Fuzzy Mamdani for the primary balloon shooter game

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ABSTRACT

Mathematics is a subject that is considered difficult for most elementary school students because it is a science of arithmetic that studies numbers and spaces in the abstract. One of them is the set of prime numbers. So, in this study, an educational game about balloon shooting prime numbers was made. In game design, the Mamdani fuzzy algorithm is applied to calculate the appearance of the balloons based on the balloon_remaining and time_remaining input variables. The application of the Mamdani fuzzy algorithm is considered successful, as evidenced by the high percentage rate of occurrence of all balloons, reaching 80%.

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1. INTRODUCTION

Mathematics is the science of arithmetic that studies numbers and spaces that are abstract. Therefore, mathematics is seen as a difficult subject[1]. Prime numbers are one of the mathematics teaching materials that are considered difficult among elementary school students[2]. Therefore, more interesting media to support the learning process so that it is easily accessible is needed. Playing is an entertaining activity that is loved by various groups, from children to adults. Traditional games that are usually played in real life can now be played in digital form. Digital games can be easily accessed on the device so that it can be played anytime and anywhere [3]. Games become more appealing to players if they can depict real-world events, which necessitates the use of artificial intelligence (AI) in their development. The application of an artificial intelligence system improves the player's behavioral and emotional abilities [4].

In this study, the game design based on mathematics taught to elementary school students is a prime balloon shooter. This game utilizes artificial intelligence. The concept is shooting the balloons with prime numbers. Balloon shooter games are very diverse, such as arithmetic balloon shooter games with colour combinations [5] or balloon shooter games designed as digital art [6]. However, among various types of balloon shooters, it is still rare to use artificial intelligence, especially fuzzy logic. In terms of decision-making, fuzzy logic is often used with calculations that model human reasoning through if-then rules to relate input and output variables [7].

The fuzzy method used in this game is fuzzy Mamdani. The min-max method on fuzzy Mamdani influences the assessment of the difficulty level according to the level in the balloon shooter game. The use of the Mamdani fuzzy method is divided into several stages, namely the formation of fuzzy sets, inference, rules components, and defuzzification. The implementation of fuzzy Mamdani has been widely used, for example in the recommendation for tourist attractions in Madura[8] . Based on this first research review, fuzzy Mamdani was applied to analyze the criteria for visitors, distance from the city center, and a review of objects that have been determined to provide tourist recommendations to tourists visiting Madura. Then another example of implementing fuzzy Mamdani is determining the amount of durian pancake production [9]. Mamdani fuzzy can also be applied to determine the feasibility of pancake products based on supply and demand data.

In this study, fuzzy Mamdani was applied in a balloon shooter with prime numbers to pop balloons at each level. The number of balloons that sum will be determined by time. The application of fuzzy Mamdani to these aspects can determine the level of difficulty in the balloon shooter game.

2. METHOD

2.1 Fuzzy logic

The basic concept of fuzzy logic is the value of reasoning or uncertainty [10]. This condition indicates that the numerical variables are shown in the form of linguistic expressions for modeling. Values in the form of linguistic expressions can produce many possibilities [11].

2.2 Mamdani inference system

- Fuzzification

Fuzzification is a process that changes the crisp value, which is a value that has membership degrees of only 0 and 1, into the form of a fuzzy set with a membership degree value that lies in the range of values from 0 to 1. In boolean logic, the result is always 0 or 1 (true or false), while in fuzzy logic, the result is somewhere between 0 and 1 [12]. The fuzzy set is a linguistic value that is then processed based on the membership function limits[13]. The shape of the curve follows the membership function for each set (trapezoid, triangle, Gaussian, etc.). As for the membership function, in fact, it represents the degree of a predetermined value [14].

- Inference

The inference is a fuzzy input processing process in the form of crisp values that are calculated based on predetermined rules in the form of "IF-THEN". After the rules have been determined, then evaluate the rules[15]. In this Mamdani method, the MIN implication function is used for each rule. After the results of the MIN implication are obtained, the composition of the new rules is carried out using the MAX function to produce a new fuzzy set output [9].

- Defuzzification

Defuzzification is the process of combining the outputs of the previous processes (fuzzification and inference) to produce a fuzzy output, which is transformed back into firm numbers [16]. In this study, defuzzification was carried out using the centroid method to calculate the crisp value with the centre point (y*) of the fuzzy region [10]. The formula for the centroid method is shown in (1).

$$y* = \frac{\sum y\mu(y)}{\sum \mu(y)} \quad (1)$$

where y∗ is the result of the defuzzification of the centroid method, y is the set of numerical values of the output variable in its domain, and μ is the level of membership of y to the combined output membership function.

2.3 Recent studies on the fuzzy method

Comparison with several other studies is the implementation of fuzzy Mamdani for the recommendation of tourist sites in Madura-Indonesia [8]. This research shows that the application of fuzzy Mamdani is very appropriate for the decision-making system. It selects tourist objects by applying three parameters, namely visitor criteria, distance, and tourist attraction reviews. The results will show recommendations for tourist attractions based on tourist attractions that have a large number of visitors[9].

Another research conducted by Apriani and Perwira is the implementation of the fuzzy inference system in determining the amount of production based on supply data. The output value generated in the simulation shows results that are in accordance with manual calculations. In a study conducted by Mohammed and Hussain, namely the application of fuzzy Mamdani to identify and recognize moving objects with an accuracy rate of 98% [17]. In this study, there were 27,307 animal images for identification and classification. Research conducted by Ningrum et al. [16] in loading the SCADA system of distribution transformers at substations using the Mamdani fuzzy inference system.

In research conducted by Sukandy et al. [11], the aim is to create an application that applies the Fuzzy Mamdani method to predict the amount of palm oil production. It is based on supply and demand data. In this study, the parameters of normal current, voltage, and traffic are used. The results were obtained in the form of a transformer load based on the simulation carried out.

In a study conducted by Mohamad Irfan et al., fuzzy Mamdani was implemented in the analysis of student status [18]. The result of the accuracy test was carried out five times with 100% accurate results. From these results, it can be used as a decision maker to analyze which students should be given a warning or drop out.

3. RESEARCH METHOD

Intelligent system flow is used to determine the appearance of the balloons in the balloon shooter game. The flow of the intelligent system can be seen in Figure 1.

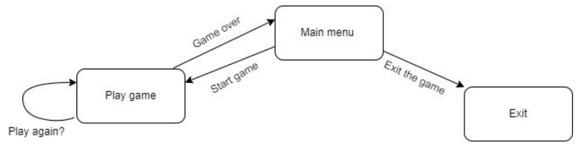

Figure 1 State diagram game balloon shooter

The game state diagram starts with the player running the game. On the main menu page, there is a play game and an exit menu. When players select the play game menu, the difficulty page is displayed. Players can decide to choose easy, medium or hard. After the player selects the level of difficulty, the game takes place in the play room view. The user will move to the next level display when the specified time has expired. Then, when the level has been reached, the player will be directed to the end view and return to the main menu page. The exit menu will direct the user out of the game.

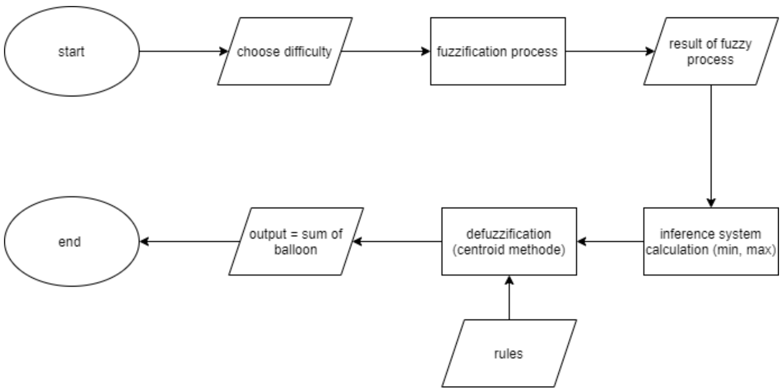

Figure 2 Flow system Mamdani fuzzy algorithm

Based on Figure 2 shows a flow chart of the Mamdani fuzzy algorithm process in the game system. The explanation of the flow chart is the results of the fuzzification process are then processed together with the rules that have been made for the Mamdani system inference process (MIN-MAX method). The implication of min is to determine the minimum value of the input value with rules. The result of the min implication is then processed in the max implication process by taking the largest value. The results of the MAX method process are then processed in defuzzification with the centroid method. Finally, the output is the number of a balloons. The process of managing the results of fuzzy calculations is as follows.

- Determine which variable to use.
  In this study, we used a set of fuzzy variables as follows:
  Inputs:
  • remaining time {short, medium, long},
  • remaining balloon {little, medium, lot of}.
  Output: appearance {little, medium, many}.

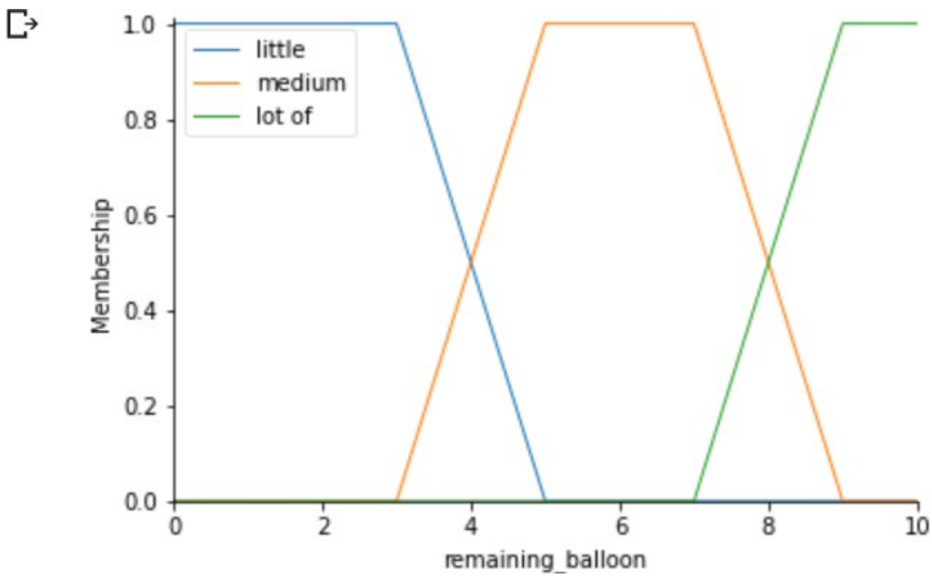

Figure 3 remaining balloon membership function

- The fuzzification of the remaining balloons is made into 3 fuzzy sets, namely little, medium, and a lot of. Representation of the residual fuzzy set of balloons using the trapezoid function as shown in Figure 3. Based on the graph in Figure 3 remaining balloon has the membership functions:

Little : remaining_balloon data ≤ 3 **Not little** : remaining_balloon data ≥ 5
Medium : remaining_balloon data ≤ 5 and remaining_balloon data ≥ 7 **Medium** : remaining_balloon data ≤ 3 and remaining_balloon data ≥ 9
Lot of : remaining_balloon data ≥ 9 **Not lot of** : remaining_balloon data ≤ 7

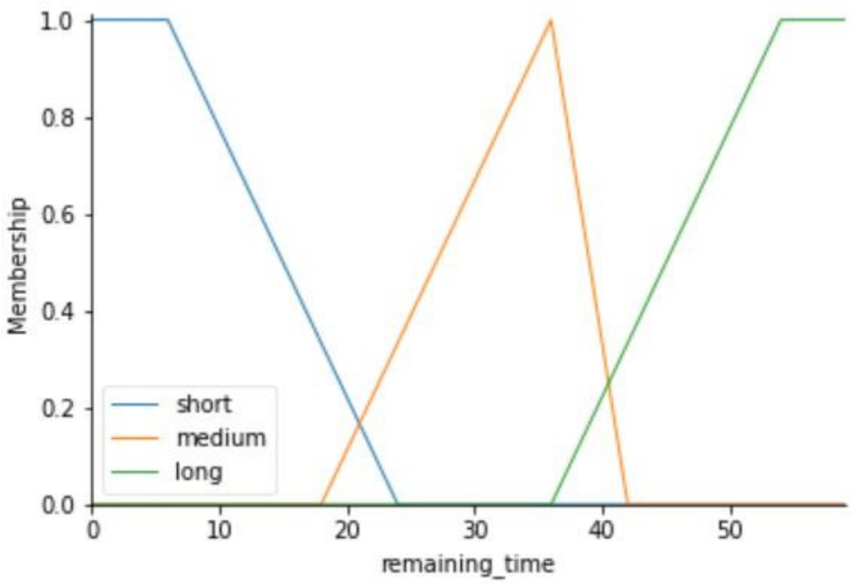

Figure 4 remaining time membership function

- The fuzzification of the remaining time is made into 3 fuzzy sets, namely short, medium, and long. Representation of the residual fuzzy set of time using the trapezoid and triangle function as shown in Figure 4. Based on the graph in Figure 4 remaining time has the membership functions:

Short : remaining_time data ≤ 6 **Not short** : remaining_time data ≥ 24

Medium : remaining_time data = 36
Not medium: remaining_time data ≤ 24 and remaining_time data ≥ 42
Long : remaining_time data ≥ 54
Not long : remaining_time data ≤ 36

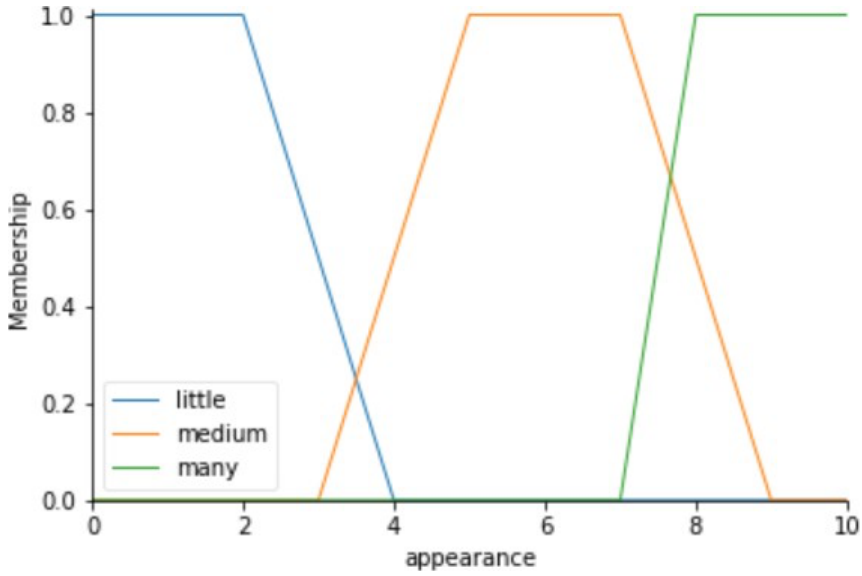

Figure 5 Appearance membership function

- The fuzzification of the remaining time is made into 3 fuzzy sets, namely little, medium, and many. Representation fuzzy set of appearance using the trapezoid function as shown in Figure 5. Based on the graph in Figure 5 remaining time has the membership functions:

Little : appearance data ≤ 2
Not little : appearance data ≥ 4
Medium : appearance data = 5
Not Medium: appearance data ≤ 3 and appearance data ≥ 8
Many : appearance data ≥ 8
Not many : appearance data ≤ 7

Based on the linguistic values above, the following is the value of the membership function:

- Remaining Balloons

$$\mu little[\text{remaining\_balloon data}] = \{ x \leq 5 ; 0 \quad 3 < x < 5 ; \frac{x-3}{5-3} \quad x \geq 3 ; 1 \} \tag{1}$$

Equation (1) represents a linear descent on the membership function of the little balloon, which is a straight line starting from the domain value 3 with the highest degree of membership on the left side of 1, then moving down to the domain value 5, which has a lower membership degree of 0.

$$\mu medium[\text{remaining\_balloon data}] = \{ x \leq 3 \; or \; x \geq 9 ; 0 \quad 3 < x < 5 ; \frac{x-3}{5-3} \quad 7 < x < 9 ; \frac{9-x}{9-7} \quad x = 5 ; 1 \} \tag{2}$$

Equation (2) represents a linear increase in the membership function of the remaining medium balloon, namely the increase in the set starting from the value of domain 3, which has a membership value of zero, moving to the right towards the value of domain 5, which has a higher degree of membership, namely 1. Then there is a descending linear representation, which is a straight line starting from the value of domain 7 with the highest degree of membership on the left side of 1, then moving down to the value of domain 9, which has a lower degree of membership of 0.

$$\mu lots\ of[\text{remaining\_balloon data}] = \begin{cases} x \le 7\ ;0 \\ 7 < x < 9\ ;\ \frac{x-7}{9-7} \\ x \ge 7\ ;1 \end{cases} \quad (3)$$

Equation (3) represents a linear increase, i.e., the increase in the set starts from the value of domain 7, which has a membership value of zero [0] and moves to the right towards the value of domain 9, which has a higher degree of membership, namely 1.

- Remaining Time

$$\mu short[\text{remaining\_time data}] = \begin{cases} x \le 24\ ;0 \\ 6 < x < 24\ ;\ \frac{x-6}{24-6} \\ x \ge 6\ ;1 \end{cases} \quad (4)$$

Equation (4) represents a linear descent on the membership function of the short time, which is a straight line starting from the domain value 6 with the highest degree of membership on the left side of 1, then moving down to the domain value 24, which has a lower membership degree of 0.

$$\mu medium[\text{remaining\_time data}] = \begin{cases} x \le 24\ or\ x \ge 42\ ;0 \\ 24 < x < 36\ ;\ \frac{x-24}{36-24} \\ 24 < x < 42\ ;\ \frac{42-x}{42-24} \\ x = 36\ ;1 \end{cases} \quad (5)$$

Equation (5) represents a triangular curve on the membership function of the medium time, which is a combination of an ascending linear representation and a descending linear representation.

$$\mu long[\text{remaining\_time data}] = \begin{cases} x \le 30\ ;0 \\ 30 < x < 36\ ;\ \frac{x-30}{36-30} \\ x \ge 36\ ;1 \end{cases} \quad (6)$$

Equation (6) represents a linear increase, i.e., the increase in the set starts from the value of domain 36, which has a membership value of zero [0] and moves to the right towards the value of domain 54, which has a higher degree of membership, namely 1.

- Appearance

$$\mu little[\text{appearance data}] = \begin{cases} x \le 4\ ;0 \\ 2 < x < 4\ ;\ \frac{x-2}{4-2} \\ x \ge 2\ ;1 \end{cases} \quad (7)$$

Equation (1) represents a linear descent on the membership function of the little balloon, which is a straight line starting from the domain value 2 with the highest degree of membership on the left side of 1, then moving down to the domain value 4, which has a lower membership degree of 0.

$$\mu medium[\text{appearance data}] = \begin{cases} x \le 3\ or\ x \ge 8\ ;0 \\ 3 < x < 5\ ;\ \frac{x-3}{5-3} \\ 5 < x < 8\ ;\ \frac{8-x}{8-5} \\ x = 5\ ;1 \end{cases} \quad (8)$$

Equation (8) represents a linear increase in the membership function of the remaining medium appearance, namely the increase in the set starting from the value of domain 3, which has a membership value of zero, moving to the right towards the value of domain 5, which has a higher degree of membership, namely 1. Then there is a descending linear representation, which is a straight line starting from the value of domain 7 with the highest degree of membership on the left side of 1, then moving down to the value of domain 9, which has a lower degree of membership of 0.

$$\mu many[\text{appearance data}] = \begin{cases} x \leq 7\ ;0 \\ 7 < x < 8\ ; \frac{x-7}{8-7} \\ x \geq 8\ ; 1 \end{cases} \quad (9)$$

Equation (9) represents a linear increase, i.e., the increase in the set starts from the value of domain 7, which has a membership value of zero [0] and moves to the right towards the value of domain 8, which has a higher degree of membership, namely 1.

- Rules

Table 1 Relation between the inputs and appearance

No.	Remaining balloons	Remaining time	Appearance
1.	Little	Short	Little
2.	Medium	Short	Medium
3.	Little	Short	Many
4.	Medium	Medium	Little
5.	Lots of	Medium	Medium
6.	Little	Medium	Many
7.	Medium	Long	Little
8.	Lots of	Long	Medium
9.	Little	Long	Many

Fuzzy logic works based on rules in mapping the input and output, which are carried out in the form of conditions and actions. Based on Table 1. It can be seen that there are two input variables, namely the remaining balloon and the remaining time, and then the appearance is as an output. The form of conditions and actions can also be called IF-THEN rules, with the format of If antecedent, then consequent. The antecedent in question is the input from the fuzzy system, while the consequent is associated with the output. The following is the form of the condition with the IF-THEN rule :

1. IF remaining_balloon = little AND remaining_time = little THEN appearance = little
2. IF remaining_balloon = medium AND remaining_time = little THEN appearance = medium
3. IF remaining_balloon = lots of AND remaining_time = little THEN appearance = many
4. IF remaining_balloon = little AND remaining_time = medium THEN appearance = little
5. IF remaining_balloon = medium AND remaining_time = medium THEN appearance = medium
6. IF remaining_balloon = lots of AND remaining_time = medium THEN appearance = many
7. IF remaining_balloon = little AND remaining_time = long THEN appearance = little
8. IF remaining_balloon = medium AND remaining_time = long THEN appearance = medium
9. IF remaining_balloon = lots of AND remaining_time = long THEN appearance = many

Can be seen on Figure 6, that In the system of playing this game, NPCs are divided into 2 types, namely: distracting balloons and prime numbered balloons. In this game, you have a goal to complete each level. The goal that must be achieved is that the user must shoot a balloon with prime numbers until the specified time, which is 60 seconds, runs out. The number of each level within the difficulty level varies. The game is considered finished when the time has expired.

Mamdani's fuzzy calculation in this game is located when the user starts shooting, as shown in Figure 6. The player starts firing bullets at the prime numbered balloons. Each shot of a prime numbered balloon determines the appearance of the next balloon. The balloon popping is governed by the remaining balloon count which is indicated by the remaining balloon status at the top right. Each appearance of a balloon is affected by the remaining time and unshot balloons on the layer.

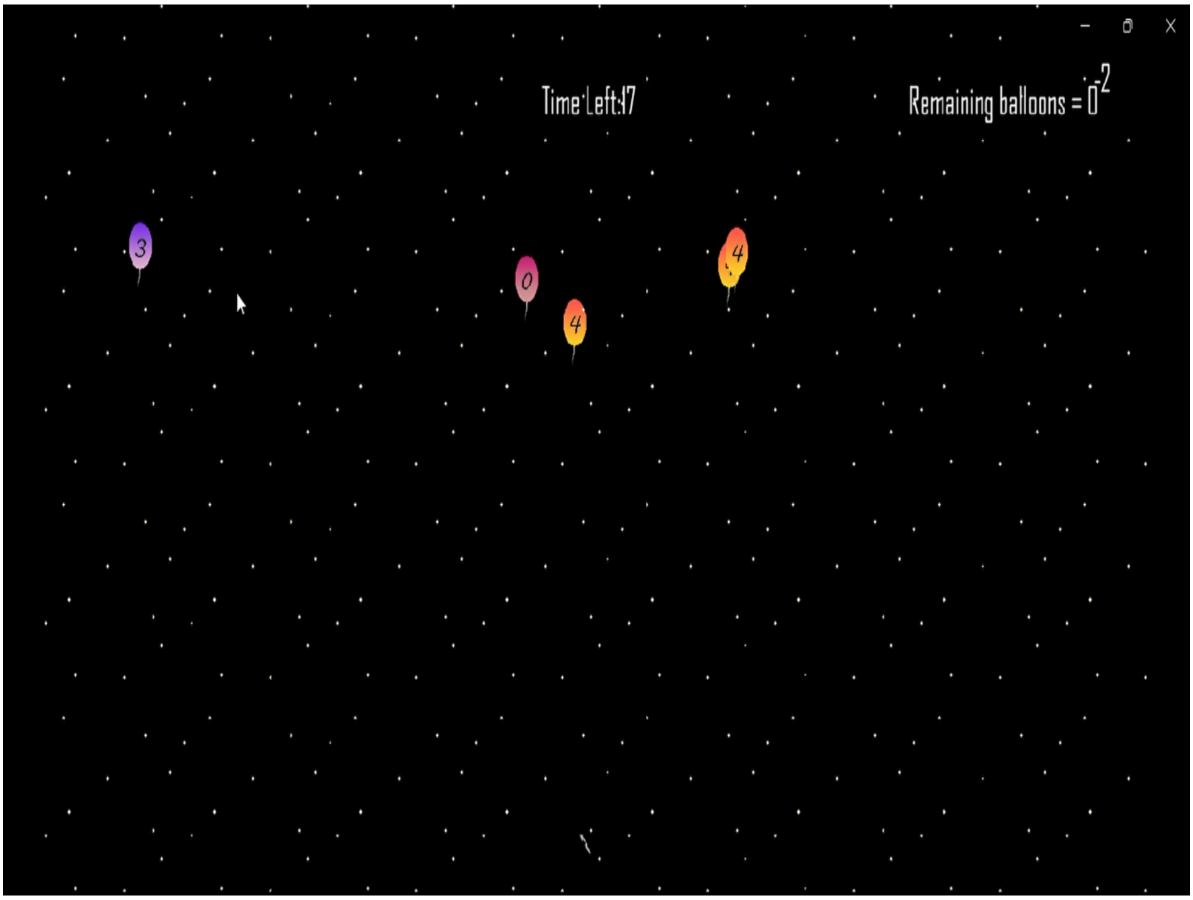

Figure 6 Shoting Game User Interface

4. RESULTS AND DISCUSSIONS

4.1 Manual calculating

The following is performed on 1 data sample, example calculation of the fuzzy Mamdani input on the remaining 4 pieces of balloons and the remaining time is 40 seconds. Fuzzy calculations to determine the number of occurrences of these cases are as follows

- Fuzzification

  Remaining balloon = little:

  $$\mu(x = 4) = \frac{4 - 3}{5 - 3} = 0.5$$

  Remaining balloon = medium:

  $$\mu(x = 4) = \frac{4 - 3}{5 - 3} = 0.5$$

  Remaining time = lots of:

  $$\mu(x = 44) = \frac{44 - 30}{36 - 30} = 2.3$$

- Inference

  There are rules that match the fuzzification results, remaining_balloon = little (0.5), remaining_balloon = medium (0.5) and remaining_time = long (2.3) there is:

  – Rule 7: if remaining_balloon little and remaining_time long then appearance little

- Rule 8: if remaining_balloon medium and remaining_time long then appearance medium

Implications min =
- µappearance little = µ remaining_balloon a little ∩ µ remaining_time long
  µappearance little = min (0.5; 2.3) = 0.5
- µappearance medium = µ remaining_balloon medium ∩ µ remaining_time long
  µappearance medium = min (0.5; 2.3) = 0.5

max value =
- µappearance = µappearance little V µappearance medium
  µappearance = max (0.5; 0.5) = 0.5

- Defuzzification
  defuzzification is solved by the centroid method.

$$\frac{(2+3+4+5+6)0.5}{(0.5+0.5 + 0.5+0.5+0.5)} = 4$$

Based on the calculation results above, the defuzzification value is 4. System testing is done by taking a certain number of samples, and the data used is the same as manual testing 10 times. Based on the comparison of system and manual testing, the performance accuracy value of the Mamdani fuzzy model is 80%.

4.2 Analysis

The following are the results of the defuzzification test that has been carried out using fuzzy mamdani based on system calculations and manual calculations shown in Table 2:

Table 2 Result manual calculating and system

Remaining balloon	Remaining time	Manual Defuzzification	System Defuzzification	Description
5	23	5	4	Success
8	24	6.5	6	Success
9	18	8	2	Unsuccessful
3	29	2.5	1	Success
8	36	7	5	Success
10	19	8	2	Unsuccessful
4	55	4.5	4	Success
8	41	6.5	6	Success
3	13	2.5	1	Success
4	40	4	4	Success

Based on Table 4.1, the results of manual calculations and the system shows the same 8 experimental results, so it can be concluded that the difference between manual and application calculations is 2 experimental results. In the defuzzification calculation, it is processed by taking random values between 1-10 according to the specified parameters. The description "appropriate" is used for manual defuzzification values, and the system is still in one output parameter and the membership function used is the same. Meanwhile, "not appropriate" information is given when the manual and system defuzzification results have different output parameter values and the membership function used is different. The difference in value between the manual count and the system occurs because of two things; namely, there is a rounding off of the defuzzification value in the system and random value taking in the defuzzification calculation both manually and by the system.

5. CONCLUSION

This research has demonstrated the design and development of a prime number math learning game called the prime number balloon shooter. This game is designed by using the fuzzy mamdani algorithm. Fuzzy mamdani is suitable to be used in making decisions on the appearance of the number of balloons. The inputs are the number of remaining balloons and remaining time. The result shows that the appearance probability of balloons is 80% based on a comparison between system calculations and manual calculations.

6. ACKNOWLEDGEMENTS

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