2% of diagnosing error. Analysing 17 traits in fuzzy.

Through the above table different types of fuzzy inference system are used in bio-mathematical modeling and also its physical applications are shown in the different biological situations.

IV. CHALLENGES AND LIMITATIONS

Fuzzy Inference System is an expert knowledge base process. Different experts' views may be different. Accuracy may vary for the same model. The system depends on the number of input variables and each input variable may be divided into three types. So, for three input parameters, 27 "IF-THEN" rules are generated. Rules increase exponentially depending on the increasing of input parameters. It is hard to design and calculate manually. It takes much time to get a result using this system. The information converted into crisp value through the defuzzification process loses its uncertainty and nuances. This system is not highly applicable to apply in high-dimensional models and its scalability is very poor for handling a large data set. There is no universal rule for every system. Rules and membership functions are defined by either the user or an expert. Due to the scarcity of available statistical data, the system faces a validation problem. The Mamdani system is more interpretable but less precise. On the other hand, the Sugeno method is more precise but less interpretable. Through the fuzzy inference system, we do not get a precise and interpretable result at a time. To be an expert in this method, one needs to acquire knowledge of input variables, fuzzification, rule evaluation, aggregation and defuzzification. One membership function is not always fit for different systems. There are a variety of membership functions, such as triangular, trapezoidal, Gaussian, Bell shape, etc., which may be difficult to handle for an expert. Due to the poor knowledge of an expert, the system may lose its reliability.

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V. CONCLUSIONS

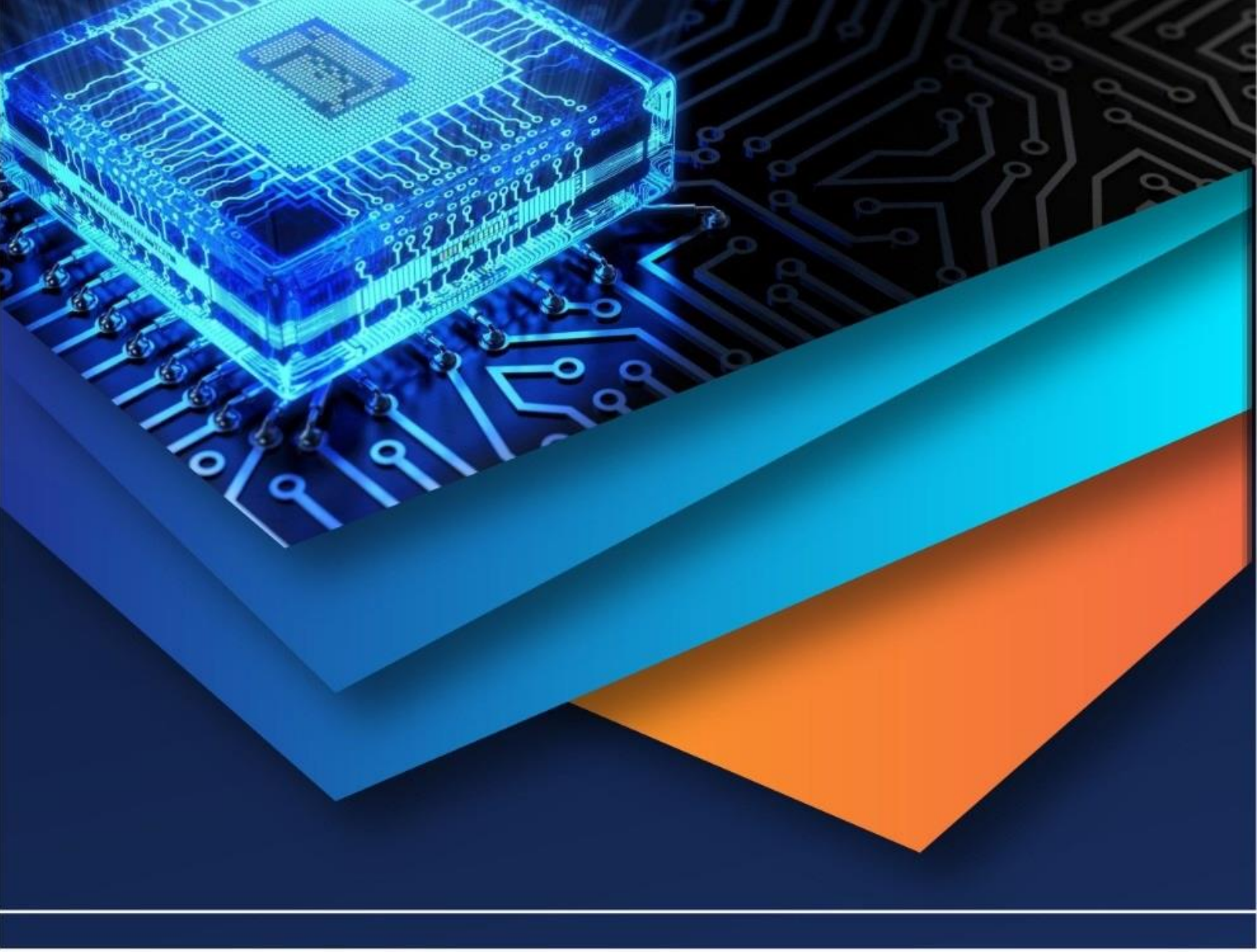
In this review manuscript, we present a modern artificial intelligence-based Fuzzy Inference Scheme with a core fuzzy-logic framework. Globally used Mamdani and Sugeno type inference process with triangular, trapezoidal and Gaussian type membership functions are described and also their applicability in bio-mathematical modelling cases is shown. Through this review work, we are capable of presenting that a fuzzy inference system can predict and control in the complex situation of disease dynamics. Especially in a developing country where precise data is unavailable, this expert-based model is meaningful. It helps to make decisions considering a large number of parameters. In [8], 17 parameters are involved in the Sugeno-type inference system and its accuracy rate is very high. Only 2% error can be neglected. Reviewing this paper, we can take a decision that if the number of parameters is increased, then the model accuracy will increase. If we apply this work to the cancer detection cases, it will be a new sunrise in medical science. We present an amazing result in the paper [8]. The Mamdani-type Inference System of Das et al. [15] showed that, in spite of all the parameters being low. The chance of occurrence of Covid-19 positivity is medium. Depending on this result, we may not apply an excessive lockdown to break down the chain of Covid-19 positive patients. This work helps to prevent rumours in Covid prevention. From the work of Adak, S. et al. [13] used Mamdani type Inference System but considered the Gauss type-2 membership function. Reviewing this paper, we also find out that the decision that the maximum dengue occurrence is due to high humidity and rainfall range 200mm -300mm. Our policymakers take decisions to control dengue cases and spread awareness programmes before the commencement of rainy seasons. Pujaru, K. et al. [12] used a Mamdani-type fuzzy Inference System in their paper. We are trying to explore a meaningful result from the manuscript. If Harvesting and tourism levels are properly maintained, then the coastal area may be a source of revenue throughout the year. This revenue will be helpful to remove the poverty of fishermen inhabited near the coastal area of the Sundarbans. Again, reviewing Khatua, A. et al. [14] paper, we notice an important point that for the highest fishing product temperature, always try to maintain a medium level, as well as fish seed quality will be tried to keep high. This decision -making knowledge has been possible only by using a Mamdani-type fuzzy Inference System. So, through this review work, we are trying to present how important the fuzzy Inference System is.

VI. ACKNOWLEDGMENT

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