JAREE-Journal on Advanced Research in Electrical Engineering
Volume 3, Number 1, April 2019

Implementation of Background Subtraction and Fuzzy Logic Control for Green-Timing Optimization on 3-Junction Traffic Light

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***Abstract* - This study presents a green-timing optimization simulation on a 3-lane traffic light to reduce the density of the vehicle queue (density) in each lane. Green timing optimization method uses fuzzy logic control which is supported by image processing applications with background subtraction method. Background subtraction functions as density extractor and fuzzy logic control as the green-timing controller itself. Green-timing optimization simulations in this simulation show a decrease in waiting time in each cycle of timing and a decrease in traffic-density of 44% to 45% compared to a fixed-time timing system.**

Keywords* - *green-timing, background subtraction, fuzzy logic control, traffic light.

I. Introduction

The increase in the number of vehicles on the road has exponentially increased traffic density in most cities. Road infrastructure that is limited in accommodating traffic density worsens congestion on the road. Unexpected vehicle travel times and significant waiting times at intersections are the main causes of energy consumption and gas emissions [1].

Traffic management is managing and controling of traffic flow by optimizing the use of existing infrastructure to provide convenience to traffic efficiently in the storage of road space and facilitate the movement system [2].

A common reason for traffic jams is because of the poor priority of traffic light, where in some situations, less traffic congestion than others is given the same green signal duration for both [3]. In some cases, the traffic light is regulated by a fixed timing method. The controller will use a fixed time cycle in changing lights. The other method is that the traffic light is regulated by the 'time of the day' scheme. This arrangement basically uses a number of certain patterns that have been determined based on historical data and apply the patterns based on the day [4].

Low capital investment that can be done to break down road density is to do traffic light management optimization. A traffic control system will be very effective in maximizing road capacity by varying the time of traffic lights according to demand in real time. Timing of the appropriate traffic lights will be able to reduce the level of the queue at the crossroads and break down the queue of vehicles according to needs. This invited many researchers to develop a traffic light control system that is reliable in accommodating and reducing congestion levels in urban areas.

In this study try to combine background subtraction as an extractor of traffic-density values on each path with fuzzy logic control to determine the duration of the green light. As in previous studies that used load values on each pathway as input references for green light timing [5]. In some studies, applied fuzzy controls provide appropriate green time to effectively increase traffic capacity and reduce waiting times at intersections, which can guarantee that vehicles do not wait too long on the road [6].

II. Related Traffic Light System

The increase in the number of vehicles in the traffic light always varies every time, giving the duration of the green light which is always constant is not appropriate to control the density of vehicles in the traffic light. Providing a long green light duration while the lane density is very low makes the duration of the green light given for the pathway too excessive, the impact that occurs is waiting time duration for the next path remains long. Long of waiting time duration also has an impact on increasing vehicle density in the next path.

Some researchers have tried to adjust the duration of green light timing based on the density in each lane. Even Adam et al. try to change the timing of the displacement cycle in each pathway based on the priority scale density in each path. most researchers gave timing duration based solely on the conditions in each path without looking at the surrounding path conditions. whereas the density conditions on the next path must be considered and made as an additional reference to give the green timing durations in each path.

The purpose of this study is to utilize the fuzzy logic control method to determine the exact duration of the green light timing for each path in the three-lane traffic light. Fuzzy logic control is applied in two stages. the first stege, fuzzy determines the value of traffic-load on the path that will be given the green light timing as well as the load on the next path. the reference used in the first fuzzy stage is percentage of density, summing rate and flow rate of the vehicle on that path. the second stage, fuzzy determines green light timing duration based on the reference of the current path load and the load on the next path. Thus giving green light timing on each path will always be affected by the traffic-load conditions on the next path.

III. Green Light Timing Method

To assess one lane having a light or heavy loads, an information extraction process is needed from the lane itself. The first step is to measure the density of the vehicle against the road (traffic-density). Besides that the reference value of traffic loads is also taken from how fast the traffic-density increase (summing-rate) and how fast it breaks the traffic-density (flow-rate)

A. Traffic-Density Extraction

Traffic-density extraction is done by processing video traffic using the background subtraction method. The video with the appearance of the vehicle will be framed to get the foreground frame and each frame subtracted with the empty road frame of the vehicle (background frame). The difference between the foreground frame and the background frame is expressed as the object detected and the area of the object compared to the area of the road being a traffic-density value. Figure 1 below is an illustration of traffic-density extraction:

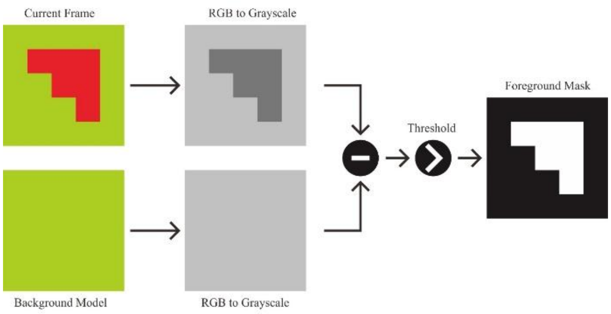

Fig. 1. Background subtraction scheme.

B. Summing-Rate Extraction

Summing-rate is the speed of increasing the traffic-density value when a line is in a red-light condition. Summing-rate is obtained from the difference in traffic-density values over the duration of the red light divided by the duration of the red light itself. Following are the equations to determine the summing-rate value.

Summing rate= δ traffic density on red/red duration (1)

C. Flow-Rate Extraction

Flow-rate is the speed of decreasing the traffic-density value when a line is in a green light condition. The flow rate is obtained from the difference in traffic-density values over the duration of the green light divided by the duration of the green light itself. Following are the equations to determine the flow-rate value.

Summing rate= δ traffic density on red/red duration (2)

D. Fuzzy Logic Control For Traffic Loads

Path loads is obtained from three references; traffic-density, summing-rate, flow-rate. Calculation to determine the weight value of a pathway is done by fuzzy logic method. Figure 2 below is a fuzzy logic scheme for extracting weight values

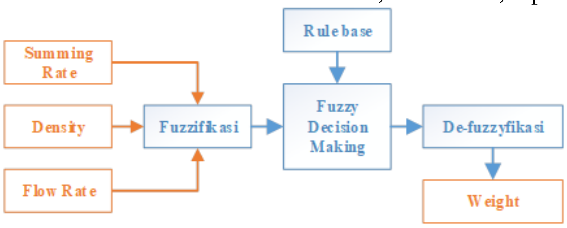

Fig. 2 Traffic loads extraction

Fuzzy logic control design to determine the traffic load values is shown in Figure 3.

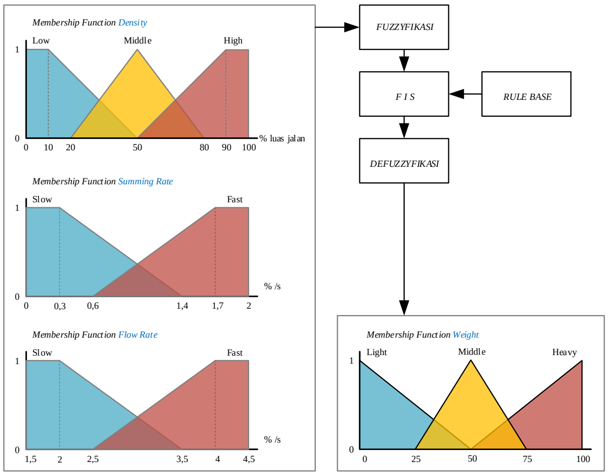

Fig. 3. fuzzy logic control for traffic load values

The membership functions of each variable are as follows:

- Traffic-density is divided into 4 membership functions.
  µDenLow[den] = {(1, den<10), ((50-den)/40, 10<den<50), (0, den>50)}
  µDenMidUp[den] = {(0, den<20), ((den-20)/30, 20<den<50)}
  µDenMidDown[den] = {((80-den)/30, 50<den<80), (0, den>80)}
  µDenHigh[den] = {(0, den<50), ((den-50)/40, 50<den<90), (1, den>90)}

- Summing Rate is divided into 2 membership functions.
  µSRSlow[sr] = {(1, sr<3), ((14-sr)/11, 3<sr<14), (0, sr>14)}
  µSRFast[sr] = {(0, sr<6), ((sr-6)/11, 6<sr<17), (1, sr>17)}

- Flow Rate is divided into 2 membership functions.
  µFRSlow[fr] = {(1, sr<20), ((35-sr)/15, 20<sr<35), (0, sr>35)}
  µFRFast[fr] = {(0, sr<25), ((sr-25)/15, 25<sr<40), (1, sr>40)}

- Traffic load values is divided into 4 membership functions.
  µLight[w] = {((1, w<0), ((50-w)/50, 0<w<50), (0, w>50)}
  µMidUp[w] = {(0, w<25), ((w-25)/25, 25<w<50)}
  µMidDown[w] = {((75-w)/25, 50<w<75), (0, w>75)}
  µHeavy[w] = {(0, w<50), ((w-50)/50, 50<w<100), (1, w>100)}

Following is the rule base to determine of traffic load values

[R1]	IF	DEN = LOW	&	SR = SLOW	&	FR = FAST	Then Weight = LOW
[R2]	IF	DEN = LOW	&	SR = SLOW	&	FR = SLOW	Then Weight = LOW
[R3]	IF	DEN = LOW	&	SR = FAST	&	FR = FAST	Then Weight = MUP
[R4]	IF	DEN = LOW	&	SR = FAST	&	FR = SLOW	Then Weight = MUP
[R5]	IF	DEN = MUP	&	SR = SLOW	&	FR = FAST	Then Weight = MUP
[R6]	IF	DEN = MUP	&	SR = SLOW	&	FR = SLOW	Then Weight = MUP
[R7}	IF	DEN = MUP	&	SR = FAST	&	FR = FAST	Then Weight = MUP
[R8]	IF	DEN = MUP	&	SR = FAST	&	FR = SLOW	Then Weight = MUP
[R9]	IF	DEN = MDO	&	SR = SLOW	&	FR = FAST	Then Weight = MDO
[R10]	IF	DEN = MDO	&	SR = SLOW	&	FR = SLOW	Then Weight = MDO
[R11]	IF	DEN = MDO	&	SR = FAST	&	FR = FAST	Then Weight = MDO
[R12]	IF	DEN = MDO	&	SR = FAST	&	FR = SLOW	Then Weight = MDO
[R13]	IF	DEN = HIGH	&	SR = SLOW	&	FR = FAST	Then Weight = MDO
[R14]	IF	DEN = HIGH	&	SR = SLOW	&	FR = SLOW	Then Weight = MDO
[R15]	IF	DEN = HIGH	&	SR = FAST	&	FR = FAST	Then Weight = HIGH
[R16]	IF	DEN = HIGH	&	SR = FAST	&	FR = SLOW	Then Weight = HIGH

Keterangan:

DEN = *Density* MUP = *Middle Up*
SR = *Summing Rate* MDO = *Middle Down*
FR = *Flow Rate*

E. *Fuzzy Logic Control For Green-timing*

Green-timings are obtained from two references; present-phase traffic load values and next phase traffic load values. We add the the next-phase traffic load values as an additional reference where some previous researchers only used the load values from one path only to determine the green light timing cycle [7] [8]. next-phase traffic load values is used as a reference consideration so that green timings are not excessive given in each cycle. Figure 4 below is a fuzzy logic scheme for green-timings.

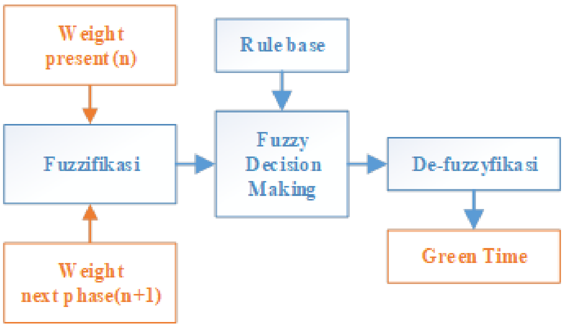

Fig. 4. Green light timing scheme

The fuzzy logic control design to determine the timing of the green light is shown in Figure 5.

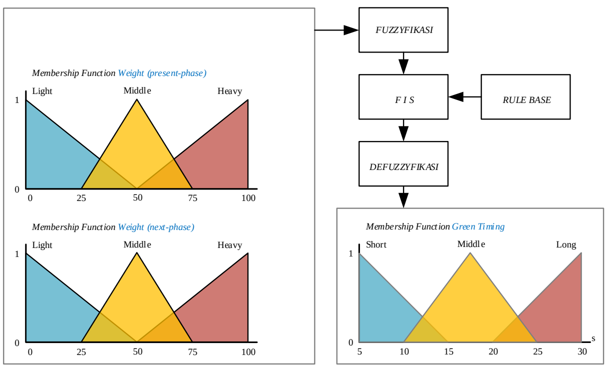

Fig. 5. Fuzzy logic control design for green light timing

The membership function for each variable is as follows:

- The present-phase traffic load values is divided into 4 membership functions
  µWPLight[wp] = {((1, wp<0), ((50-wp)/50, 0<wp<50), (0, wp>50)}
  µWPMidUp[wp] = {(0, wp<25), ((wp-25)/25, 25<wp<50)}
  µWPMidDown[wp] = {((75-wp)/25, 50<wp<75), (0, wp>75)}
  µWPHeavy[wp] = {(0, wp<50), ((wp-50)/50, 50<wp<100), (1, wp>100)}

- The next-phase traffic load values is divided into 4 membership functions
  µWNLight[wn] = {((1, wn<0), ((50-wn)/50, 0<wn<50), (0, wn>50)}
  µWNMidUp[wn]={(0, wn<25), ((wn-25)/25, 25<wn<50)}
  µWNMidDown[wn] = {((75-wn)/25, 50<wn<75), (0, wn>75)}
  µWNHeavy[wn] = {(0, wn<50), ((wn-50)/50, 50<wn<100), (1, wn>100)}

- Green light timings are divided into 4 membership functions
  µShort[gt] = {(1, gt<5), ((15-gt)/10, 5<gt<15), (0, gt>15)}
  µMidUp[gt] = {(0, gt<10), ((gt-10)/7,5)}
  µMidDown[gt] = {((25-gt)/7,5), (0, gt>25)}
  µLong[gt] = {(0, gt<20), ((gt-20)/10), (1, gt>30)}

Following is the rule base to determine of green light timing:

[R1]	IF	WP =	LIG	&	WN =	HEV	Then	GT =	SHO
[R2]	IF	WP =	LIG	&	WN =	MDO	Then	GT =	SHO
[R3]	IF	WP =	LIG	&	WN =	MUP	Then	GT =	SHO
[R4]	IF	WP =	LIG	&	WN =	LIG	Then	GT =	SHO
[R5]	IF	WP =	MUP	&	WN =	HEV	Then	GT =	SHO
[R6]	IF	WP =	MUP	&	WN =	MDO	Then	GT =	MUP
[R7}	IF	WP =	MUP	&	WN =	MUP	Then	GT =	MUP
[R8]	IF	WP =	MUP	&	WN =	LIG	Then	GT =	MUP
[R9]	IF	WP =	MDO	&	WN =	HEV	Then	GT =	MUP
[R10]	IF	WP =	MDO	&	WN =	MDO	Then	GT =	MDO
[R11]	IF	WP =	MDO	&	WN =	MUP	Then	GT =	MDO
[R12]	IF	WP =	MDO	&	WN =	LIG	Then	GT =	MDO
[R13]	IF	WP =	HEV	&	WN =	HEV	Then	GT =	MDO
[R14]	IF	WP =	HEV	&	WN =	MDO	Then	GT =	LON
[R15]	IF	WP =	HEV	&	WN =	MUP	Then	GT =	LON
[R16]	IF	WP =	HEV	&	WN =	LIG	Then	GT =	LON

Keterangan:

WP = *Weight Present-Phase* LIG = *Light*
WN = *Weight Next-Phase* MUP = *Middle Up*
GT = *Green Time* MDO = *Midle down*
HEV = *Heavy*
SHO = *Short*
LON = *Long*

IV. RESULT ANDDISCUSSION

A. *Traffic-Density Extraction Simulation*

The following will show the results of the traffic-density extraction simulation

Fig. 6. Background subtraction simulation

During the simulation process, traffic-density data is obtained as shown in Figure 7.

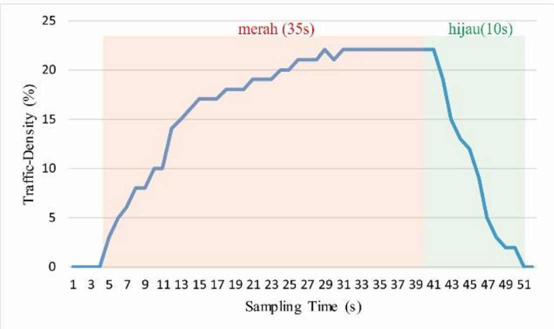

Fig. 7. Traffic density

From the graph data image 7. We can conclude the summing-rate and flow-rate values. The following is the calculation of the summing-rate and flow-rate values.

Summing-rate (%) = 22/35 = 0.63%

Flow-rate (%) = 22/10 = 2.2%

B. *Green Light Timing Simulation*

In this section will be displayed the results of the optimization of the green light timing system using fuzzy logic control on the green light timing system using fixed-time on three-lane traffic light. Figure 8 below is a 3-way traffic light simulation display.

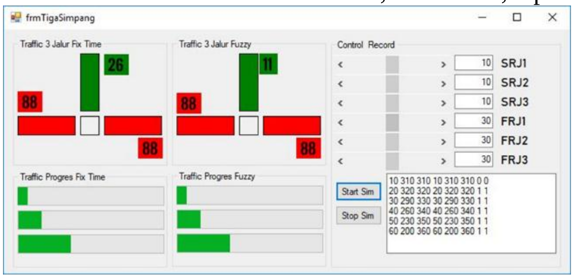

Fig. 8. 3-Juntion traffic light simulation

During the simulation data obtained from the comparison of the two timing systems. Optimization occurs in decreasing the duration of waiting time in each path. for example, we will display graph data optimizing the reduction of waiting time from line 2 to line 3. The first test is done by giving medium loading for all lines. In figure 9, a comparison of the duration of waiting time is shown on line 2.

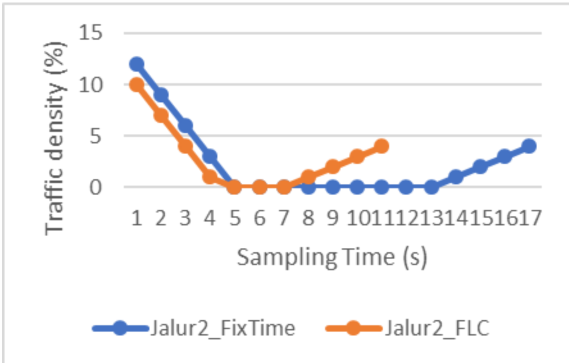

Fig. 9. Waiting time comparison on line 2 .
(*medium for all line*)

The graph in Figure 9. shows the traffic-density fixed-time line 2 has a vacuum for 20 seconds. Whereas the traffic-density line 2 of FLC has a vacuum of only 6 seconds. A short decrease in waiting time will optimize the cycle of timing changes in each path. the effect of a decrease in waiting time in each lane is a decrease in traffic-density value and the number of turnover cycles for each path. For example, in figure 10, there is a traffic-density data that occurs in line two for a span of 320 seconds

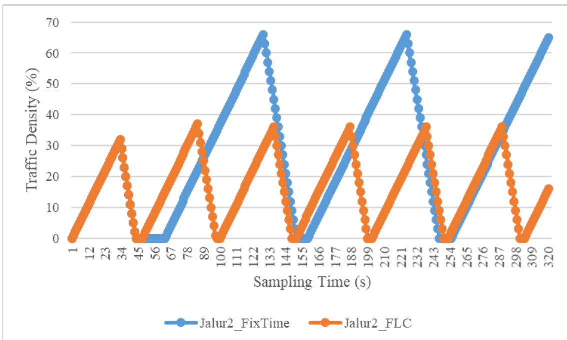

Fig. 10. Traffic density on line 2.
(*Medium on all line*)

From the graph in figure 10. we can see that the green light timing system uses fuzzy logic control to provide optimization on two things

- Traffic-density mampu diturunkan hingga 44%
- Siklus pergantian pewaktuan mampu dipercepat. Siklus fixed-time adalah 3,5 sedangkan siklus fuzzy logic control adalah 6,25

The second test, line 1, is given light load and medium load is given for lines 2 and 3. As in the previous test, we will show the optimization of the reduction in waiting time from line 2 to line 3. Comparison of waiting time for line 2 in the second test can be seen in figure 11.

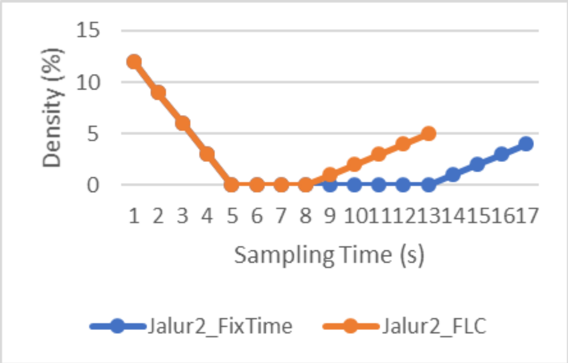

Fig. 11. Waiting time comparison on line 2.
(*light on line 1 & medium on line 2, 3*)

The graph in Figure 11. shows the traffic-density fixed-time 2 line has a vacuum for 9 seconds. While the traffic-density path 2 of FLC has a vacuum of only 4 seconds. A short decrease in waiting time will optimize the cycle of timing changes in each path. the effect of a decrease in waiting time in each lane is a decrease in traffic-density value and the number of turnover cycles for each path. For example, in figure 12, there is a traffic-density data that occurs in line two for a span of 320 seconds.

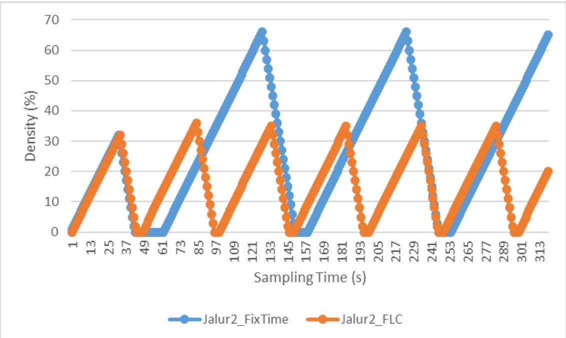

Fig. 12. Traffic density on line 2.
(*light on line 1 & medium on line 2, 3*)

From the graph in figure 12. we can see that the green light timing system uses fuzzy logic control to provide optimization on two things:

- Traffic-density can be reduced to 45.45%
- The timing turnover cycle can be accelerated. The fixed-time cycle is 3.5 while the fuzzy logic control cycle is 6.25

The third test, line 1 is given heavy loading and light loading is given for lines 2 and 3. As in the previous test, we will show the optimization of the reduction in waiting time from line 2 to line 3. Comparison of waiting time for line 2 in the second test can be seen in Figure 13.

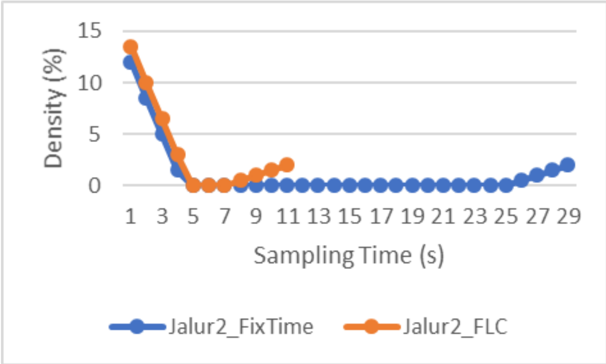

Fig. 13. Waiting time comparison on line 2.
(*heavy on line 1 & light on line 2, 3*)

The graph in Figure 13. shows that traffic-density 2 fixed-time lines have a vacuum for 21 seconds. Whereas the traffic-density line 2 of FLC has a vacancy of only 3 seconds. A short decrease in waiting time will optimize the cycle of timing changes in each path. the effect of a decrease in waiting time in each lane is a decrease in traffic-density value and the number of turnover cycles for each path. For example, in Figure 14, there is a traffic-density data that occurs in line two for a span of 320 seconds.

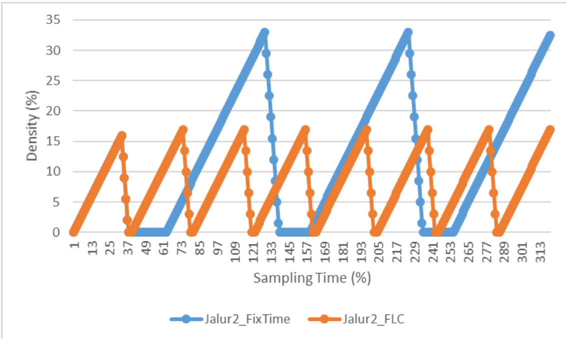

Fig. 14. Traffic density on line 2.
(*heavy on line 1 & light on line 2, 3*)

From the graph in Figure 14. we can see that the green light timing system uses fuzzy logic control to provide optimization on two things

- Traffic-density can be reduced to 45.45%
- The timing turnover cycle can be accelerated. The fixed-time cycle is 3.5 while the fuzzy logic control cycle is 7.5

V. Conclusion

The green-timing timing system on the traffic light uses a combination of background subtraction and fuzzy logic control capable of optimizing the traffic light timing system in reducing waiting times in each path which has an effect on decreasing traffic-density. The background subtraction method in general is quite good at mapping traffic-density in each path, but it is undeniable that the background subtraction method has a weakness when it detects vehicle objects that have colors close to the background frame color. The value of the RBG foreground frame that approaches the RGB background frame value makes an object that must be measured and measured to be undetectable. This condition allows the mapping of traffic-density to be less than optimal. Besides controlling the timing using fuzzy logic control can reduce waiting time which has an effect on the fast turnover cycle turnover and decrease in traffic-density up to 44% to 45% compared to the fixed-timing system. in a duration of 320 seconds the fixed-time timing method experiences a timing cycle of 3.5 times while the timing method uses fuzzy logic control which has been able to increase the timing of the rotation cycle of 6.25 to 7.5 times.

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