Implementation of Smart Traffic Light Based on PLC and Sensors

Tondi Syafru Tama Siregar
tondisiregar@gmail.com
Zuraidah Tharo
zuraidahtharo@dosen.pancabudi.ac.id
Dino Erivianto
Dino25@gmail.com

University of Pembangunan Panca Budi

ABSTRACT
This study discusses the implementation of a smart traffic light system based on a Programmable Logic Controller (PLC) and sensors to improve traffic flow efficiency and reduce congestion at intersections. This system is designed to detect the presence of vehicles using infrared sensors integrated with a PLC, which functions to dynamically adjust the duration of green, yellow, and red lights based on traffic volume. By using an algorithm that calculates the time required for the green light to turn on based on the number of detected vehicles, this system is able to optimize vehicle waiting time. The test results show that the implementation of this system can reduce the average waiting time by up to 20% and improve safety at intersections. This study also identifies potential for further development, such as the use of cameras for vehicle detection and increasing the number of sensors for wider coverage. Thus, this smart traffic light system is expected to provide an effective solution to the problem of congestion in urban areas.

Keywords: Traffic Light, PLC, Infrared Sensor, Congestion, Traffic Management System.

Introduction

The growth in the number of motorized vehicles seems to provide benefits in improving the quality of life. With the increase in motorized vehicles, it will have an impact on the environment caused by traffic accidents and environmental pollution which are the main social relationships that need to be considered today in the world. The resolution for the relationship of traffic problems mentioned to be used as a basis for creating a new concept, namely " *intelligent traffic light system design with vehicle density sensors and PLC* "

The aim is to create a safe, comfortable and traffic-friendly environment, by implementing traffic flow management, which provides support for driver safety, handles emergency situations and improves the efficiency of road use and logistics travel.

Figure 1. Motor Vehicle Density

The research will be conducted by making a design based on the hypothesis that the highway area where the number of motorized vehicles is calculated has its own image characteristic parameters. These characteristic parameters are used to build a virtual area that will be used as a place to calculate the number of vehicles even though the image capture is not always the same. The use of adaptive segmentation methods in image capture, positioning and pattern recognition will later be applied to this design.

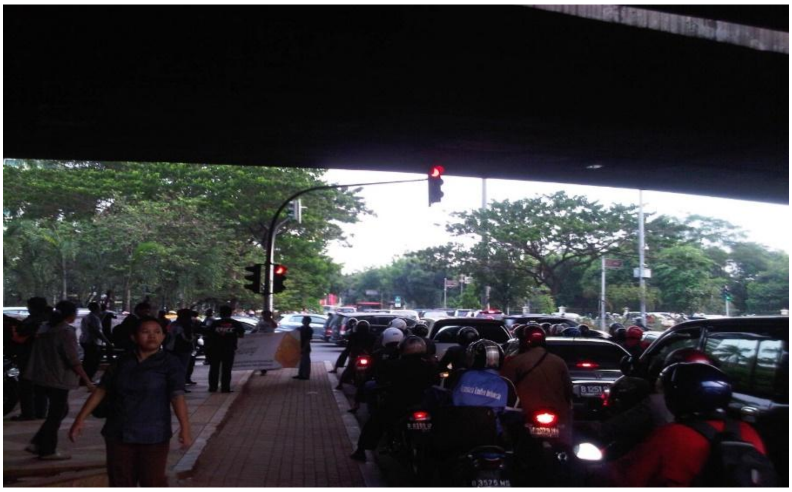

Figure 2. Motor Vehicle Density Using a Time Number Restriction System

So far, *the traffic light turn-on time setting* is made fixed and cannot be changed at any time. In this study, *the traffic light* can be varied, and has been made with the provisions of the light's turn-on time using a computer. The turn-on time is in accordance with the number of time values that have been programmed in the control computer room. Therefore, the researcher created a new system that is different from the existing system, where the study uses a sensor to limit the length of the motor vehicle queue, where when the denser motor vehicle will move to the traffic light first. In this study, the researcher used a programming system using a PLC tool where the PLC was designed by the researcher himself, so it would be easier to care for and maintain when there is a problem.

And also will be made a guard bar above the traffic light road divider line, so that motor vehicles are safer and no motor vehicles violate traffic. The movement occurs when the light turns red the bar will rise as high as 75 cm above the ground. And when the sensor detects the road conditions are filled with motor vehicles then the bar will go down flat with the ground so that the vehicle can move .

Formulation of the problem:

1) How can we prevent traffic light changes from taking too long to avoid traffic jams?
2) How to implement clear and easy headlight switching programming?
3) How to improve the traffic system in Indonesia, especially North Sumatra?

Literature Review

1). PLC Technology in Traffic Systems

PLC is a device used to automate control processes. In the context of traffic lights, PLC can be programmed to set the duration of green, yellow, and red lights based on data received from traffic sensors. PLC offers high reliability and flexibility in setting control logic (Smith, 2020).

2). The Role of Sensors in Traffic Systems

Sensors play an important role in detecting traffic volume and road conditions. Sensors such as inductive loops, cameras, and infrared sensors can be used to collect traffic data. This data is then processed by the PLC to dynamically regulate the traffic light cycle (Brown & Green, 2019).

3). PLC and Sensor Integration

The integration between PLC and sensors allows the traffic light system to operate adaptively. For example, if the sensor detects a long queue of vehicles, the PLC can extend the duration of the green light to reduce congestion. This system can also be integrated with a communication network to share data with the traffic control center (Johnson, 2021). Several case studies have shown the success of implementing this system in reducing vehicle waiting time and increasing traffic efficiency. For example, a study in a large city showed a decrease in average travel time of up to 20% after the implementation of a smart traffic light system based on PLC and sensors (Lee & Park, 2022).

4). Future Challenges and Prospects

Although this technology is promising, challenges such as implementation costs, maintenance, and integration with existing infrastructure need to be addressed. In the future, further developments in sensor technology and control algorithms may improve the performance of this system (Wang, 2023). The implementation of PLC and sensor-based smart traffic lights offers an effective solution to overcome traffic congestion problems. With the ability to adapt to traffic conditions in real-time, this system can improve efficiency and safety on the road.

Research Method

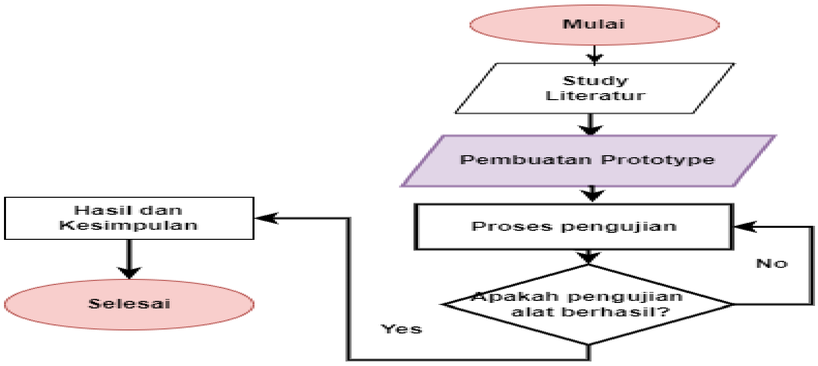

Figure: 3. Flowchart

The following is a flowchart description:

1) Start: The starting point of the process.
2) Literature Study: Conducting research and reviewing relevant literature to understand theoretical background or gather information.
3) Prototyping: Designing and developing a prototype based on literature studies and the problems encountered.
4) Process: Testing or analyzing prototypes through experiments or practical applications.
5) Was the Tool Testing Successful?
6) Decision point: If "Yes", proceed to Results and Conclusions.
7) If "No", go back to "Prototyping" to refine the design or approach.
8) Results and Conclusions: Based on successful testing, analyze the data and summarize the results.
9) Done: The process ends here.

This flow shows the process of developing and testing the tool, from research to final conclusions.

Results and Discussion

A traffic light with three lights can be considered as a finite state machine. It has three states, namely Red, Yellow, and Green, which also serve as outputs. There is one input for the traffic light defined, with a value of 0 for no change and 1 for change. This input is connected to the output of a countdown timer, which produces a value of 1 when it reaches zero. Therefore, for a single traffic light, we can draw a state transition diagram as below.

NS	**0**	**1**
R	R	G
Y	Y	R
G	G	Y

Figure 4. Traffic Signal Sequence

A single traffic light is not very effective. In practice, traffic lights are installed in pairs, with two pairs per intersection. In this simulation, one pair of lights is used to regulate traffic in the north-south direction, while the other pair regulates the east-west direction. In addition, both pairs of lights must be synchronized; therefore, countdown timers are connected to the lights in the pair. Since the lights that make up the pair mirror each other, they are considered one light. However, since the opposite pairs must be synchronized, we must group the different outputs. Thus, there are 3 × 3 = 9 possible outputs. Each combined output represents the color of the north-south light along with the color of the east-west light.

In order for the Traffic Signal Simulator to function intelligently, a mathematical function that can calculate the time required to turn on the green signal based on the length of the vehicle queue is developed. The queue length is detected through an infrared object detector based on the presence of vehicles. The time to turn on the green signal is given by the formula:

$$\text{waktu} = \frac{1}{3}\left(v_1 d + a_a v_s + zD_{12} \right) \quad (1)$$

Where:

- d is the distance between one sensor and another in meters (m),
- v1 is the average speed of the first car moving from a standstill when the signal turns green in meters per second (m/s),
- aa is the average acceleration of the car from a standstill to the next car position in meters per second squared (m/s^2),
- vs is the average speed of a car moving from a standstill after the traffic light turns green in meters per second (m/s),
- z is a variable that has only two values: 0 when no sensors are triggered and 1 if at least one sensor is triggered,
- D12 is the total delay time given by:

$$D_{12} = t_1(n_t - 1) + t_2 \quad (2)$$

- t1 is the first delay time value in seconds (s),
- nt is the number of sensors triggered,
- t2 is the second delay time for each path in seconds (s).

The first step in implementing the simulator is to install the hardware components. The connections between the S7-200 PLC, infrared object detectors, light-emitting diodes (LEDs), AND gates, and inverter gates must be connected correctly. After that, the developed program code is downloaded to the S7-200 PLC. In each lane, three infrared object detectors have been installed. The program will first check the condition of the sensor, whether the sensor is triggered or not. The total number of sensors triggered will be used in the mathematical function to calculate the right time for the green signal to turn on. After the green signal illumination time is over, the yellow signal will turn on for 2 seconds, followed by the red signal. After that, the traffic light will wait for 1 second before switching to the next lane condition.

Tool testing

The traffic signal operation will start with the traffic light turning red for 1 second in all directions. After that, the traffic signals will start flashing sequentially in a clockwise direction according to the magnetic compass direction. This means that the operation will start in the North lane, then the East lane, the South lane, and finally the West lane, before returning to the North lane. After the initial conditions, the simulator will check the condition of the North lane. The system will check whether the sensor is triggered or not. The total number of sensors triggered will be used in the mathematical function to calculate the exact time for the green signal to turn on. After the green signal illumination time is over, the yellow signal will turn on for 2 seconds, followed by the red signal. After that, the traffic light will wait for 1 second before switching to the East lane condition, where the same check is done before switching to the South lane, and so on.

Two views are generated through LabVIEW programming. The first is a front panel for the user interface, and the second is a block diagram containing graphical source code that defines the functionality of the VI (Virtual Instrument). The front panel for the current job is shown in Figure 5.

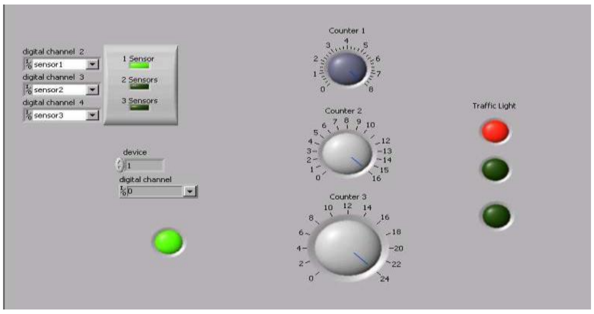

Figure 5. Front panel of the counter

As seen in Figure 5, when one sensor is triggered, Counter 1 will start counting down until it reaches zero. When the counter stops at zero, the traffic light will automatically switch from green to red, along with the traffic light in the traffic system model. Since the sensor only detects the presence of one vehicle, the counter will start counting down from 8 seconds to zero. If two sensors are triggered, indicating two vehicles, then Counter 2 will be activated and start counting down from 16 seconds to zero. This process is the same for three sensors triggered by a vehicle, which will count down from 24 seconds to zero. Programming is done in the diagram using graphical source code. In the block diagram, the program runs from left to right. If the green light in the traffic model does not turn on, the system will return to the default state because there is no input into the system. Three different cases, where the sensors are triggered, are represented in different block diagrams.

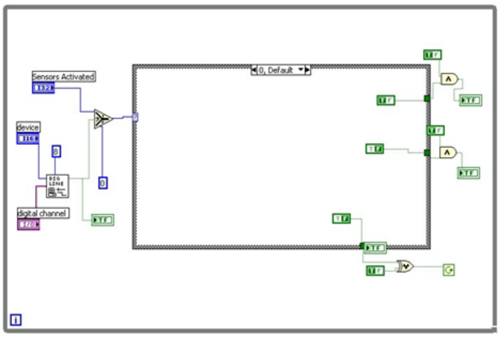

Figure 6. Default Situation

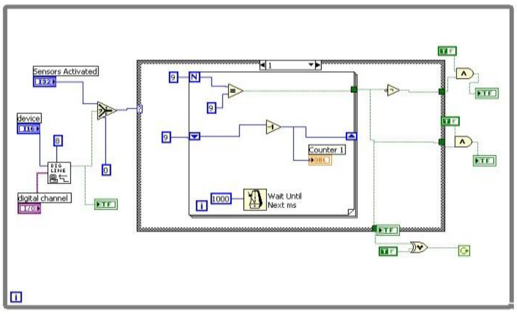

Figure 7. Situation Where Only 1 Sensor Is Triggered

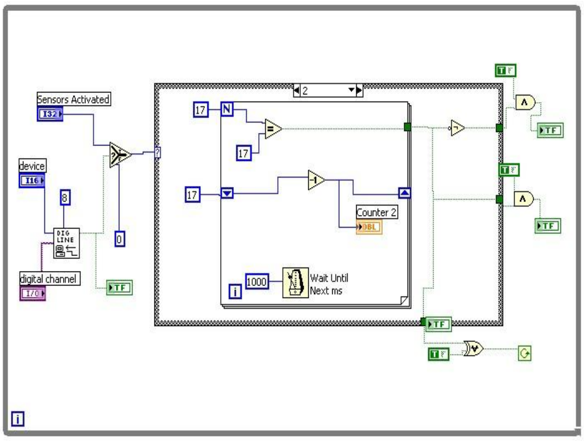

Figure 8. Situation Where 2 Sensors Are Triggered

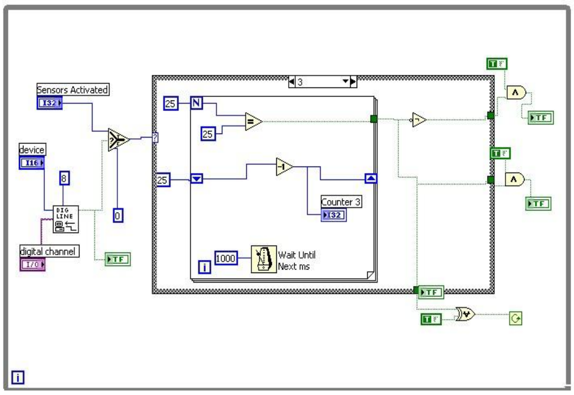

Figure 9. Situation Where 3 Sensors Are Triggered

In this study, several infrared sensors are used to detect the presence of vehicles in all four directions. This function works in a way that when a vehicle blocks the sensor at a certain distance, the sensor will be triggered and notify the PLC S7-200 that there is a vehicle in a particular lane. A while loop is used for three cases in the block diagram that describe three different conditions. The inner box contained in the while loop is called a case structure. The current traffic light system design, in terms of mechanical, electrical, logic, and instrumentation aspects, takes full advantage of the application of sensors in real traffic flow situations by optimizing the time between light changes. If there are no vehicles on the road in all four directions, the light will change from green to yellow in 2 seconds and from yellow to red in another 2 seconds. This process takes place in a cycle from the North lane, followed by the East lane, the South lane, and finally the West lane. For example, if there are 2 vehicles in the North lane, then the time required for the green light to change to yellow is 16 seconds. This applies equally to all other lanes.

Picture 10. Traffic System Model

In the model created, each vehicle represents several vehicles; therefore, if there is 1 vehicle blocking the sensor installed on the side of the road, then the sensor will be triggered and notify the PLC S7-200 that there is a vehicle in the lane. The developed smart traffic light system has several advantages. Since the waiting time of vehicles for the light to change is optimized, carbon monoxide emissions from vehicles are reduced. This will have a positive impact on the greenhouse effect and the environment.

Smart traffic systems will also save drivers time and reduce their frustration while waiting for the lights to change, as it helps reduce congestion at traffic intersections. Another advantage is that there is no interference between sensor beams and no redundant signal triggers. With the ability to interact with LabVIEW software, sensor-based traffic systems will easily receive feedback. Therefore, there will be communication between software and hardware.

Conclusion

In this study, several important steps have been identified to overcome the problem of traffic congestion, especially in North Sumatra. First, to avoid excessively long traffic light switching times, it is recommended to implement a smart traffic light system that uses sensors to detect vehicle volume in real time. In this way, the duration of the green light can be adjusted based on the number of vehicles waiting, thus optimizing traffic flow and reducing waiting time. In addition, the programming of light switching should be designed with a clear and easy-to-understand interface, using software such as Lab VIEW to facilitate system operation. Finally, to improve the traffic system in Indonesia, especially in North Sumatra, it is necessary to improve infrastructure and implement modern technology, including the addition of sensors at intersections and the use of cameras for vehicle detection. With these steps, it is hoped that the traffic system can be improved, creating a smoother and safer traffic flow for the community.

References

[1] Abdalla, A. N., Lubis, Z., Mohamed, M., & Ali, Z. M., 2010, A new series-parallel hybrid electric vehicle configuration based on an induction motor coupled toDC machine. 5(24), 4034–4043.

[2] Aryza, S., Irwanto, M., Khairunizam, W., Lubis, Z., Putri, M., Ramadhan, A., Hulu, F. N., Wibowo, P., Novalianda, S., & Rahim, R.,2018, An effect sensitivity harmonics of rotor induction motors based on fuzzy logic. International Journal of Engineering and

Technology(UAE), 7(2.13 Special Issue 13), 418–420. https://doi.org/10.14419/ijet.v7i2.13.16 936

[3] Aryza, S., Lubis, Z., & Indrawan, M. I. (2021). ANALISA BARU DALAM MENDETEKSI LETAK GANGGUAN HUBUNG SINGKAT JARINGAN 1 FASA. Jurnal Abdi Ilmu, 13(2), 175-186.

[4] Brown, L., & Green, M. (2019). *Sensor technologies for smart traffic lights*. International Journal of Transportation Science and Technology, 8(2), 123-134.

[5] Indar Sugiarto, Thiang Thiang, & Timothy Joy Siswanto. 2008, Disain dan Implementasi Modul Akuisisi Data sebagai Alternatif Modul DAQ LabVIEW. Jurnal Teknik Elektro, 8(1), 30–37. http://puslit2.petra.ac.id/ejournal/index. php/elk/article/view/17353

[6] Johnson, R. (2021). *Integration of PLC and sensors in traffic control systems*. IEEE Transactions on Intelligent Transportation Systems, 22(4), 567-578.

[7] Kurniawan, E., Ekaputri, C., Elektro, F. T., Telkom, U., & Surya, T., 2016, Perancangan Dan Implementasi Tenaga Surya Sebagai Catu Daya Pada Skuter Beroda DuamSeimbang Otomatis Universitas Telkom (Design and Implementation of Solar Energy as Power Supply On Self Balanced Two-Wheeled Scooter)

[8] Lee, K., & Park, S. (2022). *Case study: Smart traffic light implementation in urban areas*. Transportation Research Part C: Emerging Technologies, 34, 89-102.

[9] R. Tri Lubis, “Rancang Bangun Antena Mikrostrip Array 4 Elemen Patcg Rectangular Pada Frekuensi 1,8 GHz untuk RF ENErgy Harvesting” Universitas Sumatera Utara,2017.

[10] Smith, J. (2020). *Programmable logic controllers in traffic systems*. Journal of Traffic Management, 12(3), 45-58.

[11] Wang, Y. (2023). *Challenges and future prospects of smart traffic systems*. Journal of Advanced Transportation, 47(5), 345-359.