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Application of Fuzzy Inference System Takagi-Sugeno Methods for Diagnosis of Diseases and Pests of Madura Paddy Rice Based on Symptoms

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Abstract. Diseases and pests of lowland rice are one of the factors that can cause a decrease in rice yields. Therefore, it is necessary to have a diagnostic system to identify diseases and pests of paddy rice from an early age based on damage symptoms. The process of diagnosis requires expertise, knowledge, and experience from experts. Therefore, this research tries to build an expert system that can diagnose diseases and pests of paddy rice early by applying the Fuzzy Inference System Takagi with the Sugeno method. Fuzzy Inference System Takagi forms fuzzy sets using implication functions (rules). Rule composition is obtained from a data set of relationships between regulations, where the affirmation (defuzzification) and input from defuzzification is a constant or linear equation. The Sugeno method is used to diagnose diseases and pests of rice plants based on the symptoms experienced. This research aims to help plant pest control officers diagnose diseases and pests of paddy rice plants from the symptoms that attack the rice. The testing technique used is system accuracy testing and Mean Opinion Score (MOS) testing. The MOS test was carried out by involving 30 respondents consisting of 10 farmers and 20 extension workers, where 4.27 was obtained on a scale of 5 which was categorized into a good system. while testing the accuracy obtained from testing the system on two experts on diseases and pests of Madura paddy rice plants in 30 different cases has resulted in an accuracy rate of 86.66%. The expert system built in this study was able to diagnose 13 diseases and pests of Madura paddy based on the knowledge of two experts on 38 symptoms, and the plan was feasible to use and categorized into a good system. **Keywords:** Diagnosis; System; Diseases and Pests of Paddy Field; Methods; Fuzzy Inference System Takagi-Sugeno.

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1 Introduction

Rice plants have strategic value and high economic, social, and political sensitivity to achieve food security. Madura is one of the highest rice producers in East Java, mainly used for lowland rice and maize cultivation, covering 20.67% and 55% of the area, respectively. However, one of the obstacles is disease and pest attacks, so there is a potential for an increase in organisms that disturb paddy rice plants. The symptoms experienced by rice with a high attack level can cause death, affecting crop failure[1]. Therefore, efforts are needed to increase the development of disease and pest diagnosis in lowland rice plants based on the symptoms that occur so that lowland rice farmers can find out pests or diseases earlier based on symptoms. However, a machine learning method is needed to build a diagnostic system.

In several previous studies, several machine learning methods can identify diseases or pests precisely and accurately. One is the fuzzy method, where several types of fuzzy methods exist, including Tsukamoto, Sugeno, Mamdani, and so on. Research conducted by [2] In 2017, competency mapping with the fuzzy Sugeno inference system in the case of determining salaries has shown a significant increase compared to the traditional model. In the same year on, research [3] has optimized the wireless sensor network using the Sugeno fuzzy clustering method, which has grouped all sensor nodes into a balanced cluster. Then in 2018, it was developed by [4] has built an expert system for cataract eye diagnosis using the Fuzzy Mamdani method, where this method can convert assertive values into linguistic values by fuzzification and included in the rules and results of checking accuracy between system predictions and expert predictions obtained a truth value of 78% from 50 cases. Sugeno's fuzzy method is almost the same as Mamdani's. The difference is that the output is in constants or linear equations, while the production in the Mamdani method is in the form of fuzzy sets[5]. And in 2020, a comparative analysis of the fuzzy Mamdani and fuzzy Sugeno methods was carried out to determine the amount of production, the results based on the results obtained, the MAPE value of the Fuzzy Sugeno method of 8.2% is less than the Mamdani method of 7.1%[6]. According to [7] the Sugeno method has the characteristic that the consequence is not a fuzzy set but a linear equation with variables according to the input variables.

From the several advantages of the Takagi fuzzy inference system method with the Sugeno method, this study tries to apply it to a system for diagnosing diseases and pests of rice plants in Madura. The fuzzy inference system using the Sugeno method is a development method of fuzzy logic with a Weighted Average Value in the IF-THEN fuzzy rule section. And fuzzy logic is considered capable of mapping an input into an output without ignoring the existing factors[8]. Based on fuzzy logic, a model of a system capable of diagnosing diseases and pests of rice plants will be produced based on the level of rice damage experienced by several symptoms. From the results of

applying this method, the ability of the Fuzzy Inference System method with Sugeno to provide the diagnosis will be known.

2 Literature Review

This section explores related works and references on methods of diagnostic systems developed for plant disease cases, such as Fuzzy Logic, Tsukamoto, and Mamdani. However, these methods have weaknesses and cover these weaknesses in that several previous researchers have normalized data before diagnosing. This is done to increase accuracy, as in research [9] for the diagnosis of diseases in rubber plants using the Mamdani method, wherein the preprocessing stage, the data normalization process is carried out using the Min-Max method, and the resulting accuracy rate is 81.28%. In research [10] dealing with tea leaf disease decision-making using the Mamdani method based on several indicators or symptoms by implementing an inferential system to calculate the α -predicate in each rule with MIN implications and using the MAX method for composition for all rules, finally, defuzzification with the centroid method. Probability results show that category C disease has attacked 78% of tea leaves (Gray Blight). In this case, these results indicate that Mamdani-Fuzzy Inference has more optimal results than the previous method. Meanwhile, in research conducted by [11] regarding diagnosing ornamental plant diseases using the Fuzzy Logic method, fuzzy logic defines values between conventional conditions such as true or false, yes or no. Then the process of giving weight to the symptoms and normalizing the importance of these symptoms is carried out based on the criteria of resistance to pests and diseases. The results of the accuracy in this study amounted to 66.28%. In addition, research [12] regarding the banana quality-determining system, carried out using the Tsukamoto method, has resulted in an accuracy of 78%. Then developed by research[13] regarding the comparative analysis of Tsukamoto, Mamdani, and Sugeno-fuzzy inference on rice productivity in Indonesia, where the results of the predictions that have been carried out in this study, there are several results whose predictions are the same, namely between Fuzzy Mamdani and Fuzzy Sugeno.

From the several references above, this study developed the Takagi-Sugeno fuzzy inference system method for the diagnosis of diseases and pests of paddy rice plants in Madura. To apply the Takagi-Sugeno fuzzy inference system method to a diagnostic system, several variables are needed, namely the weight of the value of each symptom, the value limit, the minimum value for each symptom, the maximum value limit for each symptom, and the rules indicating the symptoms possessed by each pest. Takagi's fuzzy inference system method is used to convert non-fuzzy variables in the form of value weights, minimum and maximum interval limits of the selected symptoms into fuzzy variables so that fuzzy values are obtained. In comparison, Sugeno is used to identify pests of paddy

rice plants by applying an expert system to control pest attacks.

3 Research Methods

In this research, the method used is the Takagi-fuzzy inference system method with the Sugeno method. This study's diagnostic system will use expert system literature references as a design basis. In the methodological process used in this study regarding the system's design to be developed. Like the flow chart shown in Figure 1. The design stage is the initial stage in building a plan. [14]. With input as input selection of symptoms of pests and diseases of paddy rice plants checked by the user for reference for calculations in the following process. Then in the process, namely the analysis of the Takagi fuzzy inference system method with the Sugeno method by calculating the fuzzification process, the b value of each category of damage level, and the defuzzification process. The last step is the results of the diagnosis as information on the type of pest and disease and evaluation of the model to measure the level of accuracy. And data processing was obtained from pest and disease control officers at the Department of Agriculture, Pamekasan, Madura. The data collected is a dataset of 315 diseases and pests of rice plants with attacking symptoms, including 38 symptoms and 13 types of diseases.

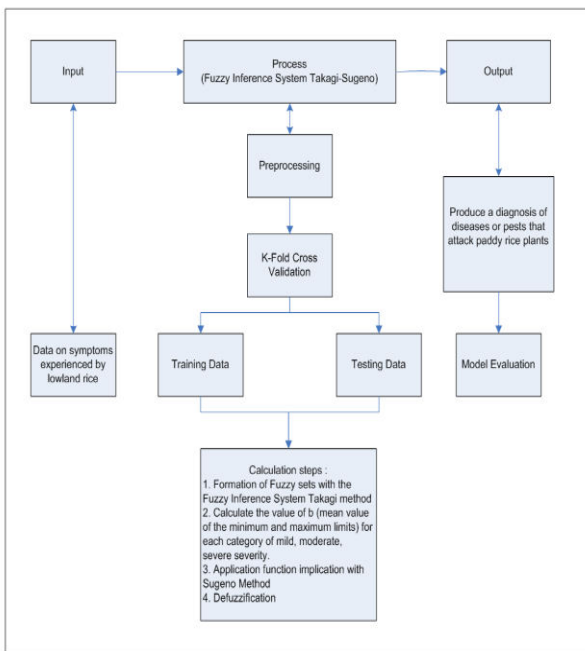


Fig. 1. General Diagram of Disease and Pest Detection in Rice Plants Using Fuzzy Inference System Takagi-Sugeno Methods

3.1 Data Preprocessing

In processing large amounts of data, it is feared that it can cause a low level of accuracy. Therefore, it is necessary to preprocess the process. Preprocessing is a technique used to convert raw data into a form that is easier to understand[15]. This process is necessary to correct errors in raw data which is often incomplete and has an irregular format. Preprocessing involves validating and imputing data. Validation aims to assess the filtered data's completeness and accuracy. Whereas

imputation seeks to correct errors and enter missing values, either manually or automatically[16]. In this study, data preprocessing was carried out to transform the observed data into fuzzy sets. A fuzzy set is a group that represents a specific condition or situation in a fuzzy variable. The fuzzy set has two attributes. Linguistics uses natural language to name a group representing a particular state or condition[17]. Fuzzy sets are used to prevent significant categorical differences. Item x can be listed in two different locations depending on the extent of its existence in the group, which can be seen from its membership value[18]. In this study, we propose using a singleton as a membership function of the consequent. Singleton is a fuzzy set with a membership function that, at a certain point, has a value and 0 outside that point[19].

3.2 Fuzzy Inference System Takagi-Sugeno Methods

Expert System is a computer-based application that is used to solve problems thought by experts[20]. Experts have particular expertise and can solve problems ordinary people cannot solve [20][21]. For example, extension workers at the plant pest and disease control service are experts who can diagnose diseases experienced by food crops and provide prevention or control of these diseases. Not everyone can make decisions regarding the diagnosis and provide solutions to the disease. The Takagi-Sugeno fuzzy inference system method is a toolbox for building fuzzy logic systems based on the Sugeno method. The main system characteristic is flexibility, which means the system makes it easy for users to modify system data. Takagi-Sugeno fuzzy inference system fixes the weakness of a pure fuzzy system to add a simple mathematical calculation as part of THEN[22]. In this change, the fuzzy system has a Weighted Average Value in the IF-THEN fuzzy rule section. Diagnostic steps using the Takagi-Sugeno fuzzy inference system, including[23]:

1. It calculates the fuzzification value of the symptoms used with the membership function. The membership function maps membership values with intervals from 0 to 1. One of the methods that can be used to obtain membership values is the functional approach. This study uses the formula for the membership function in equations (1) and (2).

$$\mu[x, a, b, c] = \begin{cases} 0 & x \leq a \text{ or } x \geq c \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \end{cases} \quad (1)$$

$$b = \frac{\sum a \text{ until } b}{n} \quad (2)$$

2. The implications of the application function regulate the basic rules, namely the rules for forming fuzzy substances which express the relationship between input variables and output variables, as in equation (3).

$$F = \frac{(x-a)}{(b-a)} \quad (3)$$

3. Defuzzification, where this process after fuzzification has been carried out on each selected

symptom, is processed based on the rules of the implication function that have been made so that a diagnosis result is obtained, as in equation (4).

$$WA = \frac{a_1z_1+a_2z_2+a_3z_3+\dots+a_nz_n}{a_1+a_2+a_3+\dots+a_n} \quad (4)$$

3.3 Captions/numbering

MOS testing is carried out to determine the feasibility of an expert system that is built based on the display provided and the use of the system [24]. The MOS test is carried out by giving weights to the questions, as shown in Table 1. After the respondents answered each of the questions presented, it was calculated by equation (5). To find the MOS value or the average score given by respondents to all question attributes, equation (6) is used in the calculation.

Table 1. MOS Test of Value Weight

MOS	Value	Class
Strongly agree (SA)	5	Good
Agree (A)	4	Good
Don't Know (DK)	3	Neutral
Disagree (DA)	2	Bad
Strongly Disagree (SDA)	1	Bad

$$mean p_i = \frac{\sum S_i B_i}{N} \quad (5)$$

where $mean p_i$ is the average score of each question attribute, S_i is the number of respondents who chose each answer attribute, B_i is the weight of each question attribute and N is the number of respondents.

$$MOS = \frac{\sum_{i=0}^n x(i)k}{N} \quad (6)$$

3.4 Accuracy Testing

Accuracy is an evaluation method used to state the accuracy level between the system's predicted results and the actual results [25]. The higher the accuracy produced by the system, the more accurate the system performs identification properly, with equation (7). In this study, for testing, the accuracy was carried out by two experts on plant diseases of Madura paddy rice. This test aims to determine the suitability of the results of an expert diagnosis with the results of a system diagnosis.

$$accuracy = \frac{\sum Test\ data\ is\ correct}{\sum total\ test\ data} \times 100\% \quad (7)$$

4 Analysis And Discussions

Discussion and analysis are needed to find out whether the results of the research have been able to solve the problem or not. The problem that has been formulated previously is whether the Takagi-Sugeno Fuzzy Inference System method can provide a diagnosis of dental disease in an expert system. In the data preprocessing process, this study changed the data on

the symptoms found in paddy rice plants. The results were plant diseases that attacked the rice plants. The analysis results using the Takagi-Sugeno fuzzy inference system method are shown in Table 2. The next step is calculating the fuzzification value into the membership function, as shown in Figure 2. In the fuzzification process, reasoning is carried out by inputting several symptoms of rice plant diseases based on expert knowledge. For example, symptom-1: There are spots on the leaves like the suction marks of nymphs from the stink bug, then a Stink Bug (P5) is identified with a weight from the expert of 0.4, while symptom-2: There are black spots on the grains of rice, identified as P5 with a weight of 0.7, Leaf Brown Spots (P10) with a weight of 0.7, and Blast (P11) with a weight of 0.2, symptom-3: On the leaves there are small oval spots, usually dark brown identified Leaf Brown Spots(P10) with a weight of 0.2, the results of the fuzzification can be seen in Table 3. Then the implication of the function is to form premise rules in this expert system into the involvement of light, medium, or heavy damage, as shown in Table 4. The last step of the Takagi-Sugeno Fuzzy Inference System method is the defuzzification process, where these symptoms are processed based on the rules of the implication function that have been made so that alternative results of the disease are obtained in the percentage of attacks can be seen in Table 5. Based on calculations using the Takagi-Sugeno Fuzzy Inference System method, which has been carried out related to the symptoms of paddy rice disease Madura experienced by farmers on S13, S14, and S25, it can be concluded that the defuzzification results of the diagnosis of Madura lowland rice disease were 50.3%.

Table 2. Calculation Results of The Fuzzy Inference System Takagi-Sugeno Method for Preprocessing Data

Symptoms	Damage Rate (%)	Category
There are spots on the leaves like the suction marks of nymphs from the stink bug (S13)	40	0.875 (Light)
There are black spots on the grains of rice (S14)	80	0.8 (Heavy)
On the leaves there are small oval spots, usually dark brown (S25)	100	0.8 (Heavy)

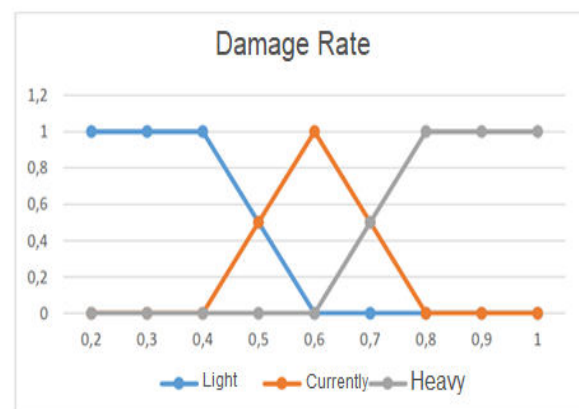


Fig. 2. Membership Function Damage Level of Madura Paddy Rice

Table 3. Calculation Results of the Takagi-Sugeno Fuzzy Inference System Method for Fuzzification

Knowledge Base	Expert Weight	Attack Value (Y)	Value
P5, S13	0.4	0.875	0.35
P5, S14	0.7	0.8	0.56
P10, S14	0.7	0.8	0.56
P11, S14	0.2	0.8	0.16
P10, S25	0.2	0.8	0.16

Table 4. Involvement of Damage Level of Madura Paddy Rice

Knowledge Base	Functional Implications		
	Light	Medium	Heavy
P5, S13	1	0	0
P5, S14	0.2	0.8	0
P10, S14	0.2	0.8	0
P11, S14	1	0	0
P10, S25	1	0	0

Table 5. Defuzzification for Sample Case

Knowledge Base	Defuzzification Process (WA)	Value (%)
S13 with P5	$(1*0.35)/1$	35
S14 with P5, P10, P11	$(0.8*0.6+0.8*0.6+1*0.35)/(0.8+0.8+1)$	50.3
S25 with P10	$(1*0.35)/1$	35

This study conducted several tests to provide information on whether the designed system met the research objectives. The MOS test involved 30 respondents of ten farmers and 20 officers from the Madura Paddy Pest and Disease Control Office. Each group of respondents was given different questions according to their level of understanding. The results of the MOS testing of the five questions regarding the system's feasibility can be seen in Table 6. Based on the results of the MOS testing by farmers, it was concluded that the results were 4.48, and the MOS testing by Madura food crop extension agents obtained the MOS calculation results of 4.06. This shows that the information displayed by the expert system for diagnosing diseases of Madura paddy rice plants using the built Takagi-Sugeno fuzzy inference system method is good. At the same time, they were testing the system on experts to determine the suitability of the results of the experts' diagnosis with the results of the system diagnosis. A comparison of expert test results can be seen in Table 7. After calculating the value of system accuracy for experts 1 and 2 for 30 cases, the system accuracy test results were 86.66%. Differences in knowledge and experience cause discrepancies in the results of the diagnosis of each expert.

Table 6. MOS Test Results with 30 Respondents

No	Questions	Farmer Respondents						Mean μ_i
		SA	A	DK	DA	SDA	Total	
1	Question 1	4	4	2	0	0	10	4.2
2	Question 2	7	3	0	0	0	10	4.7

3	Question 3	6	2	2	0	0	10	4.4
4	Question 4	6	2	2	0	0	10	4.4
5	Question 5	7	3	0	0	0	10	4.7
Sub-Total		30	14	6	0	0	50	22.4
MOS								4.48

No	Questions	Farmer Respondents						Mean μ_i
		SA	A	D K	D A	SDA	Total	
1	Question 1	0	4	5	1	0	10	3.3
2	Question 2	2	5	3	0	0	10	3.9
3	Question 3	2	7	1	0	0	10	4.1
4	Question 4	5	5	0	0	0	10	5
5	Question 5	3	4	3	0	0	10	4
Sub-Total		30	12	25	1	1	0	50
MOS								4.48

Table 7. System Accuracy Test Results

System Diagnostics Results	Expert-1 of Diagnosis Results	Expert-2 of Diagnosis Results
Tungro, 100% Blast, False White Pests, 58.12%	Tungro Blast	Tungro Blast
Leaf midrib, Leaf blight crackle, 58.51% Bacterial Leaf Blight, 100%	Leaf blight crackle Bacterial Leaf Blight	Leaf blight crackle Bacterial Leaf Blight
Dwarf, 41.5%	Leaf Brown Spots	Brown planthopper
Stem Borer, Leaf midrib 69.65%	Stem Borer	Stem Borer
Leaf midrib, 69.65%	Tungro	Leaf midrib
Tungro, 40.04%	Tungro, Phosphorus	Tungro
Leaf blight crackle, 42.36% False White Pests, 100%	Leaf blight crackle False White Pests	Leaf Brown Spots False White Pests
Tungro, 39.59%	Tungro	Tungro, Nitrogen Deficiency
Dwarf, 100%	Dwarf	Dwarf
Fusarium, 50%	Tungro	Fusarium
Leaf midrib, Leaf blight crackle, 79.70% Stem Borer, 100%	Leaf midrib Stem Borer	Leaf midrib Stem Borer
Leaf midrib, 78.62% Bacterial Leaf Blight, 100%	Leaf midrib Bacterial Leaf Blight	Leaf midrib Bacterial Leaf Blight
Field mouse, 100%	Field mouse	Field mouse
Tungro, 39.9% False White Pests, 26.57%	Tungro False White Pests	Tungro, Nitrogen Deficiency False White Pests
Leaf blight crackle, 100% Tungro, 100%	Leaf blight crackle Tungro	Leaf blight crackle Tungro
Striped Leaves, 61.47% Bacterial Leaf Blight, 78.4% Brown planthopper, 56.4%	Striped Leaves Bacterial Leaf Blight Brown planthopper	Striped Leaves Bacterial Leaf Blight Brown planthopper
Bacterial Leaf Blight, 42.36% Leaf Brown Spots, Leaf blight crackle, 50.87%	Bacterial Leaf Blight Leaf Brown Spots	Bacterial Leaf Blight Leaf Brown Spots
Fusarium, 100% Stem Borer, 61.47%	Fusarium Stem Borer	Fusarium Stem Borer
Dwarf, Leaf midrib, 79.70%	Dwarf, Leaf midrib	Leaf midrib

5 Conclusion

Based on the research, it can be concluded that the Takagi-Sugeno Fuzzy Inference System method has been able to diagnose 13 diseases and 38 symptoms based on the knowledge of two experts and produces an accuracy of 86.66% from 30 different cases. The expert system built has an average MOS value of 4.27. This indicates that the system is feasible to use and is categorized as a good system. In developing this expert system, comparisons can be made with other machine learning methods, such as fuzzy KNN, for diagnosing diseases and pests of rice plants. They can add features to develop a knowledge base.

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