A smart traffic light using a microcontroller based on the fuzzy logic

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ABSTRACT

Traffic jam that is resulted from the buildup of vehicles on the road has become an important problem, which leads to an interference with drivers. The impacts it has on cost and time effectiveness may take the form of increased fuel consumption, traffic emissions, and noise. This paper offers a solution by creating a smart traffic light using a fuzzy-logic-based microcontroller for a greater adaptability of the traffic light to the dynamics of the vehicles that are to cross the intersection. The ATMega2560 microcontroller-based smart traffic light is designed to create a breakthrough in the breakdown of congestions at road junctions, thereby optimizing the real-time happenings in the road. Ultrasonic, infrared, and light sensors are used in this smart traffic light, resulting in the smart traffic light's effectiveness in parsing jams. The four sets of sensors that are placed in four sections determine the traffic light timing process. When the length of vehicle queue reaches the sensor, a signal is sent as the microcontroller's digital input. Ultrasonic and infrared sensors can reduce congestions at traffic lights by giving a green light time when one or all of the sensors are active so that the vehicle congestions can be relieved.

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1. INTRODUCTION

In recent years, traffic issues are an essential concern to be examined. The main problem is the frequent traffic congestions in many major cities in the world [1]. The constant-time traffic-control method is not optimal in regulating traffic, and the current densities of vehicles passing during peak hours may result in unavoidable congestions [2]. The increasing volume of vehicles is not comparable to the number of roads available [3]; this results in the buildup of vehicles on certain roads during peak hours, which causes congestions on the roads. This problem interferes with drivers and affects the local economy [2]. The impacts it may have on cost and time effectiveness may take the form of increased fuel consumption, traffic emissions, and noise.

The congestion problem all over the world is caused by the growth of the number of vehicles that exceeds the available capacity [4], requiring a higher level of traffic efficiency in order to reduce the congestion. One way to increase traffic efficiency is to use an intelligent transportation system and real-time signal control system [5]–[7]. Using artificial intelligence, the traffic light system can be adjusted based on the level of vehicle density in the crossing path without ignoring the demand of the other line [8]–[13]. The traffic density can be reduced by controlling the traffic light using a fuzzy-logic-based traffic light controller; this can reduce the stopping time at the traffic light because the controller can adjust to the traffic density [9]. The arrangement of the traffic flow at the intersection is primarily intended for the vehicles in each way to move in turn so as not to interfere with the flow of vehicles in the other way. There are different types of controls that are used for traffic lights. The controls used are based on the consideration of the situations and conditions of the intersection, including the traffic volume and the geometry of the junction [14]–[21].

There are some studies offering solutions to the problem, one of which is by applying a fuzzy-logic-based controller to control the traffic at a four-way intersection. The traffic light is applied to four junction sections with a fixed movement pattern; that is, when the east-west traffic has a turn during the green light, then the north-south traffic must not pass, and vice versa. To know the number of vehicles in each direction, sensors are used to provide fuzzy logic inputs. Fuzzy logic is applied to traffic lights and simulated with MATLAB tools with the Mamdani method [8].

In an instance, researcher designed a traffic light control simulator with a fuzzy-logic-based microcontroller. The simulator was designed first for a trial using MATLAB with Sugeno's method. In the simulator, a switch is used as a sensor that serves as a density counter on one track and a microcontroller is used as a light controller of the traffic [9], [22]–[24]. In a separate study, researcher performed a simulation using adaptive neuro-fuzzy inference system (ANFIS) on a six-segment traffic light system to compare the average stopping time resulting from the use of the static method against that from the use of the dynamic method; ANFIS in the neuro-fuzzy group was applied to an intersection of six sections [25], created an efficient ANFIS based fractional order PID (FOPID) controller for an electric vehicle (EV) speed tracking control driven by a direct current (DC) motor [25].

Meanwhile, we offer a solution to the issue above by creating a smart traffic light with a microcontroller based on the fuzzy logic. This solution is very important to break down the increasingly severe congestions in major cities in Indonesia. The built-in traffic light system can adapt to the intersection environment. If there is a road that has a long vehicle queue, then the green light time is longer on that road than on the other road that has only a shorter vehicle queue.

Thus, the traffic light is more adaptive to the dynamics of vehicles that will cross the intersection. The traffic light can also communicate with neighboring traffic lights in two directions. This communication will generate information about the number of vehicles leaving the intersection toward each of the closest intersections. Using this information, apart from the information from the sensors, the traffic light will be able to recognize the number of vehicles coming in each direction.

2. RESEARCH METHOD

2.1. Power supply planning

A circuit of power supply is applied to the sensors, microcontroller, relay outputs, and light-emitting diodes (LEDs). The input voltage is supplied by the State Electricity Company (*Perusahaan Listrik Negara* in Indonesian, PLN) at 220 Volts alternating current (AC), which is then lowered to 12 Volts AC and converted into DC voltage [26]. After that, the output voltage of power supply is set to 5 Volts according to the needs of the microcontroller. The power supply circuit can be seen in Figure 1.

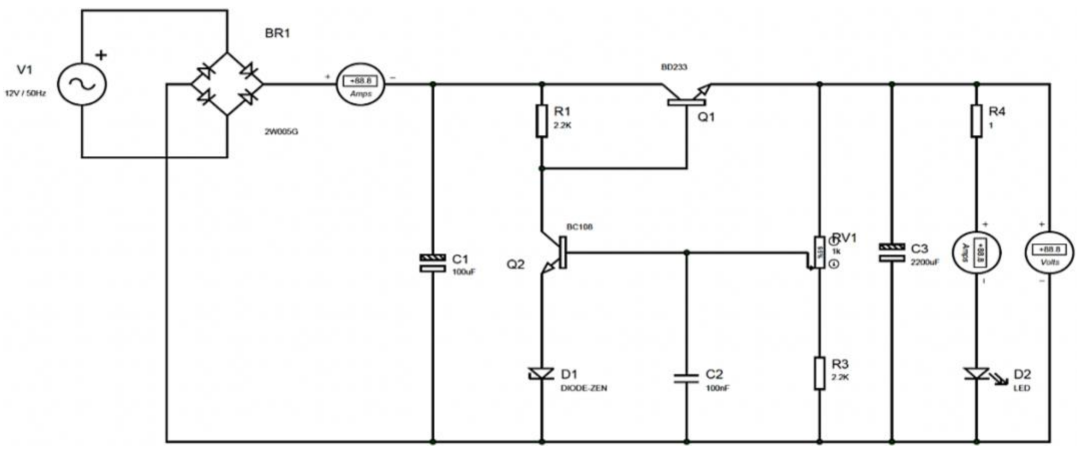

Figure 1. Power supply circuit

2.2. Input planning

The input for this circuit is from the 3 sensors used as input tools on the microcontroller. It will then be processed into output. Each has two sensors placed at each section of the intersection. One light sensor works at night when the streetlight is lit. It will be active when there are objects on the line of reach. The sensor will then send the input signal on the microcontroller and the program that has been created will then execute it.

2.2.1. Sensors planning

The sensors used are ultrasonic, infrared, and light sensors [27]–[29]. The ultrasonic sensor detects the distance of a vehicle from an object in front of it [30], [31]. This sensor is capable of detecting a distance in the range of 3 cm to 3 m. Its working principle is that the ultrasonic sensor transmitter emits a frequency of 40 kHz that is generated by the microcontroller, which then is received by the ultrasonic sensor receiver. The distance set in the program is 5 cm, so that if there are objects that are censored at a distance of 5 cm, then the ultrasonic transmitter receives a surge reflection and will send signals on the microcontroller.

The ultrasonic sensor works when it detects the vehicle density at one of the junction segments, whereas the microcontroller will adjust the time needed to reflect the signal back to the ultrasonic sensor receiver, which is comparable to 2 times the distance of the ultrasonic sensor and the density of the cars that occurs as shown in (1):

$$ultrasonic\ wave\ time = \frac{\left(\frac{s}{m}\right) x\ 2\ (t)}{v} \tag{1}$$

The ultrasonic sensor requires echo and trigger to communicate with the microcontroller, i.e., when a positive pulse (+) hits 0.58 millisecond to 23.26 milliseconds for an echo pin comparable to the distance required to propagate when a bottleneck occurs, while the trigger gets 4 milliseconds.

The infrared sensor system mainly uses infrared as a medium for data communication [32], between the receiver and transmitter. The system will work if the infrared light emitted is obstructed by an object resulting in an infrared beam that cannot be detected by the receiver. The advantages or benefits of this system in its implementation include remote control, security alarms, and system automation. The transmitter on this system is self-contained on an infrared LED equipped with a network capable of generating data to be transmitted through infrared light, while on the receiver there is a photodiode that serves to receive light. Infrared light is transmitted by the transmitter [33]. The infrared sensor set with photodiode can be seen in Figure 2. The light sensor serves as a street light sensor [34], so that the streetlight will be turned on automatically after sunset and turned off during daytime. A range of light sensors can be seen in Figure 3.

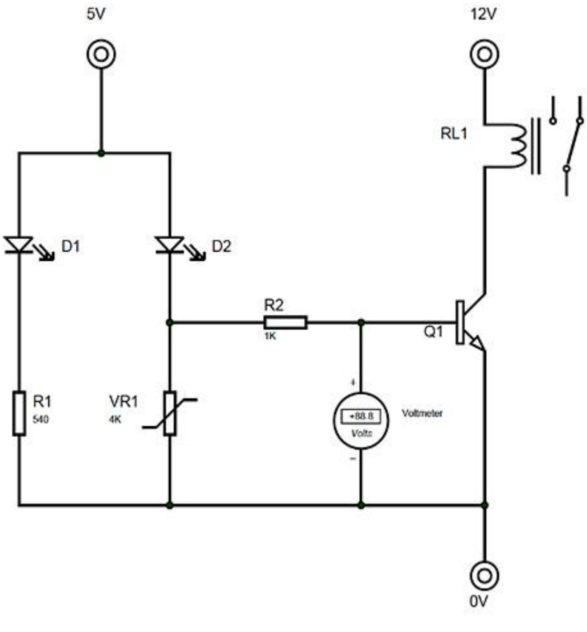

Figure 2. Infrared sensor circuit with photodiode

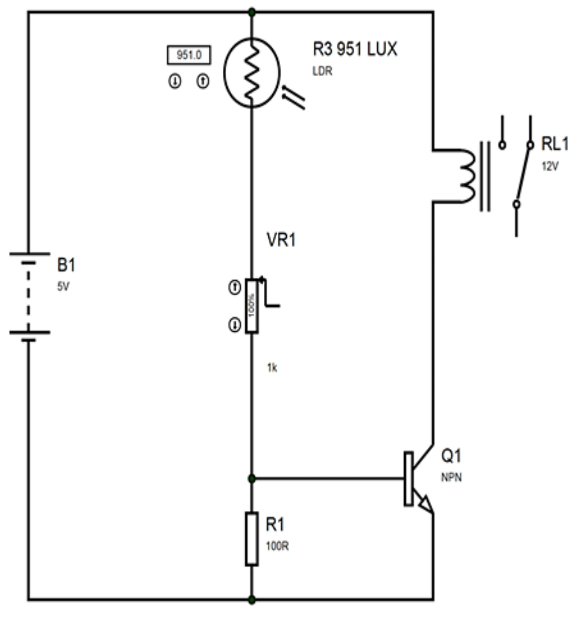

Figure 3. Light sensor circuit

2.3. Process planning
2.3.1. Microcontroller planning

The microcontroller used in this prototype is ATMega2560. The ATMega2560 microcontroller consists of 54 pins that can be used as inputs/outputs, of which 15 pins can be used as pulse width modulation (PWM), 16 pins as analog inputs, and four pins as universal asynchronous receiver/transmitter (UART). This prototype uses 23 inputs/outputs for the traffic light program.

2.4. Output planning

The outputs are LEDs as traffic indication lights as the working markers of the traffic light program. The smart traffic light based on an ATMega2560 microcontroller is designed to make new breakthroughs in breaking down congestions at crossroads so as to optimize the actual situations in the field. This tool is designed as a control system that works according to the length of the vehicle queue utilizing 4 sets of sensors that are installed at each intersection. Time is added to traffic light when the length of the vehicle queue reaches the sonsor that has been installed. The sensor will send a signal as digital input on the microcontroller that will instruct the addition of time on the program. Meanwhile, if the length of queue on the road segment does not activate the sensor, then the time applied is normal in the program. In the design of this tool, the sensor is placed in the middle of the road to receive a signal from the vehicle queue if the number of vehicles in the queue exceeds the sensor limit. The workflow of the design can be seen in Figure 4.

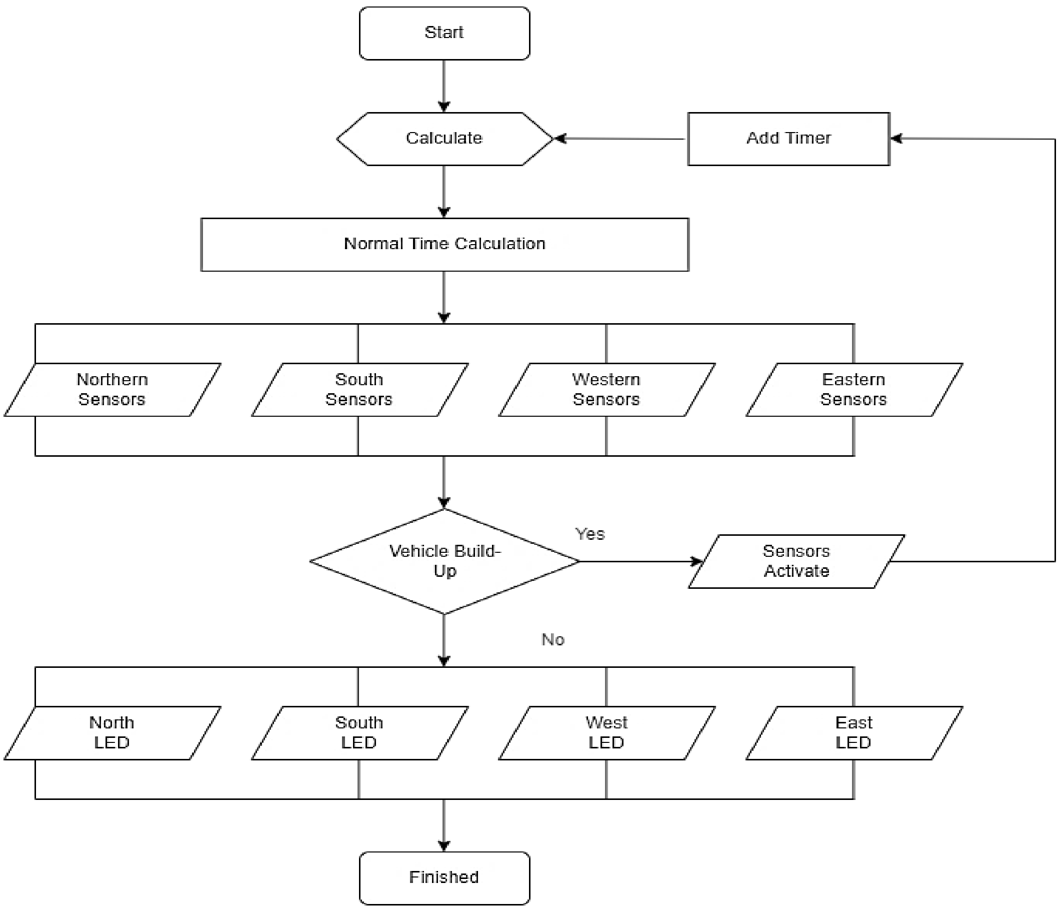

Figure 4. Flow chart of traffic light sensor

If the relay is given a voltage of 5 Volts and ground on coil legs, then the relay will work. There are seven output relays used, which can be seen in Table 1. Supporting outputs in the form of LEDs are assembled into the crossroad traffic light. There are 12 LEDs consisting of LEDs in red, yellow, and green. The LEDs are placed in each section of the road intersection. The LEDs will work when the output pin of the microcontroller signals a high on the foot of the LED by 5 volt [35], [36].

Table 1. Relay outputs

No.	Relay	Description
1	Relay 1	Congestion Sensor Relay in the West
2	Relay 2	Congestion Sensor Relay in the East
3	Relay 3	Congestion Sensor Relay in the North
4	Relay 4	Congestion Sensor Relay in the South
5	Relay 5	Northern Sensor Relay
6	Relay 6	Western Sensor Relay
7	Relay 7	Light Sensor Relay

2.5. How does it work?

Broadly, the processes that run in the smart traffic light based on ATMega2560 microcontroller include the programming process, program simulation process, instruction reading process, and sensor firing process according to instruction [37]–[40]. The smart traffic light based on ATMega2560 microcontroller is designed to create breakthroughs in breaking down congestions at road junctions, optimizing the real-time happenings in the field. This tool is designed as a control system that works according to the length of the vehicle queue utilizing four sets of sensors installed at each intersection. Time is added to a traffic light when the vehicle queue length reaches an appropriate limit according to the sensor that has been installed. The sensor will send a signal as digital input on the microcontroller that will instruct the addition of time on the program. If the length of vehicle queue in the road section does not activate the sensor, then the time calculation on the program runs normally. In the design of this tool, the sensor is placed in the middle of the road to receive a signal from the vehicle queue when the number of vehicles in the queue exceeds the sensor limit.

2.6. Program planning

ATMega2560 has 54 digital inputs/outputs, of which 14 are used as PWM outputs, 16 as analog inputs, and 4 as UART. Additionally, it has 16 MHz crystal oscillator, universal serial bus (USB) connection, power jack, ICSP header, and reset button. This module has everything we need to program a microcontroller, such as a USB cable and a power source via an adaptor or a battery. The design details are presented in the flow chart in Figure 4.

The flow chart of traffic light sensor in Figure 4 describes the details of how the signal prototype is made to determine the length of time of green and red light at an intersection and its effect on the vehicles buildup in one section of the intersection. This flow chart can help determine an efficient length of time of traffic light at a crossroads. After all the inputs from the sensors are examined, then the signal junction simulation will calculate the length of time of green and red light along with the buildup that occurs. After all the calculation process is complete, this prototype will show the best results and will run continuously to set the traffic light regularly in each section. The flow chart of the traffic light system in Figure 4 further describes the following traffic rules at the intersection: i) the lamp that is controlled using the fuzzification process is the green light of each traffic light, so that the red light of each traffic light will adjust to the green light that is active in the other traffic lights, and ii) the length of time the green light is lit in a traffic light will be limited to the absolute maximum and minimum time values, so even if the density level is very high, it will still get a stop turn following the red light to give an opportunity for the traffic from other sections to cross.

The program will run with normal time alike to the traffic light in general: the green light will be active for 3 seconds, the yellow light for 1 second, and the red light in a normal cycle for 9 seconds, but if the sensor is activated, then the stopping time will be added with 3 seconds in each section. The digital input number 8 will be active if input from the real-time counter (RTC) is received, which will instruct all flashing LEDs to be enabled for the night operating hours. In this study, the prototype time on traffic lights is made 1:10 against normal circumstances. The prototype is made using the software Arduino IDE to create a traffic light program based on an ATMega2560 microcontroller using C language. It will first determine the total number of digital pin inputs and digital outputs used.

3. RESULTS AND DISCUSSION

For the digital data, signaling requires a voltage source that has the “TTL” level, following the logic HIGH=+5 Volts and the logic LOW=0 Volt, so that the output of the light sensor system that will be fed to the parallel port must have a TTL voltage level. Table 2 describes the level of stability of the power supply. The input and output test results, computed using (1), can bee have seen in Table 3. The distance calculation results can be seen in Table 4.

Table 2. Power supply testing

Load	Voltage (V)
Without load	5.23
Ultrasonic load 1	5.15
Ultrasonic load 2	5.14
Infrared load 1	5.20
Infrared load 2	5.19
Light Sensor load	5.20

Table 3. Voltage testing results

No.	Reference voltage (V)	Input voltage (V)	Output voltage (V)
1	2.75	3.31	0
2	3.00	3.46	0
3	3.25	3.61	0
4	3.50	3.77	4.42
5	3.71	3.90	4.43
6	3.93	4.03	4.43
7	4.16	4.17	4.43
8	4.43	4.94	4.80

Table 4. The distance calculation results

No.	Distance (s/m)	Calculation	Ultrasonic wave travel time
1	0.1	$t = \frac{0.1 \text{ x } 2}{344 \text{ m/s}}$	0.58 ms
2	0.25	$t = \frac{0.25 \text{ x } 2}{344 \text{ m/s}}$	1.45 ms
3	0.5	$t = \frac{0.5 \text{ x } 2}{344 \text{ m/s}}$	2.91 ms
4	0.75	$t = \frac{0.75 \text{ x } 2}{344 \text{ m/s}}$	4.36 ms
5	1	$t = \frac{1 \text{ x } 2}{344 \text{ m/s}}$	5.81 ms
6	2	$t = \frac{2 \text{ x } 2}{344 \text{ m/s}}$	11.63 ms
7	3	$t = \frac{3 \text{ x } 2}{344 \text{ m/s}}$	17.44 ms
8	4	$t = \frac{4 \text{ x } 2}{344 \text{ m/s}}$	23.26 ms

Using the existing data, the fuzzy logic method is undertaken in the following stages: i) data input; ii) fuzzification in which membership degrees are generated; and iii) rule base. The fuzzification process can be seen on Figure 5. According to the value data, we take a distance of 3.5 meters and a voltage of 4.5 Volts then insert these into the set. The fuzzification process can be seen in Figure 6. According the existing data, distance is a blurred value in the medium and small set positions. The distance for small set membership as shown in (2).

$$\mu(x) = \begin{cases} 1; & x \leq 3 \\ \frac{4-x}{4-3}; & 3 \leq x \leq 4 \\ 0; & x \geq 4 \end{cases} \tag{2}$$

with the linear representation formula going down

$$\mu\ small\ (3.5) = \frac{4-3.5}{4-3} = \frac{0.5}{1} = 0.5. \tag{3}$$

The distance for medium set membership as shown in (4):

$$\mu(x) = \begin{cases} 0; & x \leq 3 \\ \frac{x-3}{4-3}; & 3 \leq x \leq 4 \\ 1; & x \geq 4 \end{cases} \tag{4}$$

with the triangular linear representation formula

$$\mu\ medium\ (3.5) = \frac{4-3}{4-3} = \frac{1}{1} = 1. \quad (5)$$

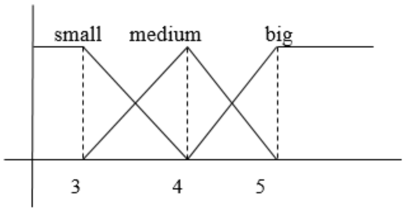

Figure 5. Set membership

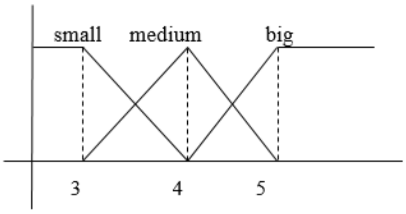

Figure 6. Distance and voltage membership set

From formulas (2) and (4), it can be concluded that the membership degree for the distance in small set is 0.5, in moderate set 1, and in large set 2. Then the membership degree for voltage is a blurred value in the medium and large set positions. The voltage for medium set membership as shown in (6):

$$\mu(x) = \begin{cases} 1; & x \leq 4 \\ \frac{5-x}{5-4}; & 4 \leq x \leq 5 \\ 0; & x \geq 5 \end{cases} \quad (6)$$

with the linear representation formula rising

$$\mu\ medium(4.5) = \frac{5-4.5}{5-4} = \frac{0.5}{1} = 0.5 \quad (7)$$

The voltage for large set membership as shown in (8):

$$\mu(x) = \begin{cases} 0; & x \leq 4 \\ \frac{x-4}{5-4}; & 4 \leq x \leq 5 \\ 1; & x \geq 5 \end{cases} \quad (8)$$

with the triangular linear representation formula

$$\mu\ big\ (4.5) = \frac{5-4}{5-4} = \frac{1}{1} = 1 \quad (9)$$

Then, the degree of membership for a voltage value of 4.5 is: small: 2, medium: 1, and large: 0.5. The rule base can be seen in Table 5.

Table 5. Rule base

Rule	Input set		Sensor Travel time
	Distance	Voltage	
1	Small	Small	Long
2	Small	Medium	Briefly
3	Small	Big	Briefly
4	Medium	Small	Long
5	Medium	Medium	Briefly
6	Medium	Big	Briefly
7	Big	Small	Long
8	Big	Medium	Long
9	Big	Big	Long

According to the rule base in Table 5, when four rules-rules 2, 3, 5 and 6-are entered into the program, then the following will apply:
Rule 2: if distance=small and voltage=medium, then the sensor time is brief.

α=min (μ small (x); μ medium (x))
α=min (1. 1)
Rule 3: if distance=small and voltage=big, then the sensor time is brief.
α=min (μ small (x); μ big (x))
α=min (1. 0.5)
Rule 5: if distance=medium and voltage=medium, then the sensor time is brief.
α=min (μ medium(x); μ medium(x))
α=min (0.4. 0.6)
Rule 6: if distance=medium and voltage=big, then the sensor time is brief.
α=min (μ medium(x); μ big(x))
α=min (0.4. 0.4)

The smart traffic light that is based on the ATMega2560 microcontroler includes a fuzzy-logic-based system design, software with the C programming language, and hardware. The designed system forms a traffic light setting according to the vehicle queue. The smart traffic light is practical in the creation of tools, smooth in the assembly, capable of breaking down congestions and vehicles density, especially during peak hours, and of minimizing violations during crossing, and safe to use. Its drawbacks lie in its limited sensor range and its susceptibility to noise.

4. CONCLUSION

The four sets of sensors placed in four sections determine the traffic light timing process. If the length of vehicle queue reaches the sensor, then the sensor is activated, a signal will be sent as digital input on the microcontroller, and the stopping time will be added with 9 seconds. The traffic light settings using fuzzy logic control still consider the interests of other traffic sections by providing a minimum of 9 seconds and a maximum of 27 seconds in 1 cycle of light traffic settings as the limits of the fuzzy logic control system. The ultrasonic and infrared sensors can reduce congestions at traffic lights by giving a green light time when one or all of the sensors are active, so that the vehicle congestions can be relieved. The automatic voltage regulator (AVR) ATMega2560 microcontroller requires some additional components such as capacitors, integrated circuit (IC) regulators, and resistors to be able to work or function as expected. Betterment for this research can be performed by adding input variables by adding multiple sensors at various intersections so as to produce real-time outputs. It is also recommended to allow access for road users, so that when a congestion is detected, the road users can consider when to pass the road as indicated by the number of vehicles.

REFERENCES

[1] H. He, C. Zhang, W. Wang, Y. Hao, and Y. Ding, "Feedback control scheme for traffic jam and energy consumption based on two-lane traffic flow model," *Transp. Res. Part D Transp. Environ.*, vol. 60, pp. 76–84, May 2018, doi: 10.1016/j.trd.2015.11.005.
[2] C. Vilarinho and J. P. Tavares, "Real-time traffic signal settings at an isolated signal control intersection," *Transp. Res. Procedia*, vol. 3, pp. 1021–1030, 2014, doi: 10.1016/j.trpro.2014.10.082.
[3] L. W. Canter, *Environmental impact of agricultural production activities*. CRC Press, 2018.
[4] H. Wang, K. Rudy, J. Li, and D. Ni, "Calculation of traffic flow breakdown probability to optimize link throughput," *Appl. Math. Model.*, vol. 34, no. 11, pp. 3376–3389, Nov. 2010, doi: 10.1016/j.apm.2010.02.027.
[5] J. Liu *et al.*, "Secure intelligent traffic light control using fog computing," *Futur. Gener. Comput. Syst.*, vol. 78, pp. 817–824, Jan. 2018, doi: 10.1016/j.future.2017.02.017.
[6] C.-Y. Cui, J.-S. Shin, M. Miyazaki, and H.-H. Lee, "Real-time traffic signal control for optimization of traffic jam probability," *Electron. Commun. Japan*, vol. 96, no. 1, pp. 1–13, Jan. 2013, doi: 10.1002/ecj.11436.
[7] A. M. de Souza and L. A. Villas, "A new solution based on inter-vehicle communication to reduce traffic jam in highway environment," *IEEE Lat. Am. Trans.*, vol. 13, no. 3, pp. 721–726, Mar. 2015, doi: 10.1109/TLA.2015.7069097.
[8] S. Komsiyah and E. Desvania, "Traffic lights analysis and simulation using fuzzy inference system of mamdani on three-signaled intersections," *Procedia Comput. Sci.*, vol. 179, pp. 268–280, 2021, doi: 10.1016/j.procs.2021.01.006.
[9] C. Karakuzu and O. Demirci, "Fuzzy logic based smart traffic light simulator design and hardware implementation," *Appl. Soft Comput.*, vol. 10, no. 1, pp. 66–73, Jan. 2010, doi: 10.1016/j.asoc.2009.06.002.
[10] M. A. Hamid, S. A. Rahman, I. A. Darmawan, M. Fatkhurrokhman, and M. Nurtanto, "Performance efficiency of virtual laboratory based on Unity 3D and Blender during the Covid-19 pandemic," *J. Phys. Conf. Ser.*, vol. 2111, no. 1, p. 12054, Nov. 2021, doi: 10.1088/1742-6596/2111/1/012054.
[11] K. Chatterjee, A. De, and F. T. S. Chan, "Real time traffic delay optimization using shadowed type-2 fuzzy rule base," *Appl. Soft Comput.*, vol. 74, pp. 226–241, Jan. 2019, doi: 10.1016/j.asoc.2018.10.008.
[12] M. Balta and İ. Özçelik, "A 3-stage fuzzy-decision tree model for traffic signal optimization in urban city via a SDN based VANET architecture," *Futur. Gener. Comput. Syst.*, vol. 104, pp. 142–158, Mar. 2020, doi: 10.1016/j.future.2019.10.020.
[13] Y. E. Hawas, M. Sherif, and M. D. Alam, "Optimized multistage fuzzy-based model for incident detection and management on urban streets," *Fuzzy Sets Syst.*, vol. 381, pp. 78–104, Feb. 2020, doi: 10.1016/j.fss.2019.06.003.
[14] Y. Zhang and R. Su, "An optimization model and traffic light control scheme for heterogeneous traffic systems," *Transp. Res. Part C Emerg. Technol.*, vol. 124, p. 102911, Mar. 2021, doi: 10.1016/j.trc.2020.102911.

[15] D. Desmira, M. A. Hamid, Irwanto, S. D. Ramdani, and T. Y. Pratama, "An ultrasonic and temperature sensor prototype using fuzzy method for guiding blind people," *J. Phys. Conf. Ser.*, vol. 1446, no. 1, p. 12045, Jan. 2020, doi: 10.1088/1742-6596/1446/1/012045.
[16] M. A. Hamid, E. Permata, D. Aribowo, I. A. Darmawan, M. Nurtanto, and S. Laraswati, "Development of cooperative learning based electric circuit kit trainer for basic electrical and electronics practice," *J. Phys. Conf. Ser.*, vol. 1456, no. 1, p. 12047, Jan. 2020, doi: 10.1088/1742-6596/1456/1/012047.
[17] A. Rahmat, A. R. Nugroho, A. Saregar, M. A. Hamid, M. R. N. Prastyo, and A. Mutolib, "Small hydropower potential of rivers in Sukabumi Regency, West Java, Indonesia," *J. Phys. Conf. Ser.*, vol. 1155, p. 12041, Feb. 2019, doi: 10.1088/1742-6596/1155/1/012041.
[18] L. Ramirez-Polo, M. A. Jimenez-Barros, V. V. Narváez, and C. P. Daza, "Simulation and optimization of traffic lights for vehicles flow in high traffic areas," *Procedia Comput. Sci.*, vol. 198, pp. 548–553, 2022, doi: 10.1016/j.procs.2021.12.284.
[19] Y. Zhao and P. Ioannou, "A co-simulation, optimization, control approach for traffic light control with truck priority," *Annu. Rev. Control*, vol. 48, pp. 283–291, 2019, doi: 10.1016/j.arcontrol.2019.09.006.
[20] S. Ma and X. Yan, "Examining the efficacy of improved traffic signs and markings at flashing-light-controlled grade crossings based on driving simulation and eye tracking systems," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 81, pp. 173–189, Aug. 2021, doi: 10.1016/j.trf.2021.05.019.
[21] Y. Perez and F. H. Pereira, "Simulation of traffic light disruptions in street networks," *Phys. A Stat. Mech. its Appl.*, vol. 582, p. 126225, Nov. 2021, doi: 10.1016/j.physa.2021.126225.
[22] R. Rossi, M. Gastaldi, F. Orsini, G. De Cet, and C. Meneguzzer, "A comparative simulator study of reaction times to yellow traffic light under manual and automated driving," *Transp. Res. Procedia*, vol. 52, pp. 276–283, 2021, doi: 10.1016/j.trpro.2021.01.032.
[23] U. Mittal, P. Chawla, and A. Kumar, "Smart traffic light management system for heavy vehicles," in *Autonomous and Connected Heavy Vehicle Technology*, Elsevier, 2022, pp. 225–244.
[24] C. A. Teixeira, E. R. L. Villarreal, M. E. Cintra, and N. W. B. Lima, "Proposal of a fuzzy control system for the management of traffic lights," *IFAC Proc. Vol.*, vol. 46, no. 7, pp. 456–461, May 2013, doi: 10.3182/20130522-3-BR-4036.00062.
[25] M. A. George, D. V. Kamat, and C. P. Kurian, "Electric vehicle speed tracking control using an ANFIS-based fractional order PID controller," *J. King Saud Univ. Sci.*, Jan. 2022, doi: 10.1016/j.jksues.2022.01.001.
[26] I. A. Darmawan *et al.*, "Electricity course on vocational training centers: a contribution to unemployment management," *J. Phys. Conf. Ser.*, vol. 1456, no. 1, p. 12048, Jan. 2020, doi: 10.1088/1742-6596/1456/1/012048.
[27] S. Adarsh, S. M. Kaleemuddin, D. Bose, and K. I. Ramachandran, "Performance comparison of Infrared and Ultrasonic sensors for obstacles of different materials in vehicle/ robot navigation applications," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 149, p. 12141, Sep. 2016, doi: 10.1088/1757-899X/149/1/012141.
[28] M. S. Mohiuddin, "Performance comparison of conventional controller with fuzzy logic controller using chopper circuit and fuzzy tuned PID controller," *Indones. J. Electr. Eng. Informatics*, vol. 2, no. 4, pp. 189–200, Dec. 2014, doi: 10.11591/ijeei.v2i4.120.
[29] B. Mustapha, A. Zayegh, and R. K. Begg, "Ultrasonic and infrared sensors performance in a wireless obstacle detection system," in *2013 1st International Conference on Artificial Intelligence, Modelling and Simulation*, Dec. 2013, pp. 487–492, doi: 10.1109/AIMS.2013.89.
[30] P. Kohler, C. Connette, and A. Verl, "Vehicle tracking using ultrasonic sensors & joined particle weighting," in *2013 IEEE International Conference on Robotics and Automation*, May 2013, pp. 2900–2905, doi: 10.1109/ICRA.2013.6630979.
[31] J. Liu, J. Han, H. Lv, and B. Li, "An ultrasonic sensor system based on a two-dimensional state method for highway vehicle violation detection applications," *Sensors*, vol. 15, no. 4, pp. 9000–9021, Apr. 2015, doi: 10.3390/s150409000.
[32] J. M. Kahn and J. R. Barry, "Wireless infrared communications," *Proc. IEEE*, vol. 85, no. 2, pp. 265–298, 1997, doi: 10.1109/5.554222.
[33] D. Liu, L. Wang, and K. C. Tan, Eds., *Design and control of intelligent robotic systems*, vol. 177. Berlin, Heidelberg: Springer Berlin Heidelberg, 2009.
[34] P. Elejoste *et al.*, "An easy to deploy street light control system based on wireless communication and LED technology," *Sensors*, vol. 13, no. 5, pp. 6492–6523, May 2013, doi: 10.3390/s130506492.
[35] M. Jaanus, A. Udal, V. Kukk, and K. Umbleja, "Using microcontrollers for high accuracy analogue measurements," *Electron. Electr. Eng.*, vol. 19, no. 6, Jun. 2013, doi: 10.5755/j01.eee.19.6.4559.
[36] B. Singh, Ed., *Computational tools and techniques for biomedical signal processing*. IGI Global, 2017.
[37] M. M. Hilgart, L. M. Ritterband, F. P. Thorndike, and M. B. Kinzie, "Using instructional design process to improve design and development of internet interventions," *J. Med. Internet Res.*, vol. 14, no. 3, p. e89, Jun. 2012, doi: 10.2196/jmir.1890.
[38] M. A. Hamid, D. Aditama, E. Permata, N. Kholifah, M. Nurtanto, and N. W. A. Majid, "Simulating the Covid-19 epidemic event and its prevention measures using python programming," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 26, no. 1, 2022.
[39] D. Desmira, N. A. Bakar, R. Wiryadinata, and M. A. Hamid, "Comparison of PCA to improve the performance of ANFIS Models in predicting energy use in EEVE Laboratories," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 27, no. 1, 2022.

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