Optimizing the traffic control system of Sultan Agung street Yogyakarta using fuzzy logic controller

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Abstract. The traffic control system is a system that functions to regulate and control traffic flow at crossroads, pedestrian crossings (zebra crossing) and other traffic flows. A good traffic control system is a system that is able to adjust the duration of the traffic lights with the density of traffic flow automatically. In big cities like Yogyakarta, traffic congestion is one of the most common problems. It is caused by the traffic lights that use a conventional regulation system. This study aims to discuss the establishment of a traffic light regulation system on Sultan Agung street and surrounding areas where there are nearby traffic lights and are interrelated with one another. Determining the duration of the green light is calculated using the fuzzy logic controller method with 3 input variables namely the number of cars, the number of motorcycles, and the length of the queue. The results of the traffic light regulation system using fuzzy logic controllers are more effective than conventional system settings. It is because the system is able to adjust the duration of the traffic lights with traffic conditions at that time, so the duration of traffic light is varied for each traffic condition.

1. Introduction

The traffic control system is a system that functions to regulate and control traffic flow at crossroads, pedestrian crossings (zebra crossing) and other traffic flows [1]. Traffic lights are the most important traffic system to manage a heavy traffic flows [2]. A good traffic light regulating system is capable of knowing the traffic conditions at the time [3], which is able to adjust the traffic flow density on the automatically regulated path. If the condition of road density changes, the system will automatically change the input and output functions [4].

A traffic light regulation in Indonesia commonly uses a conventional regulating system, that is a simple regulatory system [5] with a fixed time-based arrangement [6], so that the number of vehicles in the traffic lane does not affect the traffic light performance [7]. In addition, traffic regulation is also carried out manually by the police using intuition based on the current traffic conditions [8]. Some of the ways that the government has done to deal with congestion problems include making ring road, making new roads and flyovers in the middle of the city, limiting large vehicles passing through urban areas during peak hours, and developing modern system control and traffic monitors [9].

In big cities like Yogyakarta, traffic congestion is one of the most common problems. The high level of traffic congestion is caused by the increasing number of vehicles on the road and less effective performance of traffic control systems. The most common traffic jam happens at the intersection [10]. This is because the traffic light settings are less optimal, resulting in a buildup of vehicles at the intersection. One of the areas in Yogyakarta where traffic jams often occur is Sultan Agung.
Sultan Agung Street is one of the bustling lanes in Yogyakarta because it is located in the center of Yogyakarta and is the main route to get to tourist attractions and campuses in Yogyakarta. Along Sultan Agung street there are several traffic lights that are located close together and connected to one another. The system of setting a traffic light on Sultan Agung street affects other traffic lights. If the traffic light regulation system used is not optimal, it will have an impact on all traffic flows along Sultan Agung street, so there is an urgent need for an optimal traffic light regulation system.

Along with the development of artificial intelligence technology, the traffic light regulation system can be regulated according to human thinking. Fuzzy logic is an artificial intelligence that is able to mimic human intelligence in logic to regulate traffic lights [11]. Fuzzy Logic was first introduced by Prof. Lotfi A. Zadeh in 1965. The basis of fuzzy logic is the fuzzy set theory. In fuzzy set theory, the role of membership degree as a determinant of the existence of elements in a set is very important. Membership value or membership level or membership function is the main characteristic of reasoning with fuzzy logic [12]. Research related to the application of fuzzy logic controllers in the construction of traffic light control systems has been developed with various kinds of input variables. Mehan has developed research with input variables of the amount of traffic on the arrival path and the amount of traffic on the regulated path [13]. In addition, Wahyu used car density and road width as input variables [4], while Yudanto used input variables for the number of cars and the number of motorcycles [14], and Nugroho used the input variable of the number of cars at an intersection [6]. All of these studies used an output variable that is the length of the green light on each intersection. The results of the studies show that setting traffic lights with fuzzy logic controllers provides better traffic light performance results than conventional settings.

2. Research Method
This study discusses the establishment of a traffic light regulation system on Sultan Agung street and surrounding areas where the traffic lights are connected to each other using fuzzy logic controller. The research procedures are as follows:

1. Determine the system input and output, and the universe of each variable. In this study three input variables were used, namely the number of cars, number of motorcycles and queue length (m), while the output variable was the duration of the green light on (seconds). Based on observations on the path of Sultan Agung street, data of number of cars, motorcycles, the queue length and the duration of the green light were obtained. The universal set of the variable number of cars and number of motorcycles are [0, 20] and [0, 100], the queue length variable universe is [0, 100], while the universe of the duration of the green light is [5 150]

2. Determine the number of fuzzy sets in each input and output and membership functions. Each input variable will be defined as 3 fuzzy sets, while output variables are 5 fuzzy sets with trapezoid and triangle membership functions

3. Establish rules or fuzzy rules and determine the composition of the system rules (system inference). The system inference used is Max Min.

4. The defuzzification process using the centroid method.

5. The decision of the duration of the green light is the result of defuzzification. After the green light is on, there is a clear time for 5 seconds before the red light is on. The clear time is the time interval given to wait for a clean intersection of the vehicle.

3. Results and Discussion

3.1. Traffic light layout. Sultan Agung Street is one of the lines located in the center of Yogyakarta city with a traffic light layout as shown in Figure 1.
Based on Figure 1, some street parts connected where:
1. Line E is a one-way path
2. Vehicles passing through C are vehicles from lines A, B and E.
3. Vehicles passing F are vehicles from the G and D lines.
4. The green light on F lights up 5 seconds after the green light on G lights up
5. The green light on C lights up 5 seconds after the green light on A lights up
6. The green light on B lights up together with the green light on D
7. The green light on C lights up together with the green light on E
8. The green light lights up from A - C - G - F - B and D - E
9. On each path a sensor is placed to find out the traffic conditions of each lane.

3.2. Fuzzy logic control system. Sensors installed on each path will record the data input variables that have been determined, namely the number of cars, number of motorcycles and queue length (m). Each input variable is defined as 3 fuzzy sets with trapezoid membership function, while the output variables are defined as 5 fuzzy sets with triangle membership functions. In variable number of cars there are three membership functions defined as follow:

\[
\mu_{\text{small}}(x) = \begin{cases} 
0 & \text{if } x \geq 8 \\
\frac{8-x}{4} & \text{if } 4 \leq x \leq 8 \\
1 & \text{if } x \leq 4 
\end{cases} 
\] (1)

\[
\mu_{\text{medium}}(x) = \begin{cases} 
0 & \text{if } x \leq 4 \text{ and } x \geq 16 \\
\frac{x-4}{4} & \text{if } 4 \leq x \leq 8 \\
\frac{16-x}{4} & \text{if } 12 \leq x \leq 16 \\
1 & \text{if } 8 \leq x \leq 12 
\end{cases} 
\] (2)

\[
\mu_{\text{large}}(x) = \begin{cases} 
0 & \text{if } x \leq 12 \\
\frac{x-12}{4} & \text{if } 12 \leq x \leq 16 \\
1 & \text{if } x \geq 16 
\end{cases} 
\] (3)

In variable number of motorcycles there are three membership functions defined as follow:

\[
\mu_{\text{small}}(x) = \begin{cases} 
0 & \text{if } x \geq 38 \\
\frac{38-x}{18} & \text{if } 20 \leq x \leq 38 \\
1 & \text{if } x \leq 20 
\end{cases} 
\] (4)
\[ \mu_{\text{medium}}(x) = \begin{cases} 
0 & \text{if } x \leq 20 \text{ and } x \geq 80 \\
\frac{x-20}{40} & \text{if } 20 \leq x \leq 38 \\
\frac{80-x}{10} & \text{if } 63 \leq x \leq 80 \\
1 & \text{if } 38 \leq x \leq 63 
\end{cases} \] (5)

\[ \mu_{\text{large}}(x) = \begin{cases} 
0 & \text{if } x \leq 63 \\
\frac{x-63}{17} & \text{if } 63 \leq x \leq 80 \\
1 & \text{if } x \geq 80 
\end{cases} \] (6)

In variable queue length there are three membership functions defined as follow:

\[ \mu_{\text{short}}(x) = \begin{cases} 
0 & \text{if } x \geq 50 \\
\frac{50-x}{20} & \text{if } 30 \leq x \leq 50 \\
1 & \text{if } x \leq 30 
\end{cases} \] (7)

\[ \mu_{\text{medium}}(x) = \begin{cases} 
0 & \text{if } x \leq 30 \text{ and } x \geq 70 \\
\frac{x-30}{20} & \text{if } 30 \leq x \leq 50 \\
\frac{70-x}{20} & \text{if } 50 \leq x \leq 70 
\end{cases} \] (8)

\[ \mu_{\text{long}}(x) = \begin{cases} 
0 & \text{if } x \leq 50 \\
\frac{x-50}{20} & \text{if } 50 \leq x \leq 70 \\
1 & \text{if } x \geq 70 
\end{cases} \] (9)

In variable duration of the scheduled green light, there are five membership functions as follow:

\[ \mu_{\text{very fast}}(x) = \begin{cases} 
0 & \text{if } x \geq 40 \\
\frac{40-x}{35} & \text{if } 5 \leq x \leq 40 
\end{cases} \] (10)

\[ \mu_{\text{fast}}(x) = \begin{cases} 
0 & \text{if } x \leq 5 \text{ and } x \geq 75 \\
\frac{x-5}{35} & \text{if } 5 \leq x \leq 40 \\
\frac{75-x}{35} & \text{if } 40 \leq x \leq 75 
\end{cases} \] (11)

\[ \mu_{\text{medium}}(x) = \begin{cases} 
0 & \text{if } x \leq 40 \text{ and } x \geq 110 \\
\frac{x-40}{35} & \text{if } 40 \leq x \leq 75 \\
\frac{110-x}{35} & \text{if } 75 \leq x \leq 110 
\end{cases} \] (12)

\[ \mu_{\text{long}}(x) = \begin{cases} 
0 & \text{if } x \leq 75 \\
\frac{x-75}{35} & \text{if } 75 \leq x \leq 110 \\
\frac{150-x}{40} & \text{if } 110 \leq x \leq 150 
\end{cases} \] (13)

\[ \mu_{\text{very long}}(x) = \begin{cases} 
0 & \text{if } x \leq 110 \\
\frac{x-110}{40} & \text{if } 110 \leq x \leq 150 
\end{cases} \] (14)

Based on the number of fuzzy sets and membership function in the input and output, 27 fuzzy rules were formed as follows:

1. If the number of cars is ‘small’, the number of motorcycles is ‘small’ and the queue is ‘short’ then the duration of the green is ‘very fast’.
2. If the number of cars is ‘small’, the number of motorcycles is ‘small’ and the queue is ‘medium’ then the duration of the green is ‘very fast’.
3. If the number of cars is ‘small’, the number of motorcycles is ‘small’ and the queue is ‘long’ then the green duration is ‘fast’

4. If the number of cars is ‘small’, the number of motorcycles is ‘medium’ and the queue is ‘short’ then the green duration is ‘fast’

5. If the number of cars is ‘small’, the number of motorcycles is ‘medium’ and the queue is ‘medium’ then the green duration is ‘fast’

6. If the number of cars is ‘small’, the number of motorcycles is ‘medium’ and the queue is ‘long’ then the duration of the car is ‘fast’

7. If the number of cars is ‘small’, the number of motorcycles is ‘large’ and the queue is ‘short’ then the green duration is ‘fast’

8. If the number of cars is ‘small’, the number of motorcycles is ‘large’ and the queue is ‘medium’ then the green duration is ‘medium’

9. If the number of cars is ‘small’, the number of motorcycles is ‘large’ and the queues are ‘long’ then the duration of the green is ‘medium’

10. If the number of cars is ‘medium’, the number of motorcycles is ‘small’ and the queue is ‘short’ then the duration of the car is ‘fast’

11. If the number of cars is ‘medium’, the number of motorcycles is ‘small’ and the queue is ‘medium’ then the green duration is ‘fast’

12. If the number of cars is ‘medium’, the number of motorcycles is ‘small’ and the queue is ‘long’ then the duration of the green is ‘medium’

13. If the number of cars is ‘medium’, the number of motorcycles is ‘medium’ and the queue is ‘short’ then the duration of the green is ‘medium’

14. If the number of cars is ‘medium’, the number of motorcycles is ‘medium’ and the queue is ‘long’ then the duration of the green is ‘medium’

15. If the number of cars is ‘medium’, the number of motorcycles is ‘medium’ and the queue is ‘long’ then the duration of the green is ‘long’

16. If the number of cars is ‘medium’, the number of motorcycles is ‘large’ and the queue is ‘short’ then the duration of the green is ‘long’

17. If the number of cars is ‘medium’, the number of motorcycles is ‘large’ and the queue is ‘medium’ then the duration of the green is ‘long’

18. If the number of cars is ‘medium’, the number of motorcycles is ‘large’ and the queue is ‘long’ then the duration of the green is ‘very long’

19. If the number of cars is ‘large’, the number of motorcycles is ‘small’ and the queue is ‘short’ then the duration of the green is ‘long’

20. If the number of cars is ‘large’, the number of motorcycles is ‘small’ and the queue is ‘medium’ then the duration of the green is ‘long’

21. If the number of cars is ‘large’, the number of motorcycles is ‘small’ and the queue is ‘long’ then the duration of the green is ‘long’

22. If the number of cars is ‘large’, the number of motorcycles is ‘medium’ and the queue is ‘short’ then the duration of the green is ‘long’

23. If the number of cars is ‘large’, the number of motorcycles is ‘medium’ and queues is ‘medium’ then the duration of the green is ‘long’
24. If the number of cars is ‘large’, the number of motorcycles is ‘medium’ and the queues is ‘long’ then the duration of the green is ‘very long’

25. If the number of cars is ‘large’, the number of motorcycles is ‘large’ and the queue is ‘short’ then the duration of the green is ‘very long’

26. If the number of cars is ‘large’, the number of motorcycles is ‘large’ and the queue is ‘medium’ then the duration of the green is ‘very long’

27. If the number of cars is ‘large’, the number of motorcycles is ‘large’ and the queue is ‘long’ then the duration of the green is ‘very long’

The calculation was performed with Mamdani fuzzy inference system, Min Implication, Aggregation Max and Centroid Defuzzication we are simulated with fuzzy logic controller systems with some data, then simulation results were compared to conventional setting systems. The results of the simulation comparison with conventional settings are presented as follows:

Table 1. Comparison of simulation of fuzzy logic controller systems and conventional systems

| Path | Number of cars | Number of Motorcycles | Queue Length (m) | Conventional System | Fuzzy System |
|------|----------------|-----------------------|------------------|---------------------|--------------|
| A    | 8              | 45                    | 50               | 31 second           | 60 second    |
|      | 13             | 44                    | 60               | 31 second           | 76 second    |
|      | 5              | 58                    | 65               | 31 second           | 50 second    |
|      | 2              | 55                    | 55               | 31 second           | 30 second    |
|      | 15             | 34                    | 40               | 31 second           | 69 second    |
|      | 10             | 40                    | 70               | 21 second           | 90 second    |
|      | 12             | 30                    | 80               | 21 second           | 97 second    |
| B    | 15             | 23                    | 85               | 21 second           | 76 second    |
|      | 11             | 20                    | 60               | 21 second           | 45 second    |
|      | 7              | 35                    | 45               | 21 second           | 51 second    |
|      | 8              | 6                     | 15               | 62 second           | 30 second    |
|      | 9              | 13                    | 30               | 62 second           | 30 second    |
| C    | 10             | 13                    | 25               | 62 second           | 30 second    |
|      | 6              | 8                     | 15               | 62 second           | 26 second    |
|      | 3              | 12                    | 10               | 62 second           | 10 second    |
|      | 7              | 55                    | 45               | 21 second           | 51 second    |
|      | 12             | 67                    | 60               | 21 second           | 76 second    |
| D    | 8              | 22                    | 40               | 21 second           | 36 second    |
|      | 12             | 37                    | 50               | 21 second           | 58 second    |
|      | 15             | 42                    | 80               | 21 second           | 99 second    |
| E    | 13             | 57                    | 75               | 20 second           | 91 second    |
|      | 8              | 48                    | 60               | 20 second           | 75 second    |
|      | 5              | 76                    | 80               | 20 second           | 62 second    |
|      | 10             | 52                    | 80               | 20 second           | 90 second    |
Based on the results of system simulation with 5 different data on each path, the output was in forms of green light’s different duration according to the traffic density. From Table 1, it appears that for each of the same paths the green light duration changes if the level of traffic density alters.

| Path | Data 1 | Data 2 | Data 3 | Data 4 | Data 5 |
|------|--------|--------|--------|--------|--------|
| F    | 5      | 36     | 55     | 20 second | 71 second |
|      | 9      | 27     | 60     | 31 second | 49 second |
| G    | 11     | 44     | 85     | 31 second | 90 second |
|      | 5      | 39     | 55     | 31 second | 50 second |
|      | 7      | 52     | 70     | 31 second | 71 second |
| G    | 12     | 57     | 70     | 26 second | 90 second |
|      | 6      | 78     | 90     | 26 second | 71 second |
| G    | 4      | 58     | 65     | 26 second | 30 second |
|      | 9      | 51     | 75     | 26 second | 90 second |
|      | 13     | 84     | 85     | 26 second | 110 second |

Figure 2. Surface relationship between two input and output variables

Figure 3. Surface relationship of each input and output variables

Figure 2 shows the relationship between two input variables: number of cars and queue length, number of motorcycles and queue length, number of cars and number of motorcycles, with the duration of the green light on. Figure 3 shows the relationship of each input variable in the number of cars, the number of motorcycles, and the length of the queue, with the duration of the green light on. From these two figures, it is known that the input variables and the relationships between these variables greatly affect the duration of the green light on. Along with the increase of the number of vehicles and the length of the queue, the green light lights up longer.

4. Conclusion
Based on the results of data processing, it can be concluded that the system of setting traffic lights by using fuzzy logic controllers is more effective than conventional setting systems. It is due to the fact that the system with fuzzy logic controllers are able to adjust the traffic light duration with traffic conditions
in the mean time automatically, while in conventional systems the traffic light duration is constant for all traffic conditions.

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