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Assessing Physical Fitness of Elementary School Students: A Case Study of SD Negeri 002 Lubuk Baja, Batam City

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ABSTRACT

This study applies the Mamdani Fuzzy Logic method to assess the physical fitness levels of students at SD Negeri 002 Lubuk Baja, Batam. Physical education, which has been implemented since first grade, aims to improve students' physical fitness, playing an important role in enhancing learning effectiveness. However, many students are unaware of their fitness levels, which can affect their learning performance. The sample consisted of two students, one male and one female, who were tested with Sit-Up, Squat Jump, and Running exercises. The results were categorized as 'fit' based on their heart rate before and after physical activities. Validation of the results was conducted by comparing the Mamdani output with assessments from physical education teachers and experts. The validation metrics showed 100% accuracy in classifying the students' fitness levels, based on manual calculations and MATLAB simulations. For the male student, the output was 141 (MATLAB) and 140.9967 (manual), with the fitness decision being 'fit.' For the female student, the output was 122 (MATLAB) and 121.7945 (manual), with the fitness decision also being 'fit.' This study demonstrates that the Mamdani Fuzzy Logic method is effective for assessing students' physical fitness and provides accurate decisions that align with the students' actual fitness.

1. INTRODUCTION

The integration of game-based learning into physical education (PE) has emerged as a pivotal strategy for enhancing motor and social skills among young learners, particularly in elementary school settings such as SD Negeri 002 Lubuk Baja. Research underscores the effectiveness of traditional games in fostering gross motor development. For instance, the study [1] highlights that activities like long jump games significantly improve students' gross motor skills by encouraging active movement and engagement.

Similarly, the study [2] emphasizes that traditional games, which often require children to navigate obstacles, play a crucial role in enhancing their gross motor capabilities. These findings highlight the importance of incorporating game-based learning into PE curricula to support physical development. Physical fitness is a critical determinant of students' learning effectiveness, particularly in elementary education. To strengthen this relationship, this research also refers to local data from SD Negeri 002 Lubuk Baja. The data collected includes students' academic records as well as results from physical fitness measurements using the Indonesian Physical Fitness Test (TKJI). Data analysis shows a positive correlation between physical fitness levels and students' academic grades. Students with better physical fitness tend to have higher academic scores, reinforcing previous research on the relationship between physical fitness and academic achievement. Defined as the capacity to perform daily activities without excessive fatigue while retaining energy for subsequent tasks, physical fitness is essential for maintaining concentration and motivation in academic environments. Empirical studies have consistently demonstrated that students with higher levels of physical fitness tend to exhibit better academic performance and greater engagement in learning processes [3-5]. Regular physical activity is fundamental to maintaining and improving physical fitness levels, with research indicating that physically active students generally outperform their sedentary peers in terms of both physical and cognitive outcomes [6]. The importance of structured physical education programs in schools cannot be overstated. Studies have shown that well-designed PE curricula significantly influence students' physical fitness and overall health outcomes [7, 8] established a clear link between regular physical activity and improved health-related fitness among primary school children. Furthermore, innovative teaching methods, such as mobile technology-supported learning models, have been shown to enhance students' motor skills and engagement in PE [9]. These findings underscore the need for schools to prioritize the enhancement of their PE programs to ensure that students achieve and maintain adequate fitness levels.

The integration of Physical Education, Sports, and Health (PJOK) within the school curriculum is essential for fostering students' physical well-being and enhancing their overall learning experiences. The scope of this research focuses on determining the physical fitness levels of elementary school students using specific variables: Sit-Up, Squat Jump, and Running. These variables are selected as they are fundamental indicators of physical fitness in children. Research indicates that physical fitness is positively correlated with academic performance, as it improves concentration and focus, thereby contributing to better academic outcomes [10, 11] This relationship highlights the importance of policies that allocate more time for PJOK lessons, as increased physical activity is associated with improved cognitive functioning and learning outcomes [12, 13]. The assessment of students' physical fitness using standardized tools, such as the Tes Kebugaran Jasmani Indonesia (TKJI), is critical for evaluating their overall health and performance capabilities. The TKJI includes a variety of tests, such as a 40-meter sprint, flexed-arm hang, 30-second sit-ups, vertical jump, and a 600-meter run, which collectively provide a comprehensive overview of students' physical fitness levels. The research has demonstrated that these standardized tests are essential for accurately measuring physical fitness, as they allow for systematic classification and comparison of fitness levels among students [14, 15]. The use of such tools not only facilitates the identification of students' fitness status but also underscores the importance of regular physical activity in maintaining and improving fitness levels [16, 17]. The role of physical education infrastructure in enhancing instructional effectiveness and improving student fitness outcomes is well documented. Studies have shown that the availability and quality of PE facilities significantly influence learning outcomes in elementary schools. For instance, Loganathan et al. [18] emphasize that physical resources, including infrastructure, must be adequately managed and utilized to support learning activities and improve school quality. This assertion is supported by Rathour et al. [19] who highlighted that appropriate facilities are essential for creating an effective PE learning process, ultimately motivating students and aiding teachers in assessing student performance.

Baibordy et al. [20] studied on the physical fitness levels of elementary students in Banyumas Regency, Central Java, utilized a robust multistage random sampling method to ensure a representative sample of 353 students. This methodological approach is critical in educational research, as it enhances the validity and reliability of findings by minimizing selection bias and allowing for generalization to the broader population of elementary students in the region [21, 22]. The collaboration with 20 physical education teachers further strengthened the study's design, ensuring that the assessment of physical fitness was aligned with local educational standards and practices [23, 24]. One innovative approach to assessing students' physical fitness levels involves the application of Fuzzy Logic, specifically the Mamdani method. The choice of the Mamdani method in this research is based on several considerations. Mamdani is more suitable for producing linguistic output that is easy to understand and interpret by users, especially in the context of decision-making involving subjective variables. Although the Sugeno method can also be used in Fuzzy Logic systems, we chose Mamdani because of its superior ability to handle uncertainty and imprecision in input data. Furthermore, previous studies have shown that the Mamdani method often provides higher accuracy in similar contexts. This method is preferred due to its ability to process multiple data inputs for computational analysis. While the Mamdani approach is widely used, other Fuzzy Logic methodologies, such as the Sugeno and Tsukamoto methods, offer alternative calculation techniques for decision-making within Fuzzy Logic systems. In this study, the Mamdani Fuzzy Logic method was chosen due to its simplicity and suitability for the research objectives. However, it is important to note that this method has limitations, including potential inaccuracies in determining students' physical fitness levels, as it does not always yield entirely precise results. Additionally, the manual assessment of students' physical fitness by teachers remains a challenge, as educators may struggle to observe and evaluate each student individually with a high degree of accuracy. This limitation underscores the need for further refinement in automated assessment methodologies to enhance precision and reliability in physical fitness evaluation.

2. METHODS

Fuzzy logic is a powerful decision-making methodology that effectively addresses uncertainty and ambiguity, particularly in complex systems where precise classifications are challenging to establish. This methodology is particularly beneficial in educational settings, such as assessing the physical fitness levels of elementary school students. By employing fuzzy logic, educators can create a more nuanced classification system that recognizes varying degrees of fitness rather than relying on rigid binary categories. This flexibility allows for a more accurate representation of students' physical capabilities and needs, which is essential for tailoring appropriate interventions and support [25, 26].

Fuzzy logic theory is fundamentally characterized by its capacity to map an input space to an output space through the application of IF-THEN rules, which are integral to the operation of a Fuzzy Inference System (FIS). This mapping process is crucial as it allows for the representation of uncertainty and vagueness in data, enabling more nuanced decision-making compared to traditional binary logic systems. The FIS operates by evaluating all predefined rules concurrently, which necessitates the careful construction of these rules prior to the system's implementation. This predefinition is essential for the FIS to accurately interpret inputs and generate meaningful outputs, as the effectiveness of the inference process heavily relies on the quality and comprehensiveness of the rules established [27, 28].

A FIS is a sophisticated computational framework that interprets numerical values from an input vector, applies predefined IF-THEN rules to draw conclusions, and subsequently produces an output vector. This operational mechanism allows FIS to handle uncertainty and imprecision, making it particularly useful in various decision-making processes across multiple domains. The design process of an FIS involves several sequential steps, including defining input and output variables, establishing membership functions, formulating IF-THEN rules, performing inference, and executing defuzzification to obtain crisp outputs [29-33].

By leveraging fuzzy logic, systems can handle imprecise or vague data more effectively, making it particularly useful in fields such as education, healthcare, and engineering. Its ability to model human reasoning and decision-making processes, despite the presence of uncertainty, underscores its significance as a tool for solving real-world problems. However, the effectiveness of fuzzy logic depends on the careful design of the FIS, including the accuracy of rule formulation and the appropriateness of membership functions, to ensure reliable and meaningful outcomes. Figure 1 shows the concept of FIS.

A. Fuzzy Logic of the Mamdani Method

The Mamdani method, often referred to as the Max-Min method, was introduced by Ebrahim Mamdani in 1975. This method requires four stages to produce an output [11].

1. Formation of Fuzzy Sets

In the Mamdani method, both input and output variables are divided into one or more fuzzy sets. This step involves defining the membership functions for each variable to represent their degrees of belonging to specific sets.

2. Application of Implication Function

The Mamdani method employs the Min function as its implication function. This step involves applying the minimum operator to the membership values of the input variables to determine the strength of each rule.

3. Composition Rules

If the system consists of multiple rules, the inference is derived from the combination of these rules. There are three primary methods used in performing fuzzy system inference:

a. Max (Maximum) Method: This method selects the maximum value from the combined rules.

b. Additive Method (Sum): This method sums the outputs of all rules.

c. Probabilistic OR Method (Probor): This method uses a probabilistic approach to combine the rules.

4. Affirmation (Defuzzification)

The defuzzification process takes a fuzzy set obtained from the composition of fuzzy rules as its input and produces a crisp value as its output. This step involves converting the aggregated fuzzy set into a single, precise value within the defined range. Common defuzzification techniques include the centroid method, bisector method, and mean of maximum. The defuzzification process can be seen in the following Figure 2.

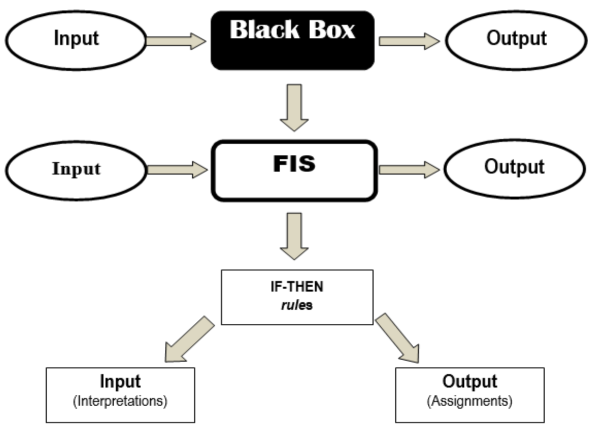

Figure 1. General concept of FIS development process chronology

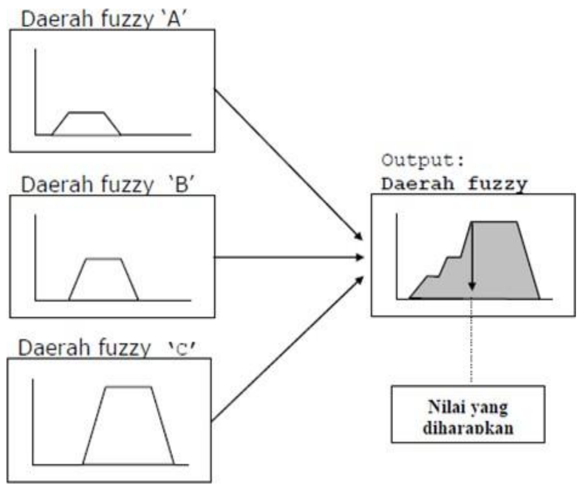

Figure 2. Defuzzification process

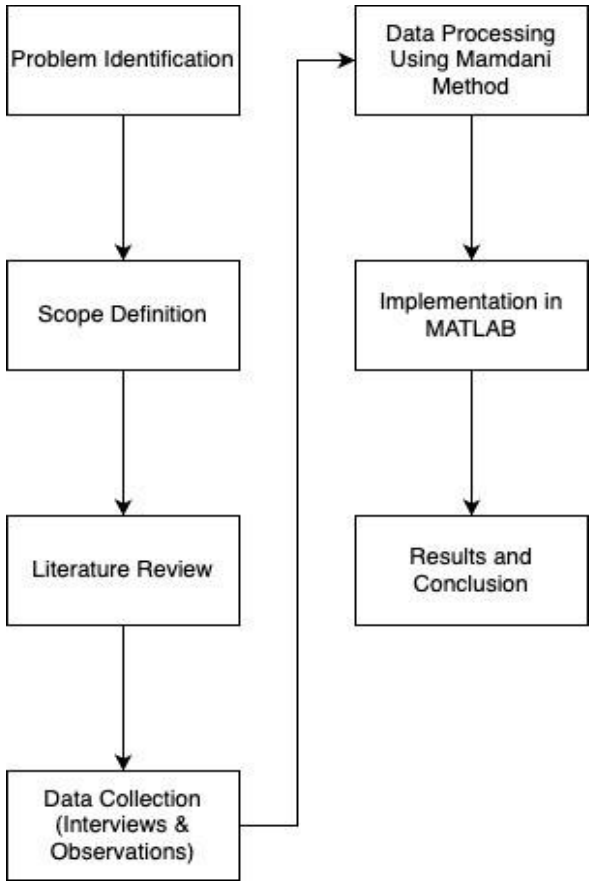

Figure 3. Research stages

The research stages carried out in the analysis to determine the level of physical fitness in elementary school students using the Mamdani method. As a validation step, the fuzzy rules used in this study have been validated with the PJOK teacher at SD Negeri 002 Lubuk Baja. The PJOK teacher provided feedback regarding the relationship between the fitness test results and the fitness categories produced by the fuzzy system. This was done to ensure that the rules used in the fuzzy system reflect the real conditions in the field and are relevant to the fitness assessments carried out by teachers in schools. The PJOK teacher also plays a role in evaluating whether the decisions generated by the fuzzy system align with their understanding of student fitness in Batam City, which can be described in Figure 3.

In the composition of Mamdani's rules, several defuzzification methods are employed to derive crisp solutions from fuzzy sets. These methods include:

a. Centroid Method (Composite Moment)

In this method, the crisp solution is obtained by calculating the center point (Z*) of the fuzzy region. This is achieved by determining the weighted average of the membership function, providing a balanced representation of the fuzzy set.

b. Bisector Method

This method involves identifying the value within the fuzzy domain that divides the area under the membership function into two equal parts. The bisector represents the point where half of the total membership value lies on either side.

c. Mean of Maximum (MOM) Method

Here, the crisp solution is derived by taking the average value of the domain that exhibits the maximum membership value. This method focuses on the most prominent values within the fuzzy set.

d. Largest of Maximum (LOM) Method

In this approach, the crisp solution is obtained by selecting the largest value from the domain that has the maximum membership value. This method prioritizes the upper bound of the most significant fuzzy region.

e. Smallest of Maximum (SOM) Method

This method determines the crisp solution by taking the smallest value from the domain that has the maximum membership value. It emphasizes the lower bound of the most prominent fuzzy region. These defuzzification techniques provide diverse approaches to converting fuzzy outputs into precise values, each suited to specific applications and requirements.

The research stages conducted to analyze and determine the physical fitness levels of elementary school students in Batam City using the Mamdani method are illustrated in Figure 3. The process involves systematic steps, including data collection, fuzzification, rule evaluation, composition, and defuzzification, to ensure accurate and reliable results. This structured approach enables the effective application of fuzzy logic in assessing physical fitness, offering a flexible and adaptive framework for decision-making in educational settings.

The research design, as illustrated in Figure 3, is explained through the following systematic steps:

1. Problem Identification:

The author identifies and elaborates on the research problem. In this study, the key issues are:

a. The physical fitness levels of students at SD Negeri 002 in Batam City have not been systematically assessed.

b. Low physical fitness among students can negatively impact their academic performance and learning outcomes.

c. Manual identification of physical fitness levels in elementary school students is prone to inaccuracies, as teachers are unable to observe and evaluate each student individually with precision.

2. Scope of the Study:

The scope of this research focuses on determining the physical fitness levels of elementary school students using specific variables: Sit-Up, Squat Jump, and Running. Sample Size and Gender Distribution This study involved 50 students from SD Negeri 002 Lubuk Baja, Batam, with a balanced gender distribution (25 males and 25 females) to ensure data representativeness. Students were selected based on inclusion criteria that included:

(1) Students who are active in physical activities at school,

(2) Students who do not have medical conditions that limit participation in physical fitness tests. Students with medical conditions that hinder participation in fitness tests, such as heart problems or respiratory issues, were excluded from this study to maintain the accuracy of the results. These variables are selected as they are fundamental indicators of physical fitness in children.

3. Literature Review:

A comprehensive literature review is conducted to understand the theoretical foundations of the study. This includes exploring concepts such as fuzzy logic, the Mamdani method, and the criteria for assessing physical fitness in elementary school students. References are drawn from relevant journals, books, and other scholarly sources to support the research framework.

4. Data Collection:

Data is collected through interviews with Physical Education (PJOK) teachers at SDN 002 Lubuk Baja in Batam City. The interviews focus on understanding the criteria for assessing students' physical fitness levels from various perspectives. Additionally, observations and physical fitness tests (e.g., Sit-Up, Squat Jump, and Running) are conducted with the students to gather empirical data.

5. Data Processing Using the Mamdani Method:

The collected data is processed using the Mamdani method, which involves four key stages:

a. Formation of Fuzzy Sets: Defining membership functions for input and output variables.

b. Application of Implication Functions: Using the Min operator to evaluate fuzzy rules.

c. Composition of Rules: Combining multiple rules to derive fuzzy outputs.

d. Defuzzification: Converting fuzzy outputs into crisp values using appropriate methods (e.g., centroid, bisector).

6. Implementation Using MATLAB Software:

The processed data is implemented and simulated using MATLAB software. This stage involves coding the Mamdani method and applying it to the collected data to generate results. MATLAB is chosen for its robust computational capabilities and suitability for fuzzy logic applications.

7. Results and Conclusions:

The final stage involves analyzing the results and drawing conclusions based on the findings. The research outcomes are documented comprehensively, providing insights into the physical fitness levels of the students and the effectiveness of the Mamdani method in this context. Recommendations for future research and practical applications are also discussed.

This structured research design ensures a systematic and rigorous approach to assessing physical fitness levels in elementary school students, leveraging fuzzy logic and the Mamdani method to address the limitations of manual evaluation processes.

3. RESULTS AND DISCUSSION

To examine the results of the research taken from case examples, it was then implemented into fuzzy logic which was used to determine physical fitness in elementary school students in Batam City using the Mamdani method. The final goal of this study has been to collect data and interview results with teachers of PJOK SD Negeri 002 Lubuk Baja.

To find out the physical fitness, students are given a sports test to find out how fit the student is. The data obtained was in the form of calculation of student pulse rate which was carried out by calculating the pulse rate before doing exercise within 1 minute. Then the student did a sports test and recalculated the student's pulse after doing the exercise. The types of sports tests used are Sit Up, Squat Jump, and Run. Pulse measurement is performed using a Polar Heart Rate Monitor that can provide accurate and consistent pulse readings. Measurements are taken at two different times: first, before the students take the fitness test, and second, immediately after the fitness test is completed. The measurements are conducted in a controlled environment, at the same time (in the morning) to minimize variations caused by external factors.

Data analysis was conducted by entering the heart rate data of students obtained based on the types of sports performed by SDN 002 Lubuk Baja students. The sample consisted of 50 students, both male and female is illustrated in the Figure 4. The data was then used as a variable to be processed using the Mamdani method, which is illustrated in the Figure 5. A fuzzy set was created from the data, and the results were entered into the application for further analysis.

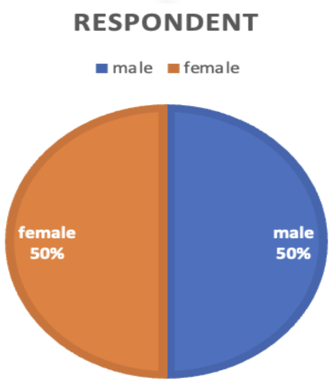

Figure 4. Percentage of respondents

Table 1. Universe of male student talks

Function	Variable	Universe of Conversation	Information
Input	Lying Down Sitting	[50 200]	Pulse rate rating
	Jumping Squats	[50 200]	Pulse rate rating
	Run	[50 200]	Pulse rate rating
Output	Student Fitness	[50 200]	Fitness Results

In creating a fuzzy system, a universe of speech is needed, where a universe of speech is a benchmark value to determine the permissible value in operating a fuzzy variable. There are two universes of conversation in this study, namely the universe of conversation for male students and the universe of conversation for female students. The universe of the conversation can be seen in the Table 1 for male students and Table 2 for female students.

Table 2. The universe of female student talks

Function	Variable	Universe of Conversation	Information
Input	Lying Down Sitting	[50 200]	Pulse rate rating
	Jumping Squats	[50 200]	Pulse rate rating
	Run	[50 200]	Pulse rate rating
Output	Student Fitness	[50 200]	Fitness Results

The steps in applying fuzzy Mamdani to obtain the output value require 4 stages, namely, the Formation of the Fuzzy Set (Fuzzification), the Application of the Implication Function, the Composition of the Rules, and the Affirmation (Defuzzy).

1. Formation of Fuzzy Sets (Fuzzification)

The formation of the fuzzy set made to determine the input variables in this study consisted of 3 types of exercise such as Sit Up, Squat Jump, and Run, while the output was student fitness. The function of membership degrees for the values of the three variables is determined from the three variables, namely lying down, squatting, jumping, and running.

The fuzzy set used as a variable has an interval between 50 to 200 for male students and 50 to 150 for female students.

2. Decreasing Linear Function

Decreasing Linear Function is chosen to describe the decline in students' fitness levels as their heart rate increases after engaging in physical activities. According to exercise physiology theory, a higher heart rate indicates greater physical fatigue, which is related to a decrease in students' physical capacity. The Decreasing Linear Function represents a gradual decline in fitness levels, with membership values decreasing as the input variable values, such as heart rate, increase. This ensures that the system can handle the uncertainty and imprecision associated with assessing physical fitness more flexibly. Where a score of 200 indicates the highest membership, while a value of 50 indicates the lowest value of membership for male students, and a function of female student membership degrees a value of 150 indicates the highest membership value, while a value of 50 indicates the lowest value. The formation of a fuzzy set of input for male and female students can be seen in the Table 3 and the formation of the fuzzy set of its output can be seen in the Table 4. Meanwhile, the formation of the fuzzy set of female student input can be seen in the Table 5 and the formation of the fuzzy set of its output can be seen in the Table 6.

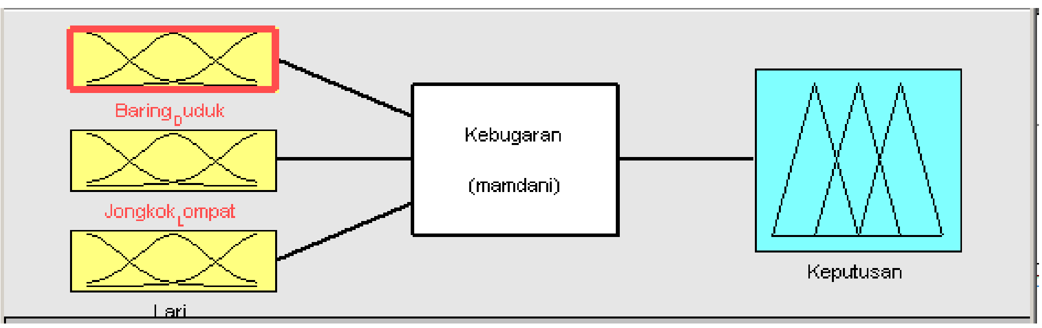

Figure 5. Input and output variables of the Mamdani method

Table 3. Formation of the fuzzy set of male student input

Variable	Fuzzy Bundle	Domain	Membership Function	Parameters
Lying Down Sitting	Slow	[50 120]	Linier Turun	(50; 50; 110; 120)
	Usual	[110 150]	Trapesium	(110; 120; 140; 150)
	Fast	[140 200]	Linier Naik	(140; 150; 200; 200)
Jumping Squats	Slow	[50 125]	Linier Turun	(50; 50; 115; 125)
	Usual	[115 155]	Trapesium	(115; 125; 145; 155)
	Fast	[145 200]	Liniear Naik	(145; 155; 200; 200)
Run	Slow	[50 130]	Linier Turun	(50; 50; 120; 130)
	Usual	[120 160]	Trapesium	(120; 130; 150; 160)
	Fast	[150 200]	Linier Naik	(150; 160; 200; 200)

Table 4. Formation of the fuzzy set of male student outputs

Variable	Fuzzy Bundle	Domain	Membership Function	Parameters
Student Physical Fitness	Less Fit	[50 120]	Linier Turun	(50; 50; 110; 120)
	Fit	[120 200]	Linier Naik	(120; 130; 200; 200)

Table 5. Formation of a fuzzy set of female student input

Variable	Fuzzy Bundle	Domain	Membership Function	Parameters
Lying Down Sitting	Slow	[50 95]	Linier Turun	(50; 50; 90; 95)
	Usual	[90 120]	Trapesium	(90; 95; 115; 120)
	Fast	[115 150]	Linier Naik	(115; 120; 150; 150)
Jumping Squats	Slow	[50 100]	Linier Turun	(50; 50; 95; 100)
	Usual	[95 125]	Trapesium	(95; 100; 120; 125)
	Fast	[120 150]	Liniear Naik	(120; 125; 150; 150)
Run	Slow	[50 105]	Linier Turun	(50; 50; 100; 105)
	Usual	[100 130]	Trapesium	(100; 105; 125; 130)
	Fast	[125 150]	Linier Naik	(125; 130; 150; 150)

Table 6. Formation of fuzzy sets of female student output

Variable	Fuzzy Bundle	Domain	Membership Function	Parameters
Student Physical Fitness	Less Fit	[50 90]	Linier Turun	(50; 50; 80; 90)
	Bugar	[90 150]	Linier Naik	(90; 100; 150; 150)

Membership functions are used to assess students' physical fitness based on heart rate measurements from various physical activities. Figure 6 and Figure 7 illustrate the membership functions for the Lying Down variable for male and female students. Figure 8 and Figure 9 present the membership functions for the Squat Jump variable for both genders. Figure 10 shows the membership function for Running for male students, while Figure 11 and Figure 12 display the membership functions for the Physical Fitness Output for both male and female students. These functions help classify fitness levels into categories such as slow, normal, and fast, based on the heart rate data collected from the three physical activities.

a. Function of variable membership degree Input bed-sitting

Siswa laki-laki

$$\mu_{\text{Lambat}}[x] = \begin{cases} (120-x)/(120-110) & 110 \le x \le 120 \\ 0; & x \ge 120 \end{cases}$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & x \le 110 \text{ atau } x \ge 150 \\ (x-110)/(120-110); & 110 \le x \le 120 \\ 1; & 120 \le x \le 140 \\ (150-x)/(150-140); & x \ge 150 \end{cases}$$

$$\mu_{\text{Cepat}}[x] = \begin{cases} 0; & x \le 140 \\ (x-140)/(150-140); & 140 \le x \le 150 \\ 1; & x \ge 150 \end{cases}$$

Siswa Perempuan

$$\mu_{\text{Lambat}}[x] = \begin{cases} (95-x)/(95-90); & 90 \le x \le 95 \\ 0; & x \ge 95 \end{cases}$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & x \le 90 \text{ atau } x \ge 120 \\ (x-90)/(95-90); & 90 \le x \le 95 \\ 1; & 95 \le x \le 115 \\ (120-x)/(120-115); & x \ge 120 \end{cases}$$

$$\mu_{\text{Cepat}}[x] = \begin{cases} 0; & x \le 115 \\ (x-115)/(120-115); & 115 \le x \le 120 \\ 1; & x \ge 120 \end{cases}$$

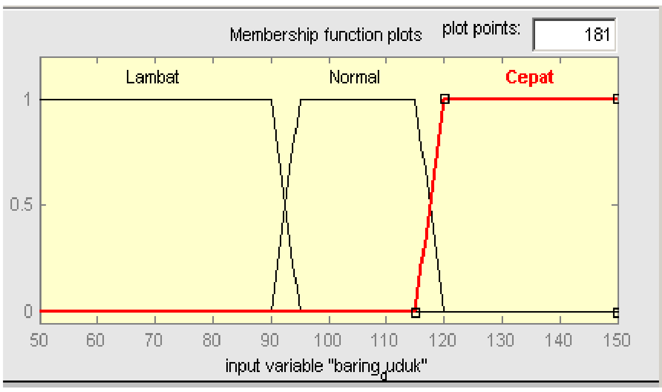

Figure 6. Membership functions of female student sitting bed score input

b. Function of the degree of membership variable input squat jump

Siswa laki-laki

$$\mu_{\text{Lambat}}[x] = \begin{cases} (125-x)/(125-115); & 115 \le x \le 125 \\ 0; & x \ge 125 \end{cases}$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & x \le 115 \text{ atau } x \ge 155 \\ (x-115)/(125-115); & 115 \le x \le 125 \\ 1; & 125 \le x \le 145 \\ (155-x)/(155-145); & x \ge 155 \end{cases}$$

$$\mu_{\text{Cepat}}[x] = \begin{cases} 0; & x \le 145 \\ (x-145)/(155-145); & 145 \le x \le 155 \\ 1; & x \ge 155 \end{cases}$$

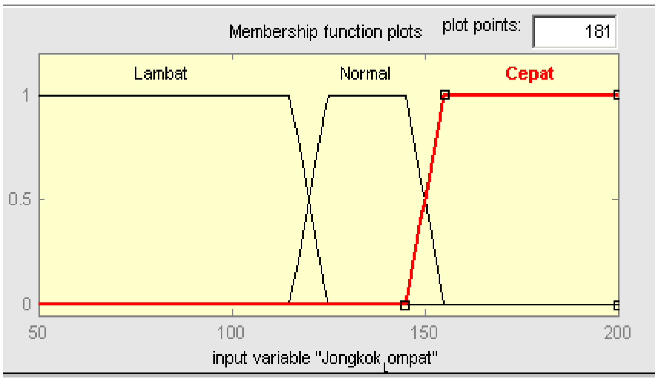

Figure 7. Membership functions input value squat male jump

Siswa Perempuan

$$\mu_{\text{Lambat}}[x] = \begin{cases} (100-x)/(100-95); & 95 \le x \le 100 \\ 0; & x \ge 100 \end{cases}$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & x \le 90 \text{ atau } x \ge 120 \\ (x-95)/(100-95); & 90 \le x \le 95 \\ 1; & 95 \le x \le 115 \\ (125-x)/(125-120) & x \ge 125 \end{cases}$$

$$\mu_{\text{Cepat}}[x] = \begin{cases} 0; & x \le 120 \\ (x-120)/(125-125); & 120 \le x \le 125 \\ 1; & x \ge 125 \end{cases}$$

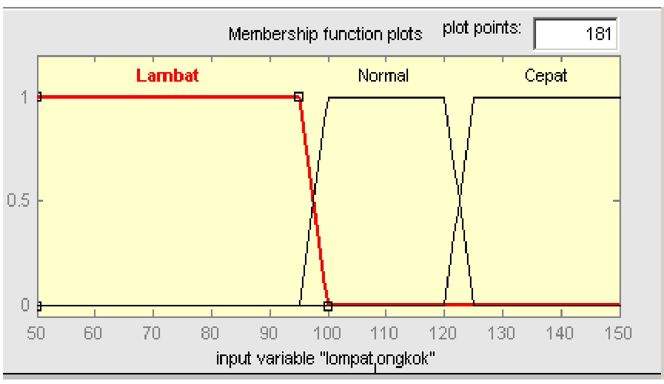

Figure 8. Membership functions of female jumping squat value [1] input

c. Function of the degree of membership of the variable input run

Siswa laki-laki

$$\mu_{\text{Lambat}}[x] = \begin{cases} (130-x)/(130-120); & 120 \le x \le 130 \\ 0; & x \ge 130 \end{cases}$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & x \le 120 \text{ atau } x \ge 160 \\ (x-120)/(130-120); & 120 \le x \le 130 \\ 1; & 130 \le x \le 150 \\ (160-x)/(160-150); & x \ge 160 \end{cases}$$

$$\mu_{\text{Cepat}}[x] = \begin{cases} 0; & x \le 150 \\ (x-150)/(160-150); & 150 \le x \le 160 \\ 1; & x \ge 160 \end{cases}$$

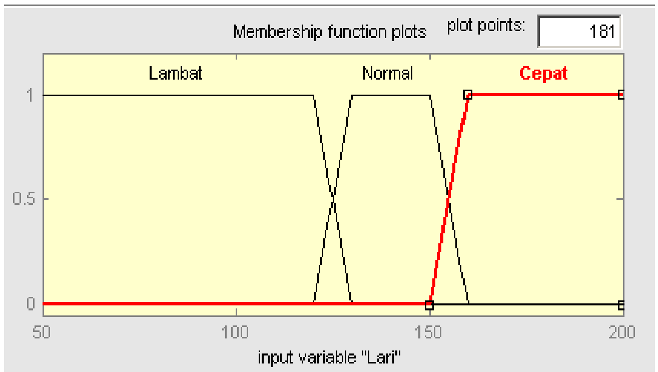

Figure 9. Function of membership degree input male running value

Siswa Perempuan

$$\mu_{\text{Lambat}}[x] = \begin{cases} (105-x)/(105-100); & 100 \le x \le 105 \\ 0; & x \ge 105 \end{cases}$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & x \le 100 \text{ atau } x \ge 130 \\ (x-100)/(105-100); & 100 \le x \le 105 \\ 1; & 105 \le x \le 125 \\ (130-x)/(130-125); & x \ge 130 \end{cases}$$

$$\mu_{\text{Cepat}}[x] = \begin{cases} 0; & x \le 125 \\ (x-125)/(130-125); & 125 \le x \le 130 \\ 1; & x \ge 130 \end{cases}$$

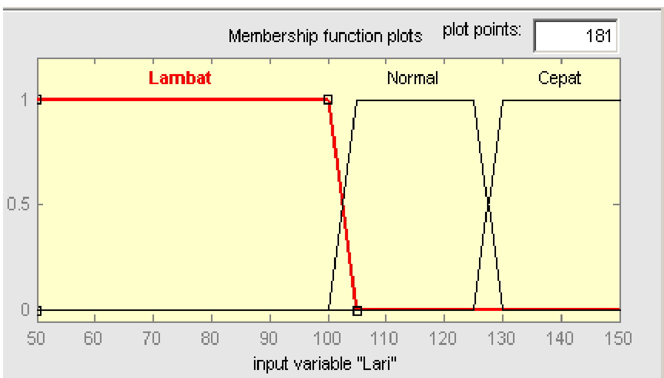

Figure 10. Functions of membership degree input women's running score

d. Function of fitness output variable membership degree

Siswa laki-laki

$$\mu_{KurangBugar}[x]=\begin{cases}(120-x)/(120-110); & 110\le x\le 120\\ 0; & x\ge 120\end{cases}$$

$$\mu_{Bugar}[x]=\begin{cases}0; & x\le 120\\ (x-120)/(130-120); & 120\le x\le 130\\ 1; & x\ge 130\end{cases}$$

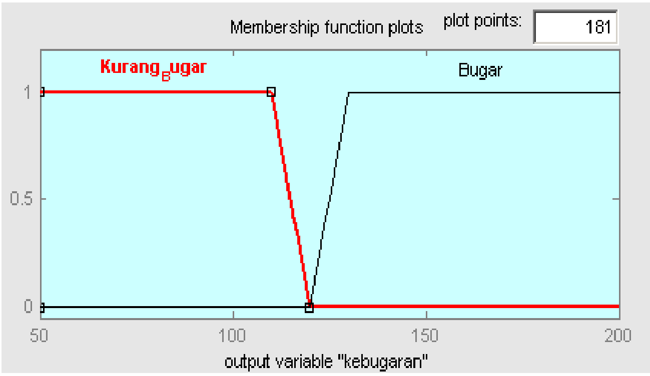

Figure 11. Membership functions output men's fitness value

Siswa Perempuan

$$\mu_{KurangBugar}[x]=\begin{cases}(80-x)/(90-80); & 80\le x\le 90\\ 0; & x\ge 90\end{cases}$$

$$\mu_{Bugar}[x]=\begin{cases}0; & x\le 90\\ (x-90)/(100-90); & 90\le x\le 100\\ 1; & x\ge 100\end{cases}$$

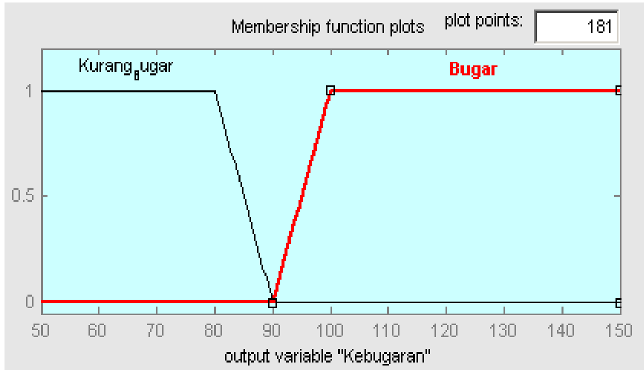

Figure 12. Membership functions output women's fitness value

Table 7. List of rules for determining students' physical fitness

Rule	Condition
Rule 1	If Baring_Duduk is Slow and Jongkok_Lompat is Slow and Running is Slow then Fitness is Kurang_Bugar
Rule 2	If Baring_Duduk is Slow and Jongkok_Lompat is Slow and Running is Normal then Fitness is Kurang_Bugar
Rule 3	If Baring_Duduk is Slow and Jongkok_Lompat is Slow and Running is Fast then Fitness is Kurang_Bugar
Rule 4	If Baring_Duduk is Slow and Jongkok_Lompat is Normal and Running is Slow then Fitness is Kurang_Bugar
Rule 5	If Baring_Duduk is Slow and Jongkok_Lompat is Normal and Running is Normal then Fitness is Fit
Rule 6	If Baring_Duduk is Slow and Jongkok_Lompat is Normal and Running is Fast then Fitness is Fit
Rule 7	If Baring_Duduk is Slow and Jongkok_Lompat is Fast and Running is Slow then Fitness is Kurang_Bugar
Rule 8	If Baring_Duduk is Slow and Jongkok_Lompat is Fast and Running is Normal then Fitness is Fit
Rule 9	If Baring_Duduk is Slow and Jongkok_Lompat is Fast and Running is Fast then Fitness is Fit
Rule 10	If Baring_Duduk is Normal and Jongkok_Lompat is Slow and Running is Slow then Fitness is Kurang_Bugar
Rule 11	If Baring_Duduk is Normal and Jongkok_Lompat is Slow and Running is Normal then Fitness is Fit
Rule 12	If Baring_Duduk is Normal and Jongkok_Lompat is Slow and Running is Fast then Fitness is Fit
Rule 13	If Baring_Duduk is Normal and Jongkok_Lompat is Normal and Running is Slow then Fitness is Fit
Rule 14	If Baring_Duduk is Normal and Jongkok_Lompat is Normal and Running is Normal then Fitness is Fit
Rule 15	If Baring_Duduk is Normal and Jongkok_Lompat is Normal and Running is Fast then Fitness is Fit
Rule 16	If Baring_Duduk is Normal and Jongkok_Lompat is Fast and Running is Slow then Fitness is Fit
Rule 17	If Baring_Duduk is Normal and Jongkok_Lompat is Fast and Running is Normal then Fitness is Fit
Rule 18	If Baring_Duduk is Normal and Jongkok_Lompat is Fast and Running is Fast then Fitness is Fit
Rule 19	If Baring_Duduk is Fast and Jongkok_Lompat is Slow and Running is Slow then Fitness is Kurang_Bugar
Rule 20	If Baring_Duduk is Fast and Jongkok_Lompat is Slow and Running is Normal then Fitness is Fit
Rule 21	If Baring_Duduk is Fast and Jongkok_Lompat is Slow and Running is Fast then Fitness is Fit
Rule 22	If Baring_Duduk is Fast and Jongkok_Lompat is Normal and Running is Slow then Fitness is Fit
Rule 23	If Baring_Duduk is Fast and Jongkok_Lompat is Normal and Running is Normal then Fitness is Fit
Rule 24	If Baring_Duduk is Fast and Jongkok_Lompat is Normal and Running is Fast then Fitness is Fit
Rule 25	If Baring_Duduk is Fast and Jongkok_Lompat is Fast and Running is Slow then Fitness is Fit
Rule 26	If Baring_Duduk is Fast and Jongkok_Lompat is Fast and Running is Normal then Fitness is Fit
Rule 27	If Baring_Duduk is Fast and Jongkok_Lompat is Fast and Running is Fast then Fitness is Fit

The Min implication function used in the Mamdani method is used to combine each degree of membership of each if then rule created and expressed in the form (α). An example of a Min implication function for rule 1, rule 5, rule 10, and rule 15 (Table 7) can be written as follows:

$\alpha1={}_{\mu Slow}(\text{Baring\_Duduk})\cap{}_{\mu Slow}(\text{Jongkok\_Lompat})\cap{}_{\mu Slow}(\text{Run})$
$=\min({}_{\mu Slow}(\text{Baring\_Duduk}),\ {}_{\mu Slow}(\text{Jongkok\_Lompat}),\ {}_{\mu Slow}(\text{Run}))$

$\alpha5={}_{\mu Slow}(\text{Baring\_Duduk})\cap{}_{\mu Normal}(\text{Jongkok\_Lompat})\cap{}_{\mu Normal}(\text{Run})$
$=\min({}_{\mu Slow}(\text{Baring\_Duduk}),\ {}_{\mu Normal}(\text{Jongkok\_Lompat}),\ {}_{\mu Normal}(\text{Run}))$

$\alpha10={}_{\mu Normal}(\text{Baring\_Duduk})\cap{}_{\mu Slow}(\text{Jongkok\_Lompat})\cap{}_{\mu Slow}(\text{Run})$
$=\min({}_{\mu Normal}(\text{Baring\_Duduk}),\ {}_{\mu Slow}(\text{Jongkok\_Lompat}),\ {}_{\mu Slow}(\text{Run}))$

$\alpha15={}_{\mu Normal}(\text{Baring\_Duduk})\cap{}_{\mu Normal}(\text{Jongkok\_Lompat})\cap{}_{\mu Hurry}(\text{Run})$

$=\min(\mu_{Normal}(Baring\_Duduk), \mu_{Normal}(Jongkok\_Lompat), \mu_{Fast}(Run))$

3. Composition Rules

To get the results of the rules that have been made, the Max (Maximum) method used from the three methods in inferencing the fuzzy system to determine the physical fitness of students. The fuzzy set output solution is obtained by taking the maximum value of the corresponding rule, then using it to modify the fuzzy region and applying it to the output.

4. Affirmation (Defuzzy)

In Affirmation (Defuzzy), the method used to determine students' physical fitness is the Centroid (Composite Moment) method. In the centroid method, the crips solution is obtained by taking the center point (z*) of the fuzzy region. In general, it is formulated:

$$z^* = \frac{\int_z z\mu(z)dz}{\int_z \mu(z)dz}$$

with:

z: Output value

z*: The center point of the fuzzy output area

μ(z): Membership function of the fuzzy output set

D: Area of fuzzy output

In the discussion, a trial or calculation was carried out from the existing cases in calculating.

To assess physical fitness using the Mamdani method, data were collected from 50 students (25 male and 25 female) in Class IV.B at SD Negeri 002 Lubuk Baja Batam during the 2016/2017 academic year. For illustrative purposes, two representative cases—one male and one female—were selected for detailed manual calculations. These cases exemplify the method's application while maintaining methodological rigor. The data can be seen in Table 8. The Mamdani method was applied to these cases to demonstrate the computational process, with results generalized to the broader sample. This approach aligns with common practices in fuzzy logic studies, where in-depth analysis of subset data validates system robustness before full-scale implementation.

Table 8. Example of student data

Student Name	Lying Down Sitting	Jumping Squats	Run
Said Hanafi Pratama	115	123	132
Nabilah Chintia	95	99	118

The result of the physical fitness score of male students in the manual calculation is 140.9967, where the value is included in the fitness category, so that the fitness of a student named Said Hanafi Pratama is included in the fitness membership.

Then it is seen from fuzzy reasoning using the MATLAB simulation program that has been provided in the Fuzzy Toolbox in Figure 13.

The first column in Figure 13 shows the membership level of the pulse value 115 in the variable lying down sitting, the second column shows the membership level of the pulse value 123 in the variable squat jump, the third column shows the membership level of the pulse value 132 in the variable running, and the fourth column shows the output value and consequences of the rule implication function that corresponds to the conditions in columns 1, 2, and 3. The implication function used in this process is the MIN function, which takes the minimum area of the input variable as its output, then takes. The last row and the last column show the combined fuzzy areas of each rule, which are the consequences of the composition of the fuzzy rules. As seen in the Figure 13, the thick red vertical line in the fourth column in the fitness variable is the output value of the student's fitness. In this column, the output value produced from the three inputs is 141. This value is included in the membership of the fit fuzzy set, so it can be concluded that the fitness of a student named Said Hanafi Pratama using the MATLAB simulation program is fit.

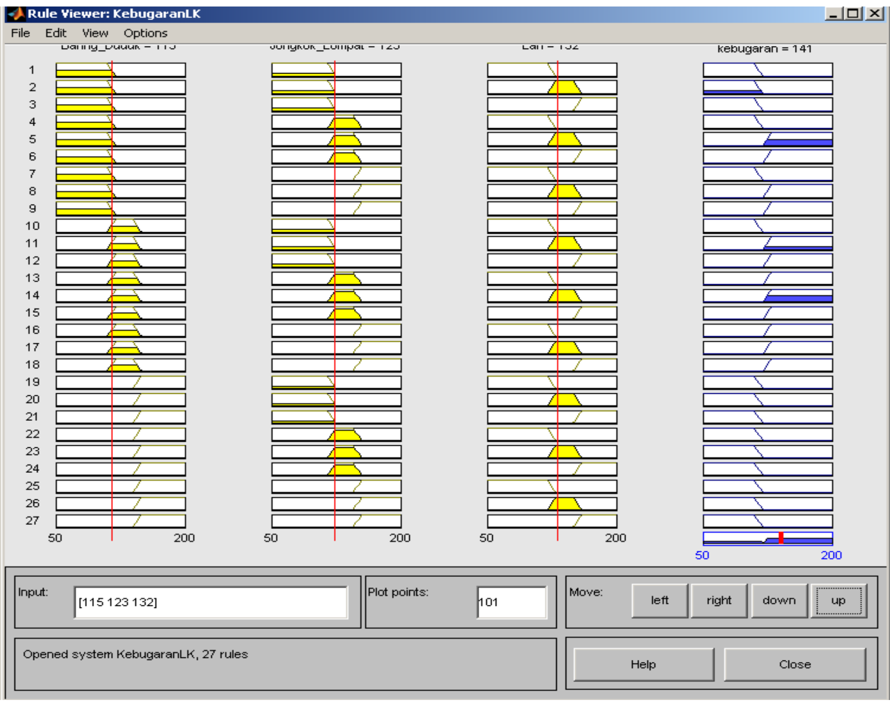

Figure 13. Fuzzy reasoning of the fitness MATLAB simulation program LK

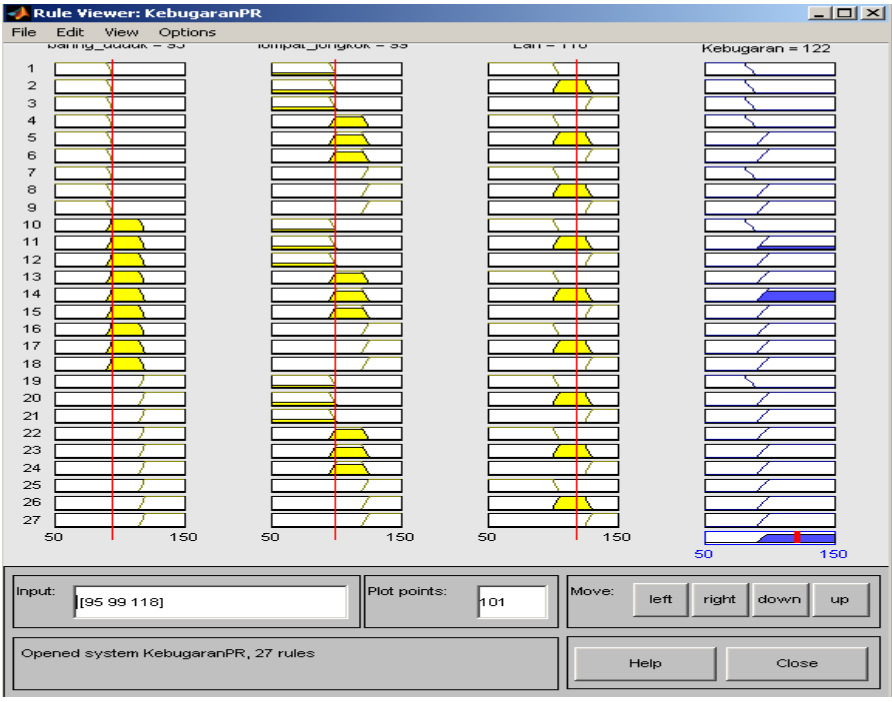

Figure 14. Fuzzy reasoning MATLAB simulation program FitnessPR

The result of the physical fitness score of female students in the manual calculation is 121.7945, where the value is included in the fitness membership, so that the fitness of the student named Nabilah Chintia is included in the fitness membership.

Then it is seen from fuzzy reasoning using the MATLAB simulation program that has been provided in the Fuzzy Toolbox shown in Figure 14.

The first column in the Figure 14 shows the membership level of the pulse rate value of 95 in the seated variable, the second column shows the membership rate of the pulse rate of 99 in the squat jumping variable, the third column shows the membership rate of the pulse rate of 118 in the running variable, and in the fourth column shows the output value and consequences of the rule implication function corresponding to the conditions in columns 1, 2, and 3. The implication function used in this process is the same as that of male students, namely the MIN function. The last row and last column show the sum of the fuzzy regions of each rule, which is a consequence of the composition of the fuzzy rule.

As can be seen in the figure, the thick vertical line in red in the fourth column of the fitness variable is the output value of the student's fitness. In this column, the output value produced from the three inputs is 122. This value is included in the membership of the fuzzy fit association, so it can be concluded that the fitness of a student named Nabilah Chintia using the MATLAB simulation program is fit.

From the two examples of the case, there is a difference between manual calculations and calculations using MATLAB programs. This is due to the rounding of numbers in the calculation, so that it will affect the value obtained manually. Although the resulting fitness output values are different, both fall into the same category both manually and using MATLAB programs.

4. CONCLUSION

Based on the results of the tests that have been carried out in this study, several conclusions are obtained, namely:

1. Based on the implementation and testing using the fuzzy logic of the Mamdani Method on the system that is made can help in making decisions quickly, based on the data that the researcher can get, namely the pulse value of the student sports test, namely Lying Down, Squatting, Jumping, and Running then processed to the fuzzy logic of the Mamdani Method by doing four stages to produce output, namely: Degree of Membership, Function of Implication, Composition of Rules, and Affirmation (Defuzzy).

2. How to determine students' physical fitness using fuzzy logic Mamdani's method in MATLAB software, there are two examples of cases taken by researchers in the previous chapter to determine the level of physical fitness of elementary school students through the stages of processing membership degrees and applying reasonable rules so as to produce output in the form of firm grades and decisions, for the example of male students the output results obtained are 141 for calculation using software MATLAB and 140.9967 for manual calculation, with the student's fitness decision being fit, while in the case of female students, the output obtained was 122 for the calculation using MATLAB software and 121.7945 for manual calculation, with the student's fitness decision being fit.

To strengthen the method's validity and scalability, we propose:

Expanded Trials: Replicating the study with a larger sample (e.g., 200+ students across multiple schools) to validate statistical significance.

IoT-Enhanced Monitoring: Integrating wearable IoT sensors (e.g., Polar H10 chest straps) for real-time, continuous pulse rate tracking during exercises, reducing manual measurement errors.

Multivariate Analysis: Incorporating additional fitness indicators (e.g., BMI, muscle endurance) into the fuzzy logic system to improve decision accuracy.

Longitudinal Studies: Tracking students' fitness trends over multiple years to assess the model's predictive capabilities.

While the Mamdani method shows promise for fitness assessment, these advancements are critical to confirm its effectiveness at scale.

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