Adaptive Traffic Light Controller using FPGA

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***Abstract*—Through this paper, the design of ATLC using Spartan 3E FPGA is presented. It adapts to the traffic based on density and it prioritizes emergency vehicles like ambulance, fire brigades etc. Due to urbanization, the number of vehicles in metropolitan cities has increased tremendously resulting in increase in traffic congestion. Traffic control is a challenging task since its proper operation can bring the difference between smooth flowing traffic and a grid-lock. Generally, the traffic signals are fixed-time signals which follow a pre-determined sequence of signal operation, always providing the same amount of time to vehicle movement whether traffic is present or not. This consumes more time and doesn't have any provision for sensing and prioritizing emergency vehicles. This problem can be overcome by using adaptive traffic light controller implemented on FPGA. The system is designed to sense the traffic density and the presence of any emergency vehicles on individual roads. Once an emergency vehicle is sensed, priority is given to the traffic of that particular direction. During normal operation, the signal will be controlled based on traffic density. The system has been designed using Verilog HDL and is implemented on Spartan 3E FPGA. This system overcomes the limitations of conventional TLC by efficient traffic road management.**

Keywords— Adaptive Traffic Light Controller (ATLC), Finite State Machine (FSM), Field Programmable Gate Array (FPGA), Density Sensor (DS)

I. INTRODUCTION

One of the greatest obstacles is applying sound principles to traffic engineering is that simply installing a traffic signal will solve any traffic problem. The traffic control mechanism currently being used doesn't have a provision for ensuring smooth movement of ambulance. During peak hours, when people are travelling, traffic will be maximum. The absence of an effective ATLC system results in traffic jams. This could lead to loss of life due to the inability of the ambulance to reach the hospital on time. The problem arises due to an imbalance in the traffic movement at the junctions which causes major congestion on the affected directions. For this, many ideas about the traffic control systems have come up in the recent past to simplify the complex problem of the traffic congestion. [1] B. Dilip et al. have implemented FPGA based advance traffic light controller which controls the traffic light based on traffic density. However, this paper does not allocate appropriate time for green signal based on the density. Also, it does not function effectively when two or more roads have same amount of traffic. [2] D. Bhavana et al. have presented traffic light controller, wherein specific switching mechanism is used to control traffic effectively. [5] Sourav Nath et al. have designed FPGA based intelligence traffic light controller for 12 roads with 6 traffic lights. [7] Shwetank Singh et al. have implemented FPGA based dynamic traffic controller which alters the timing based on density of traffic. [8] Taehee Han has implemented intelligence traffic light Controller (ITLC) with VHDL which saves time by allocating signal timing based on the width of the road, but no provision to detect the presence of ambulance in order to ensure smooth ambulance movement. The above methods for traffic control have dynamic allocation of time based on density but don't prioritize any emergency vehicle in the road. The adaptive traffic light controller (ATLC) presented in this paper is designed using less number of states compared to above mentioned papers. Also we have employed One-hot encoding for the FSM states. This makes operation run faster. The ATLC ensures smooth movement of emergency vehicles by continuously checking for the presence of an emergency vehicle and prioritizing the road with the emergency vehicle. Adaptive traffic light controller reduces conflicts in an area that is shared amongst multiple intersections. This is done by controlling the access to junctions and allocating effective time period between various users. ATLC has been implemented using FPGA. The advantages of using FPGA over Microprocessors are more number of input and output ports, improved performance, high speed, design flexibility etc. which are all very important in ATLC design, at the same time it is cheap compared to ASIC since mass production of custom IC becomes prohibitively expensive due to small quantity.

II. BLOCK DIAGRAM

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The idea of ATLC is to develop a 24-hr traffic light controller to manage the traffic movement of the roads at the same time, achieving maximum utilization of the roads and to ensure smooth movement of ambulance at the junction. Maximum utilization of the road is achieved by measuring the traffic density with the help of sensors. The sensors are placed along each side of the intersection at fixed distances from the signal. All these sensors are interfaced to the controller (FPGA). The block diagram of adaptive traffic light controller is shown in fig.1. Whenever vehicles reach the junction along each side, the sensor detects the vehicles and sends a signal to the controller. Based on the number of sensors active along each road the controller decides which of the four roads has more traffic and makes it green. The controller also determines the time for which the signal will be green based on the number of active sensors. However, if an ambulance present at one of the roads; the road where it is present will go green, ensuring it passes smoothly.

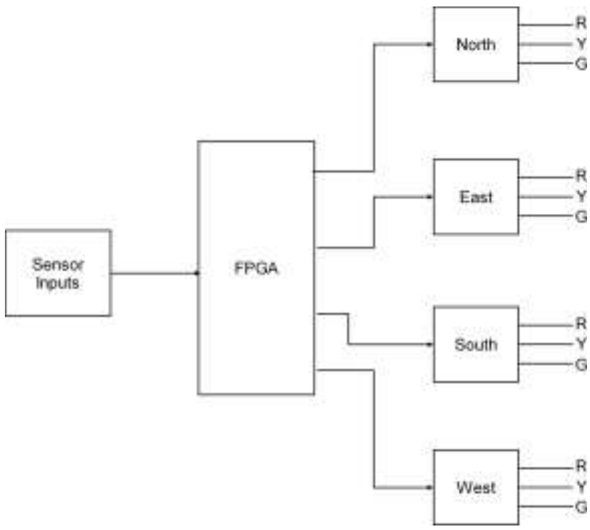

Fig. 1. Block Diagram

III. METHODOLOGY

The road structure depicted in fig.2 has four traffic signals across each road at the junction. The four traffic signals are represented by N, E, S, and W.

Along each of these roads four sensors are placed at a fixed distance from the traffic signal. These sensors detect the density of traffic across each road.

Another set of sensors which is used to detect the ambulance are placed along each of the four roads.

The sensors (density detection) across each road are named as:

- Along N side: A1, A2, A3 & A4
- Along E side: B1, B2, B3 & B4
- Along S side: C1, C2, C3 & C4
- Along W side: D1, D2, D3 & D4

The sensors placed for detection of ambulance are:

- Along N side: Z1
- Along E side: Z2
- Along S side: Z3
- Along W side: Z4

The road where an ambulance is detected will go green. The traffic signal at that road remains green until the ambulance passes the signal. Otherwise, the traffic signal at the road which has the highest number of active sensors at a given instant of time will go green. The duration for which it remains green depends upon the number of sensors active at that road. The operation of the ATLC can be divided into three modes:

- Emergency mode:
  When an ambulance is detected at any sides of the roads at the intersection, the road where the ambulance is present goes green. It remains green until the ambulance has passed the signal.

- Negligible traffic mode:
  The ATLC operates in this mode when there is very little traffic. During off peak hours when none of the sensors are active, the ATLC operates in normal traffic sequence i.e. clockwise in this case.

- Heavy traffic mode:
  This mode arises when at least one of the sensors along the road is active. When there is heavy traffic along a particular road, the traffic signal at that particular road goes green and remains green until the traffic at that road is cleared.

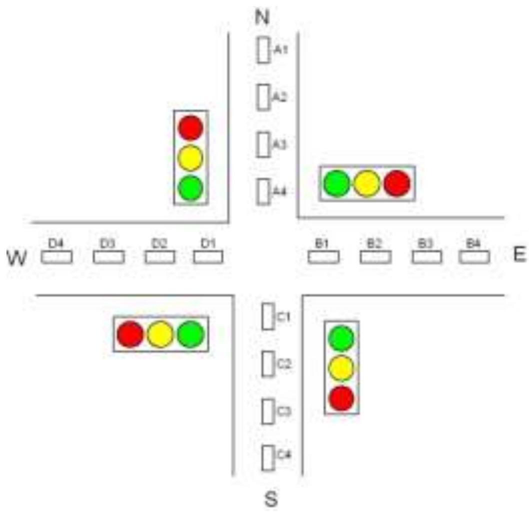

Fig.2 . Four way traffic signal with sensor

The timing set for the ATLC is as follows:

- Emergency mode:
  Once an ambulance is detected:
  GREEN
  The signal will be green for 6s before turning amber
  AMBER
  The signal will be amber for 3s before turning green again.
  The cycle repeats until the ambulance passes the signal.

- Less traffic mode (sensors inactive):
  GREEN
  The duration of green light at all the traffic signals is for 6s.
  AMBER
  The duration of amber light at all the traffic signals is 3s when there is negligible traffic.
  RED
  The duration of red light at all the traffic signals is 6s when there is less/negligible traffic.

- Heavy traffic mode:
  During this time sensors will be active. Depending upon the number of sensors active the duration of red/green light will be set. The timing of amber light remains 3s.
  The timing for green light depending upon the number of active sensors is summarized in Table.1.

Table.1. Delay Table

No. of sensor/sensors active	***Timing***
1	***6s+5s=11s***
2	***6s+10s=16s***
3	***6s+15s=21s***
4	***6s+20s=26s***

Here 6s is the time for green/red during regular sequence (low traffic condition)
If an ambulance is detected at any one of the roads, the road where it is present will go green for 6s and then turns amber for 3s. The traffic light continuously switches from green to amber while other signals remain red until the ambulance passes the signal. Consider the condition where there's heavy traffic at N and W sides, moderate traffic at E and S sides. Let the number of active sensors at N, W, S, E side be 4,3,2,1 respectively.

First the traffic signal at N side will go green and will remain green for about 26s.The remaining roads remain red meanwhile. Next the signal at W side goes Amber for about 3s and then turns green. It remains green for 21s. Now the signal at S side goes amber for 3s before going green for 16s. Finally, the signal at E side goes amber for about 3s and turns green for 11s. Fig.3. illustrates the flowchart of ATLC.

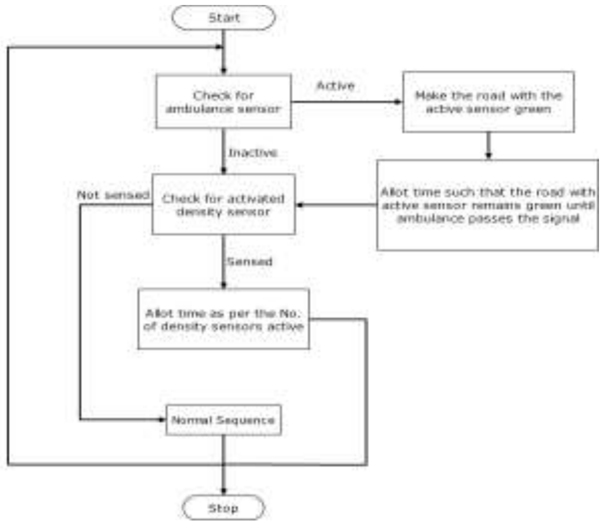

Fig.3. Flow chart of ATLC

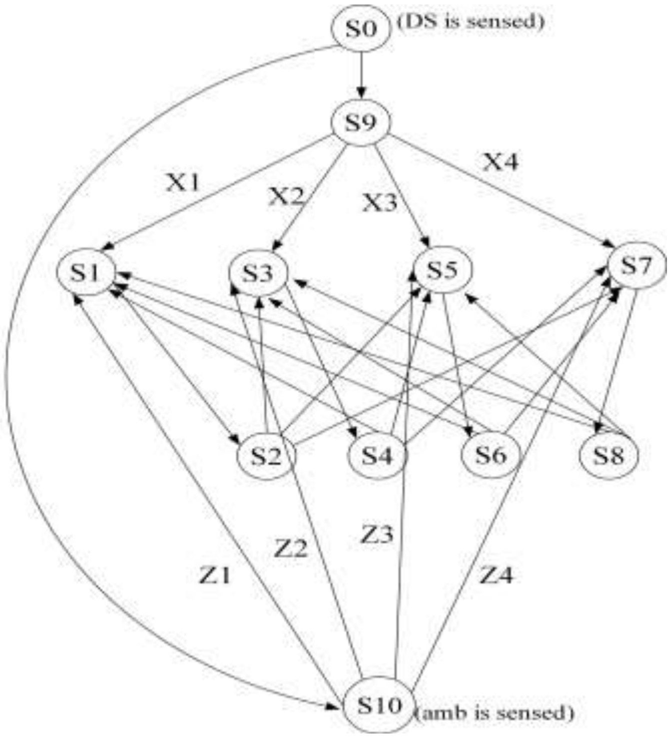

Fig. 4 State diagram

Fig.4 and Table.2 depict the state diagram and state transition table of the adaptive traffic light controller respectively. S0 is the default state. The comparison of density takes place in S9 state. Depending upon which of the roads have higher density the state changes. Also, a delay is generated for green light depending upon the number of sensors active. For instance, If X1 is active the transitions take place from S0 to S1 and finally to S2 where N turns green. Depending upon the number of sensors active along the N side, a delay is generated. In case of emergency if any of the roads have ambulance sensor active then the transition will take place from the existing state to the state where the road with the ambulance sensor active goes green.

Table.2. State transition table

Traffic of Road	State responsible for allowing Traffic to pass	Traffic Light	Sensor Status				Time alloted for respective traffic light(in sec)
	S0	R	Amb->S10, Density->S9, Otherwise=S1				
	S9	R	Density sensor sensed				
N	S1	Y	(X1 is sensed)				(3s)
	S2	G	A1	A2	A3	A4	default (6s)
			1	0	0	0	6+5
			1	1	0	0	6+10
			1	1	1	0	6+15
			1	1	1	1	6+20
E	S3	Y	(X2 is sensed)				(3s)
	S4	G	B1	B2	B3	B4	default (6s)
			1	0	0	0	6+5
			1	1	0	0	6+10
			1	1	1	0	6+15
			1	1	1	1	6+20
S	S5	Y	(X3 is sensed)				(3s)
	S6	G	C1	C2	C3	C4	default (6s)
			1	0	0	0	6+5
			1	1	0	0	6+10
			1	1	1	0	6+15
			1	1	1	1	6+20
W	S7	Y	(X4 is sensed)				(3s)
	S8	G	D1	D2	D3	D4	default (6s)
			1	0	0	0	6+5
			1	1	0	0	6+10
			1	1	1	0	6+15
			1	1	1	1	6+20
	S10	R	Amb is sensed				
N	S1	Y	(Z1 is sensed)				(3s)
	S2	G					(6s)
E	S3	Y	(Z2 is sensed)				(3s)
	S4	G					(6s)
S	S5	Y	(Z3 is sensed)				(3s)
	S6	G					(6s)
W	S7	Y	(Z4 is sensed)				(3s)
	S8	G					(6s)

IV. IMPLEMENTATION AND RESULT

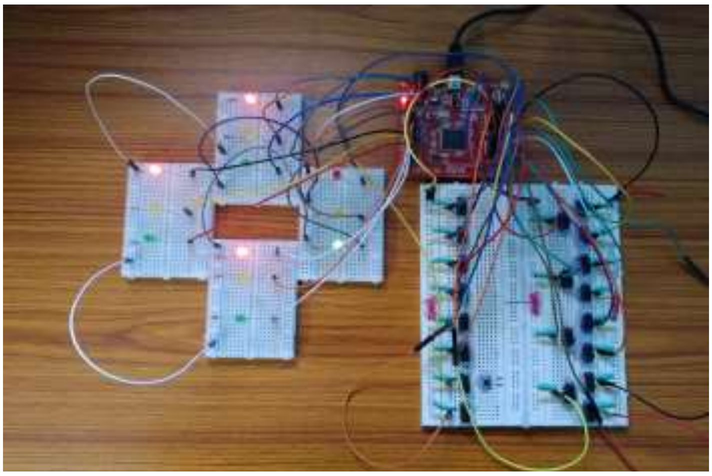

Fig.5. Implementation of ATLC using FPGA

The hardware for Adaptive Traffic Light is implemented using Papilio One 500k FPGA Board as shown in fig.5. The code is synthesized using Xilinx ISE and the RTL Schematic diagram is shown in Fig.6. Three LEDs (Red, Yellow, and Green) are connected on a breadboard representing a road and four of such combination represents a four-way traffic structure. Four switches are connected along each road (N, E, S, and W) to indicate density. Additional four switches are used to indicate an emergency vehicle. We have used four switches along each road as to demonstrate the proof of concept. In reality the switches can be replaced with the appropriate sensors like IR sensors, Magnetic sensors etc. However the basic idea remains the same. The four sensors along each of the four roads will make it easier to calculate the density. When the vehicles start to fill up the road, the sensors gets activated one by one. The sensor outputs are then added to find the amount of density in each road. The density of all the four roads is compared and the road with maximum density is selected. Appropriate time is allotted for the signal depending on number of sensors active (Table 1.)

Fig.7, 8 and 9 depict the simulation results obtained for various conditions wherein different sets of sensors are activated.

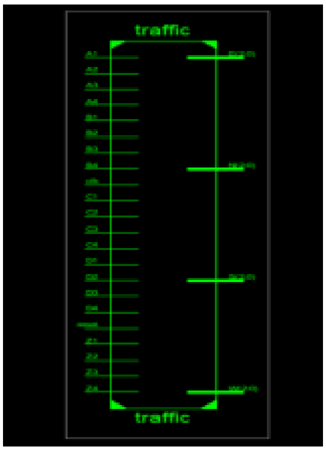

Fig.6. RTL Schematic of ATLC

Testbench results:

Case (i) Sensor Z4 is sensed along West side

Fig.7. Sensor Z4 is sensed along West side

Input Z4 is activated along west side indicating the presence of an ambulance/emergency vehicle. This road is given priority over any other road and needs to be cleared first. This feature is demonstrated in both simulation and hardware

Case(ii) 3 sensors on East side and 4 sensors on West side are activated

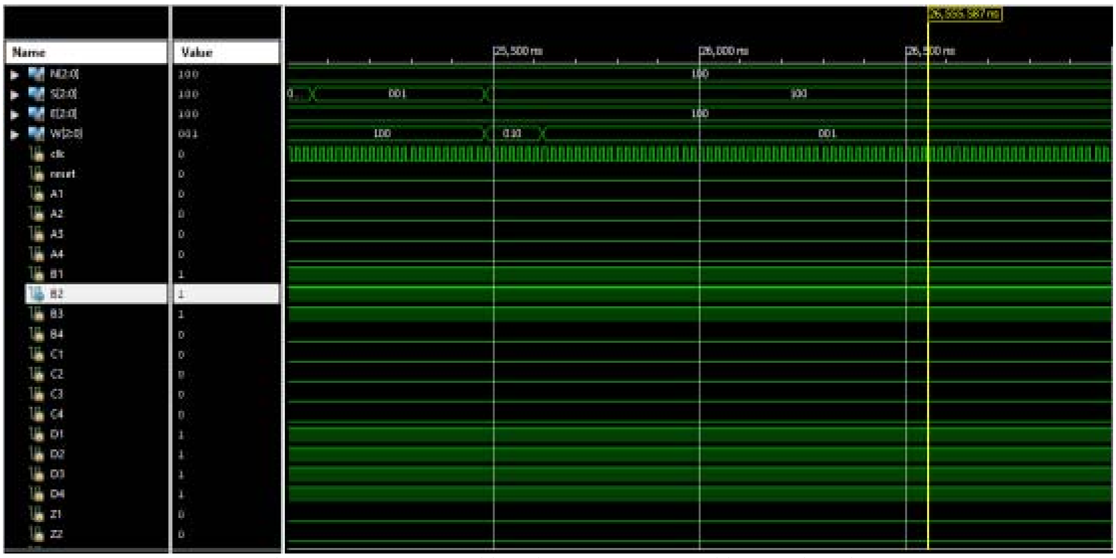

Fig.8. 3 sensors on East side and 4 sensors on West side are activated

The ATLC compares all the four roads for maximum density and selects the road with four sensors activated. The green light will be ON for 6 + 20s. The result is obtained as expected both in simulation and hardware.

Case(iii) Sensor Z2 is activated on East side and 3 sensors are activated on South side

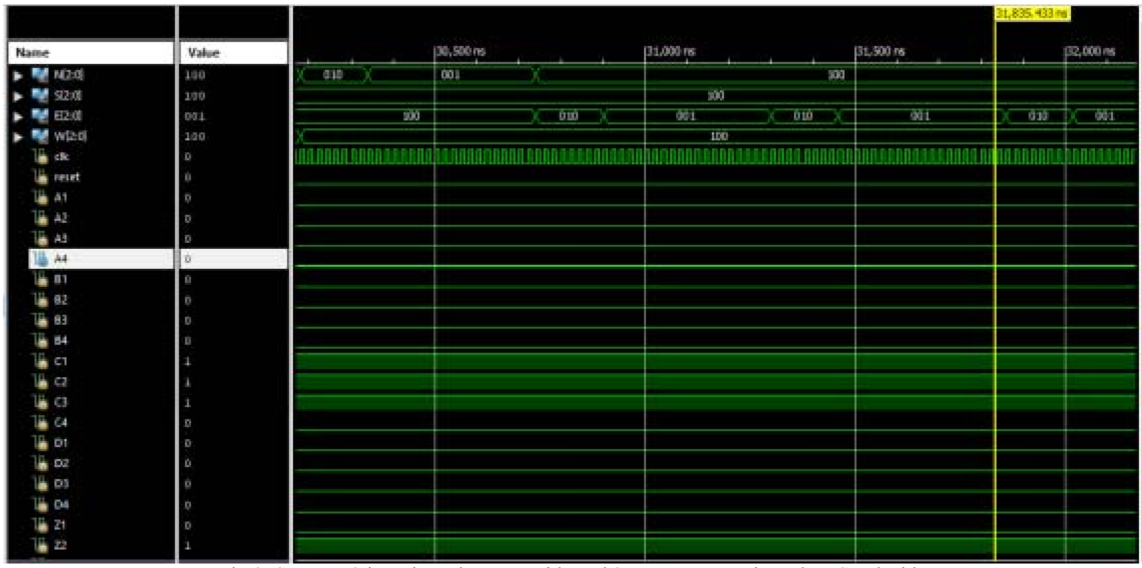

Fig.9. Sensor Z2 is activated on East side and 3 sensors are activated on South side

Z2 is activated on East side and three density sensors are activated on South side. As the priority is given to ambulance over density the ATLC selects the East side. The result is obtained as required both in simulation and hardware.

V. CONCLUSION

An Adaptive traffic light controller using FPGA has been successfully designed, simulated, implemented and the desired results are obtained. The system has been designed using Verilog HDL and is implemented on hardware on Spartan 3E FPGA using Papilio One 500k FPGA Board. The traffic density at each of the four roads is sensed and accordingly time is allocated to the signal with maximum density such that the traffic at that road is cleared. This system provides an efficient way for allocating the time to signals depending on density and also has a provision to detect and give priority to ambulance. It overcomes the limitations of conventional traffic controllers, with the capability of providing varying green cycle interval based on dynamic traffic load changes at every lane. The design of the ATLC is easy to realize and implement. It provides a fast response time ensuring efficient traffic management. This design can further be modified by incorporating changes based on the topology of an area.

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