Smart Traffic Light Design Based on Histogram of Oriented Gradient and Support Vector Machine

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Abstract: Traffic congestion is one of the frequent problems in big cities, especially at intersections. Congestion occurs because the setting time of traffic lights installed still using the fixed timing without consider to the ups and downs of vehicle density that have the potential to cause congestion. To reduce these problems, the traffic light timing system must be in accordance with the circumstances in each intersection path. In this study, a traffic light simulation was made using the Histogram of Oriented Gradient (HOG) and Support Vector Machine (SVM) methods to detect vehicles that would determine the level of vehicle density. Webster method used to determine the duration of the traffic light based on the parameters of the density of vehicle. The output of this simulation is in the form in traffic light prototype that is controlled by NodeMCU and monitored by an application.

1 INTRODUCTION

Traffic congestion is one of the problems that often occurs in big cities and generally occurs at road intersections. The number of vehicles that continues to increase from year to year, the growing population, the imbalance between traffic demand and transportation infrastructure, and the inability of traffic management to control and reduce traffic flow are one of the main causes of congestion. (Hartanti et al., 2019). The right way to control traffic congestion is by using traffic lights. (Mohanaselvi & Shanpriya, 2019). However, the use of traffic lights does not always solve traffic congestion problems. In one situation, the traffic light will be very helpful in the smooth flow of traffic, but in another situation, it will make the traffic jam worse. (Toar-lumimuut et al., 2015). A common example is congestion during peak hours, i.e. in the morning and evening. This congestion occurs because the traffic light timing settings used today still apply a conventional or fixed-cycle traffic light (FCTL) timing system or fixed/static red and green light durations without considering real-time road conditions, such as vehicle density in each lane of the intersection. (Ng & Kwok, 2020), (Siswipraptini et al., 2018). Such timing will lead to the accumulation of vehicles on one side of the intersection and is very prone to causing congestion. With the different density levels at the intersection, a smart traffic light cycle timing system is needed, which can adjust the cycle time automatically.

Several studies have been conducted to overcome these problems. Fibrilianty et.al, have made a traffic light timing system based on vehicle density detection using the Histogram of Oriented Gradient (HOG) method. The output of this simulation is a Traffic Light prototype that has been designed on Arduino which is connected to a program that has been designed in Matlab. Simulation of Trafic light timings designed to get more efficient system performance results compared to traffic lights with automatic timers in general. (Fibriliyanti et al., 2017). Another study designed an application using MATLAB 2009a Software and Digital Camera as processing and input of traffic light images to detect density using the bwarea method. The results of this system can determine the length of time the green light is on based on the density of the road section. (Toar- lumimuut et al., 2015). Noval, C. et.al have conducted research on traffic light optimization using the *webster* method. In this study, the *webster* method isable to optimize traffic cycle time based on vehicle density detection using infrared sensors. (Noval et al.,2018).

The purpose of this research is to create a simulation of a miniature traffic light that works adaptively, namely a traffic light that adjusts the

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duration of the green light based on vehicle density conditions in each lane.

2 RESEARCH METHODS

The system will control the work of the traffic light by detecting the level of density in each lane of the intersection, then the results of density detection will determine the duration of the green light, where if the lane is in a congested condition, the duration of the green light will be longer than the free lane.

2.1 System Overview

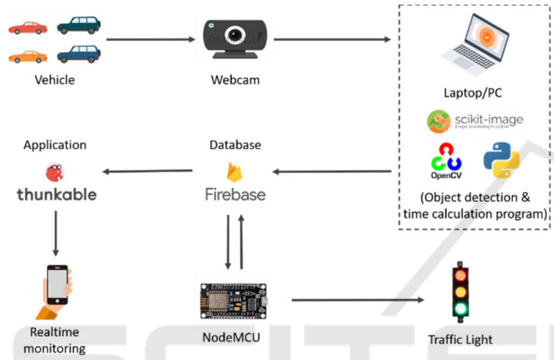

Figure 1: System Overview.

In Figure 1 above, the general system is explained, the first stage is image capture at a miniature traffic light intersection using a webcam camera. The captured image is then processed by the OpenCV library programmed on a laptop/PC. The image is processed to detect the level of vehicledensity at the traffic intersection using the HOG and SVM methods. The detected vehicle density level will then determine the length of time the traffic lightworks. based on the webster method, and will activate the traffic light according to the calculated time length and display it on the application for the monitoring system.

2.2 System Flowchart

Figure 2 shows how the smart *traffic light* system works. The camera will start working since the system starts operating, then the camera will detect the level of vehicle density using the HOG and SVM methods. If the detected image is able to determine the level of density, the system will continue to

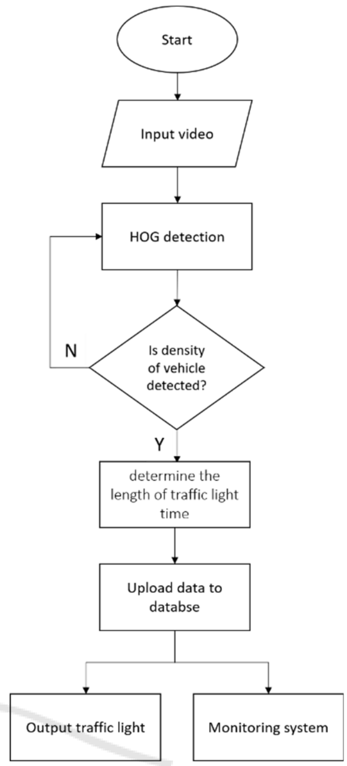

Figure 2: System Flowchart.

process it for setting the length of time the*traffic light* works based on the level of vehicle density thathas been detected. Next, the system will send the data that has been obtained to the database. The data stored in the database will then be read and will activate the *traffic light*based on the data read in the database. The data in the database will also be read for the monitoring system on Android.

2.3 Domain Spesific Design

This specific domain design is a breakdown of the specific system design of each domain.

2.3.1 Mechanical Domain Design

The design scheme of the miniature traffic intersection is made using a two-lane traffic intersection with a two-phase traffic light arrangement. There are two cameras installed towards each lane at the intersection and two traffic light modules are used as system outputs and a TM1637 module as a display to show the length of time the green light is on.

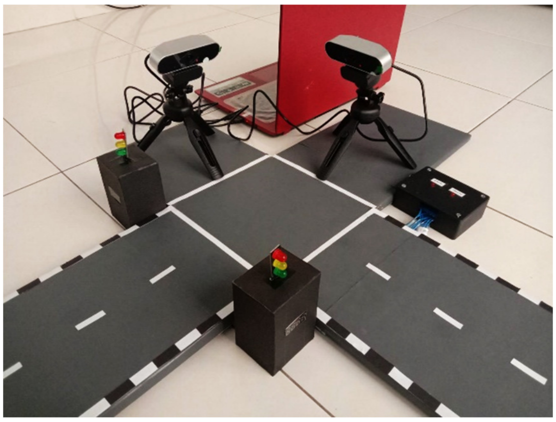

Figure 3: Miniature Traffic Light Intersection.

2.3.2 Electric Domain Design

The electrical design will be made of components according to the needs of the tool. NodeMCU is used as a microcontroller, traffic light module, TM1637 display module as an indicator to calculate the green light timer, and LED as an indicator of online and offline modes.

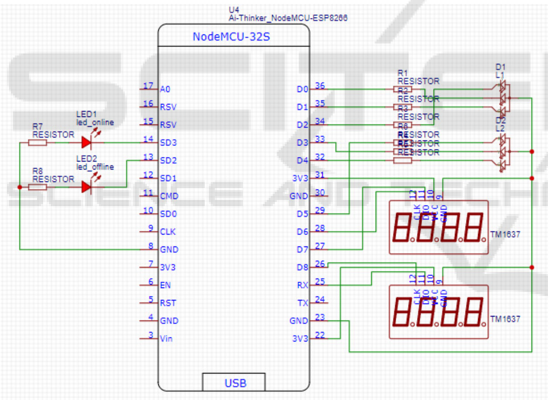

Figure 4: Electrical Circuit.

2.3.3 Informatic Domain Design

The vehicle density detection algorithm consists of five parts:

a. Object Detection System Design

The first stage in making this system is character extraction on the image data that has been collected using the HOG method. (Pranoto et al., 2017). Characteristic extraction is performed on an image measuring 32x32 pixels. The image piece will be divided into several overlapping blocks, in which there are several cells, where each cell is composed by several pixels. Then, in each cell, the horizontal and vertical image gradient values are calculated using the formulas in equations (2.1) and (2.2).

$$f_x(x, y) = I(x + 1, y) - I(x - 1, y) \quad (2.1)$$

$$f_y(x, y) = I(x, y + 1) - I(x, y - 1) \quad (2.2)$$

After that, the magnitude and orientation values are calculated using the formulas in equations (2.3) and (2.4).

$$m(x, y) = \sqrt{f_x(x, y)^2 + f_y(x, y)^2} \quad (2.3)$$

$$\theta(x, y) = tan^{-1}\left(\frac{f_y(x, y)}{f_x(x, y)}\right) \quad (2.4)$$

Next, normalization is performed using the formula in equation (2.5), to avoid value differences due to lighting differences.

$$V_n = \frac{V_i}{\sqrt{\|V\|_2^2 + \epsilon^2}} \quad (2.5)$$

From the calculation results, a histogram will be built by voting the θ value according to the predetermined bin value (binning process). Then, the histogram of all cells in one block will be merged.

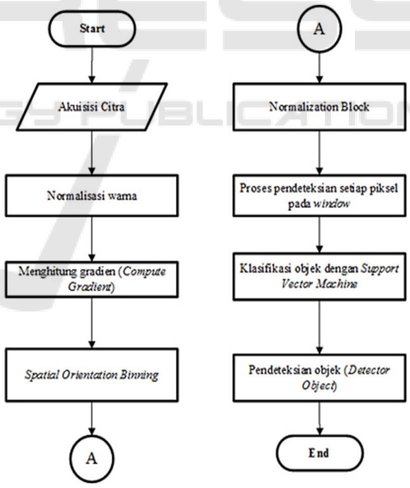

Figure 5: Flowchart HOG and SVM method.

Then the data that has been extracted will be trained using SVM by giving the data class a value of 1 for positive images and -1 for negative images. From the training results, a model in the .npy format is produced as a model for the vehicle object detection process.

In this vehicle object detection process using a sliding window with each window extracting 32x32 pixel characteristics. The window moves from the top left corner to the right, and then down by extracting HOG and SVM process and will produce data in the form of an image marked with a box indicating that the boed image is a detected objects/vehicle. The number of vehicles detected indicates the density division described in table 1.

Table 1: Density Level Based on Number of Vehicle.

No	Number of Vehicle	Density Level
1	0 – 3	Low
2	4 – 7	Normal
3	> 7	High

b. Webster Method Timing Design

The Webster method is a concept to determine the optimal cycle length and calculate the traffic light time duration based on vehicle density and road width. Factors that influence the Webster method are as follows: (Noval et al., 2018)

1) Determine the order and number of phases

2) Determine the saturation flow (s)

Saturation flow (s) is the number of vehicle departures in the queue when vehicles are at a constant rate. In Webster's method, the saturationflow can be estimated based on the road width.

Table 2: Saturation flow by road width.

Road width	Saturation flow
3,05	1850
3,35	1875
3,65	1900
3,95	1950
4,25	2075
4,60	2250
4,90	2475
5,20	2700

3) Determine the normal flow (q)

4) Determine the level of traffic flow

5) Calculate the ratio between traffic volume and saturation flow of each entersection

$$yi = qi/si \tag{2.6}$$

6) Determining lost time

$$L = 2n + R \tag{2.7}$$

7) Determine the optimum cycle time

$$C0 = \frac{1{,}5L + 5}{1 - Y} \tag{2.8}$$

8) Specifies settings for effective green light duration

$$Gi = \frac{yi(Co - L)}{y} \tag{2.9}$$

c. Database and Output Design

Data from density detection and green light duration calculations that have been carried out are then sent to the firebase database in real time. This data is intended to be read by nodemcu to activate thetraffic light module at the miniature traffic light intersection and read by the application for the monitoring system.

d. Interface Program Design

Figure 6 is a view of the thunkable application that functions to monitor the system. The data displayed is the density of each lane and the durationof the traffic light. (green light, red light, cycle time length). For the main page there are also buttons to activate and turn off the system.

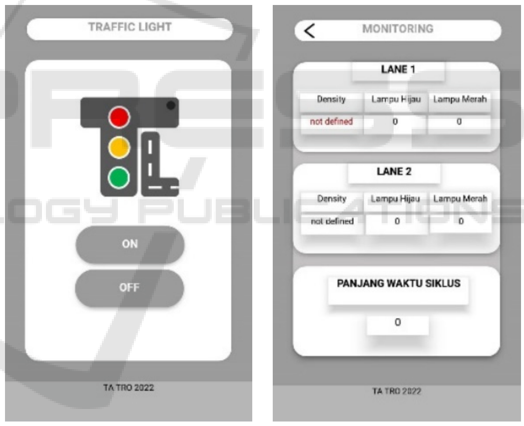

Figure 6: Monitoring application.

3 RESULT AND DISCUSSION

The automatic traffic light testing process iscarried out on a miniature traffic light intersection asan image capture input. Image input is taken using a webcam.

3.1 Testing the Effect of Light

This detection test was conducted to determine the effect of lighting on the number of vehicles detected.

Table 3: Test result for the effect of light.

Light	Actual Number of Objects	Number of Detected Objects	Difference	Error
100000 lux	1	1	0	0,00
	2	2	0	0,00
	3	3	0	0,00
	4	4	0	0,00
	5	5	0	0,00
	6	6	0	0,00
	7	7	0	0,00
	8	8	0	0,00
	9	9	0	0,00
	10	8	2	0,20
	Average (%)			2,00
200 lux	1	1	0	0,00
	2	2	0	0,00
	3	3	0	0,00
	4	4	0	0,00
	5	5	0	0,00
	6	6	0	0,00
	7	7	0	0,00
	8	8	0	0,00
	9	8	1	0,11
	10	8	2	0,20
	Average (%)			3,10
50 lux	1	1	0	0,00
	2	2	0	0,00
	3	3	0	0,00
	4	4	0	0,00
	5	5	0	0,00
	6	6	0	0,00
	7	5	2	0,29
	8	6	2	0,25
	9	6	3	0,33
	10	8	2	0,20
	Average (%)			10,07

From the test result in table 3, it can be sees that the error on detection is higher in 50 lux light conditions, which is 10,07%. From these result it is concluded that the system runs better in light condition >= 200 lux.

3.2 Density Detection Testing

Testing of vehicle density detection is carried out to ensure that the level of vehicle density in the observation area scenario can be detected by the system. The density level description is L for low, N for normal, and H for high, S for successful and US for unsuccessful.

Table 4: Density detection test result.

Actual Condition		Detection Result		Note
Number of Objects	Density Level	Number of Objects	Density Level	
1	L	1	L	S
2	L	2	L	S
3	L	3	L	S
4	N	4	N	S
5	N	5	N	S
6	N	6	N	S
7	N	8	H	US
8	H	8	H	S
9	H	9	H	S
10	H	7	N	US

Accuracy value = (Correct data/Number of data) * 100% = (8/10) * 100% = 80%.

From table 4, it can be seen that the system is able to detect the level of density based on the number of cars detected with an accuracy rate of 80%.

3.3 Green Light Time Testing

This test is conducted to determine the length ofgreen light time based on the density of vehicles on lane 1 and lane 2 that have been detected and compareit with the results of *fixed cycle* time. L1 for lane 1 and L2 for lane 2.

Table 5: Green light duration test result based on density.

Density		Green Light Duration (sec)		Cycle Time (sec)	
L1	L2	L1	L2	Adaptive	Fixed
L	L	15	15	41	80
L	N	17	21	49	80
L	P	18	26	55	80
N	L	21	17	49	80
N	N	25	25	62	80
N	P	28	31	71	80
P	L	26	18	55	80
P	N	31	28	71	80
P	P	36	36	83	80
Total				536	720

From the table 5 above, it is known that the adaptive traffic light timing runs according to the density conditions of each lane, where lanes with low density conditions will get fewer green light than lanes with normal or high density conditions with a total cycle time of 536 seconds, less when compared to the fixed cycle time of 720 seconds.

4 CONCLUSION

Based on the results of design and testing in this final project, it can be concluded that:

1. The vehicle detection system using the HOG and SVM methods can work more optimally in lighting conditions above 200 lux with an average error of 1.56%.
2. The HOG and SVM methods are able to detect vehicle density on the path with 80% accuracy.
3. The Webster method is able to optimize the traffic light cycle time based on the density in each lane.

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