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FPGA-Based Intelligent Traffic Controller with Remote Operation Mode

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ABSTRACT

This paper covers the design and implementation of an intelligent traffic management system for an isolated intersection. The vehicular traffic management system employs Field Programmable Gate Array (FPGA) as the central decision-making unit and combines its speed and high number of I/O with other system components such as the ESP8266 Wi-Fi module, to record real-time traffic information and apportion green-time for each phase of traffic signal. The design and implementation incorporate three different operational modes namely, fixed time mode, sensor actuated mode and remote control mode, to alleviate vehicular traffic congestion and also reduce the risk of accidents at intersections. The incorporation of remote control mode, which enables an authorized personnel to remotely control the traffic, using a cloud-based application running on a portable device, makes this system different from previous works. Simulation using a prototype of the model on a model intersection, shows that the system can reduce waiting time and increase throughput at the intersections.

Keywords: Intelligent Traffic; FPGA Traffic Controller; Remote Control; Busy Intersection.

1. INTRODUCTION

The problem of vehicular traffic congestion is one that accompanies development and urbanization in every country. Road traffic congestion is undesirable for reasons such as increased pollution levels [1], high risk and rate of vehicular accidents due to driver impatience and massive economic losses. Since urbanization is inevitable and hence its accompanying road traffic congestion problem [2], various ways must be devised to reduce the road traffic congestion as much as possible. One attempt by government to handle the congestion problem is to construct more roads. But construction of more roads (increasing resources) alone does not deal with traffic congestion since busy intersections and connecting roads can become bottle neck to traffic flow. Thus, effective and efficient management systems should be developed to manage increasing traffic, especially at busy intersections, to maximize throughput and minimize crashes. The two main means of vehicular traffic control at busy intersections are through the use of traffic signal light and human traffic conductor. However, the existence of a traffic signal light or human traffic conductor does not necessarily alleviate traffic congestion at busy intersections in most cases.

In the case of traffic signal light, majority intersections use the fixed-time sharing and the sharing policy is designed at the time of construction. This means, any drastic change in traffic dynamics such as happens during peak hours can create traffic congestion. Besides, when there is the need to give right of way to priority vehicles, these traffic controllers become handicapped. The human traffic controllers are used mostly as a solution to the congestion caused by drastic change in traffic dynamics; malfunctioning traffic signals or to give right of way to priority/emergency vehicles such as fire trucks, ambulances, police responding to duty call, etc. The human conductors usually stand at the center of the intersection and direct drivers using hand gestures. The human traffic conductors are however not efficient since the humans, though supposed to act as feedback control system, have limitation such as:

a) limited field of view and therefore limited information about traffic dynamics, consequently queue management is not optimized due to limited knowledge of queue growing rates on specific roads;
b) sometimes, the traffic conductors' signals conflict with that of the traffic lights when they are on at the material moment, thereby creating confusion and occasionally leading to accidents;
c) some drivers may not see the police conductors' signals which are usually hand gestures and this can lead to accidents; and
d) the human traffic conductors can easily get distracted by drivers, phone calls, etc.

In order to address these challenges, this paper employs three different operational modes of traffic signal control namely:

a) the adaptive/sensor actuated mode,
b) the remote control mode, and
c) the fixed-time mode.

The actuated mode is the main operational mode for the system. The remote control mode is used to grant access to emergency vehicles and whenever it becomes necessary for human conductors to step in (example, due to sensor malfunctioning). The fixed-time mode is used to control traffic during maintenance or when there is sensor failure. Many researchers/authors have argued the superiority of FPGA over ASIC and Microcontrollers and proceeded to develop Traffic Light Controllers (TLC) using FPGA [3–5]. However, to the best of the authors' knowledge, none of them provides a remote control interface for human conductors. This paper presents a system with an option for an authorized personnel to control the traffic light using an application running on a portable device. The rest of the paper is organized as follows: Section 2 covers the literature review and related works; section 3 covers the design and implementation methodology with detailed description of the controller architecture and operational modes; section 4 covers the description of the prototype and results; followed by conclusion and future work.

2. RELATED WORKS

Research into intelligent traffic control begun decades ago and has received great attention in the past two decades. The ultimate research issues that researchers seek to address in the area of intelligent traffic control include, but not limited to, how to reduce traffic congestion [6]; avoid crashes [7]; automatically give right of way to emergency vehicles [8]; provide road traffic information to users; allow remote control of traffic at intersections; and coordinate the traffic flow through adjacent intersections [9]. In general, the intelligent traffic controller involves both hardware and software. The hardware includes the central processing and control unit, sensors for vehicular traffic density and flow estimation, communication hardware for interconnecting the sensors and the hardware, and database for storage and retrieval of traffic information. The software includes intelligence program for traffic flow/density estimation using sensor data, time allocation algorithms, communication protocols for communication, and traffic flow coordination algorithms. The data acquisition usually involves the use various sensors such as the inductor loop detectors, microwave detectors, radar detectors, infrared sensors, ultrasonic detectors, acoustic detectors, magnetometers and traffic cameras [8]. Researchers in [10] designed an IoT based intelligent traffic signal system to decongest intersections on the arrival of emergency vehicle to give right of way to lane with the emergency vehicle. They made use of Node MCU 1.0 DEVKIT for message transmission, Raspberry Pi for data connectivity between various messages, RFID Tag and Readers for identification of emergency vehicles. The raspberry Pi is the main central processing unit and the Node MCU is used for wireless communication of the RFID tag reader's signal to the Raspberry pi.

In [11], a traffic flow control algorithm which has two aspects was proposed. The first aspect is the prioritization of roads and the second aspect is the allocation of green-time duration of the traffic signal. The system has been developed using Laboratory Virtual Instrument Engineering Workbench (LabVIEW) which allows for effective real-time camera interfacing and image processing along with control of traffic lights. Researchers in [12] made an attempt to provide some traffic management strategy which is self-changing in nature, so as to fit in to continuously changing real time traffic scenarios. The work seeks to address two main problems, heavy traffic jams during peak hours and allocation of green-time to roads when there is no traffic on them using image processing based traffic light controller. The work in [13] focused on presenting a new framework for traffic density estimation based on a topic model, which is an unsupervised model. The paper used two thresholds to determine types of traffic density such as light-density, medium-density and high-density. They evaluated their approach using the University of California San Diego (UCSD) database [14]. Reference [15] presented a framework for developing a new intelligent traffic control system for Taiwan in the form of a Mobile Intelligent Traffic Control System (MITCS). They emphasized on interconnection of controllers using wireless media, reducing size and cost and usage of non-intrusive optical vehicle detection systems. Researchers in [3] developed a new method for designing and simulating an intelligent traffic control system based on Mamdani fuzzy logic controller using FPGA. They made use of traffic density and average vehicular speed for the green-time allocation. However, special vehicles have to key in codes before they are given a right of way.

Researchers in [16] built a prototype of an adaptive traffic control system which uses proximity sensors for vehicular frequency detection and uses the vehicular frequency to select from a set of 5 time categories to set the green-time for a traffic light. Researchers in [2] presented a prototype but did the extraction using MATLAB and vehicular counting using remote controlled vehicles. The paper did not account for heavily congested intersections. Other researchers have considered the use of artificial intelligence manage vehicular traffic and reduce congestion [17]. The system presented in this paper, among others, incorporate the use of adaptive time sharing and IoT based remote control interface to reduce traffic congestion at a busy intersection and allow human conductors to give right of way to priority/emergency vehicles by remotely controlling the traffic signals.

3. DESIGN METHODOLOGY

The architecture of the system consists of both hardware and software components. The hardware consists of:

a) main central processing unit for the system;

b) an array of sensors;
c) a WIFI-Module; and
d) a remote control hardware (which is a mobile phone)

The software consists of a (a) queue length estimation and green-time allocation software; and (b) remote control interface. These components are categorized into three as depicted in Figure 1 and described below.

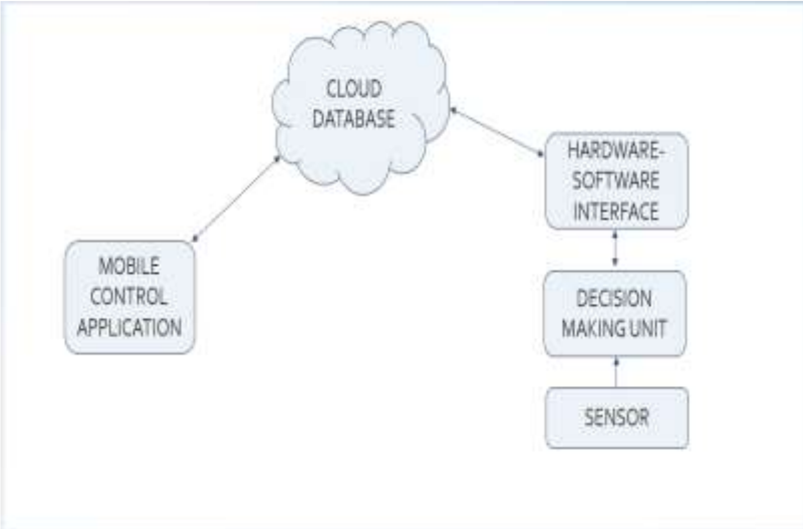


Figure 1. Architecture of proposed system

3.1 Field components

This consists of sensors which collect traffic density data; decision making unit which is responsible for making the real-time traffic decisions based on inputs from the sensors and software-hardware interface which is responsible for interfacing the decision making unit with cloud database i.e. it is responsible for receiving and implementing remote instructions.

3.2 Cloud Components

This is a secured database for storage and retrieval of the current state of the traffic signal. The cloud also serves as a bridge between the remote control interface and the controller.

3.3 Remote Control Component

The remote control component is a mobile interface with a mobile application that serves as the human-machine interface. This enables an operator to remotely check the status of the traffic signals as well as switching from one mode to another.

3.4 Intersection Description

Figure 2 shows the model of the intersection that was used for testing of the system. This assumes an intersection that connects two busy roads. The intersection is equipped with six traffic signal lights labelled T1, T2, T3, T4, T5 and T6. Each signal light has a red (R), an amber (Y) and a green (G) lamp. T1 and T3 control traffic flow from North to South and from South to North respectively.

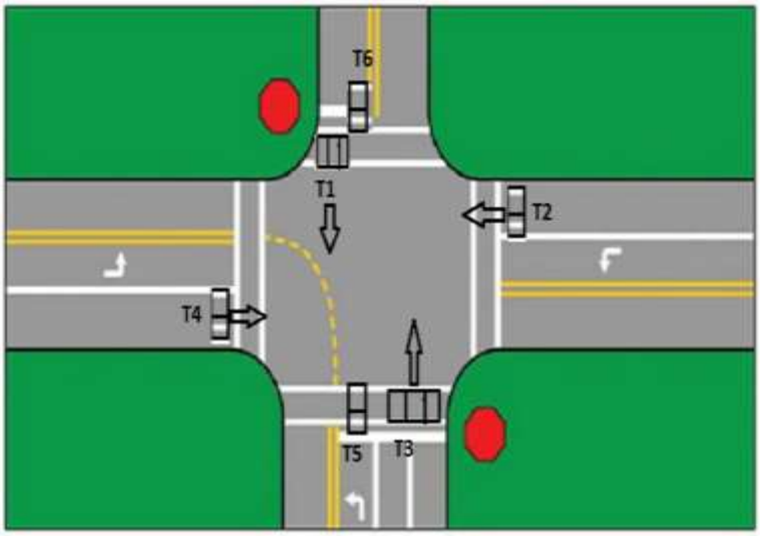


Figure 2. Architecture of proposed system

T2 and T4 control traffic flow from East to West and from West to North respectively. T5 controls traffic turning from North unto the East Road while T6 controls traffic turning from the South unto the East Road. This is modelled after one of the busiest intersections in Kumasi, Ghana – the Anloga Junction intersection. Currently, the junction is controlled by a fixed-time traffic controller. The duration of phase 1 is 60 seconds. Phase 2, Phase 3 and Phase 4 last for 22 seconds each. Table 1 shows the traffic light configuration for the various states (phases).

Table 1. Traffic light configuration for the various states of the model intersection.

	T1	T2	T3	T4	T5	T6
State 0	**R**	**R**	**R**	**R**	**R**	**R**
State 1	**G**	**R**	**G**	**R**	**R**	**R**
State 2	**Y**	**R**	**Y**	**R**	**R**	**R**
State 3	**R**	**G**	**R**	**G**	**R**	**R**
State 4	**R**	**Y**	**R**	**Y**	**R**	**R**
State 5	**R**	**R**	**R**	**R**	**G**	**R**
State 6	**R**	**R**	**R**	**R**	**Y**	**R**
State 7	R	R	R	R	R	**G**
State 8	R	R	R	R	R	**Y**

3.5 Operational Modes

The intelligent traffic management system consists of three main operational modes namely

(a) Sensor Actuated (Adaptive) mode (MODE 1);
(b) Remote Control mode (MODE 2); and

(c) Fixed-timer mode (MODE 3).

Figure 3 shows the three modes and the permissible inter-mode transitions. These transitions are accomplished through the remote control interface

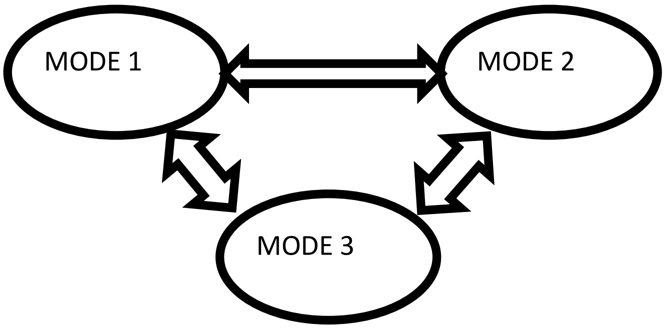


Figure 3. Inter-mode transitions diagram

3.5.1 Display style

By design, MODE 1 is the normal operational mode for the system. This is a real-time traffic density estimation system. It makes real-time decisions based on the perceived traffic density at each of the traffic states under consideration. In this mode, the controller uses data gathered by the sensors to estimate traffic queue length on each of the roads and allocate green-time based on the queue length. The state transition diagram for the system during the actuated mode is shown in Figure 4.

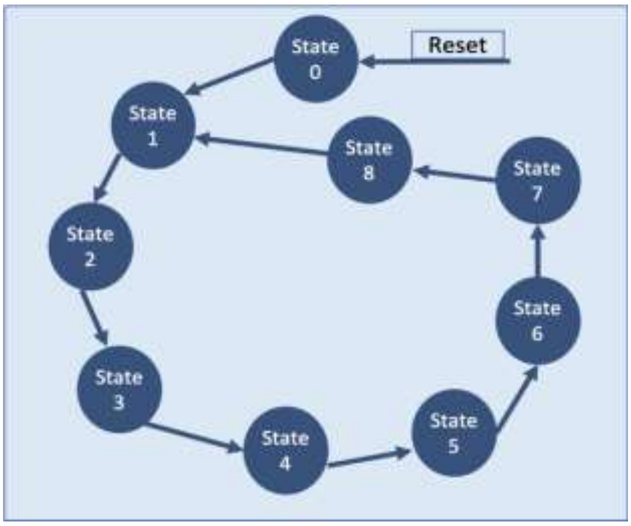


Figure 4. State transition diagram for the sensor actuated mode

3.5.2 Mode 2

By design, MODE 2 is an emergency override mode. This mode is used when there is the need to override the control sequence for emergency vehicles, a convoy, etc. The state transition diagram for this mode is shown in Figure 5. During this mode, an operator with the requisite control permission, controls the traffic signals from a portable device.

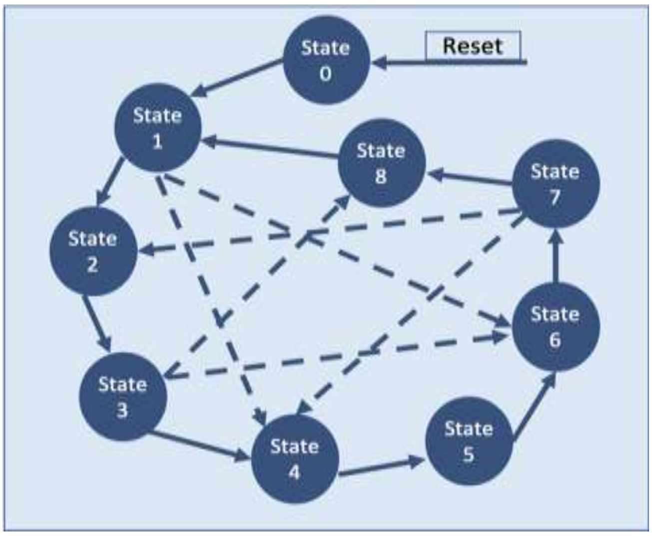


Figure 5. State transition diagram for the Remote Control mode

3.5.3 Mode 3

MODE 3 is used when MODE 1 fails due to sensor malfunctioning or failure; or when connection to the cloud database fails. For this mode, the controller uses pre-allocated fixed time sequence for the signal control. This is similar to mode 1 except that the timing is not adaptive. The state transition diagram for mode 3 is shown in Figure 6.

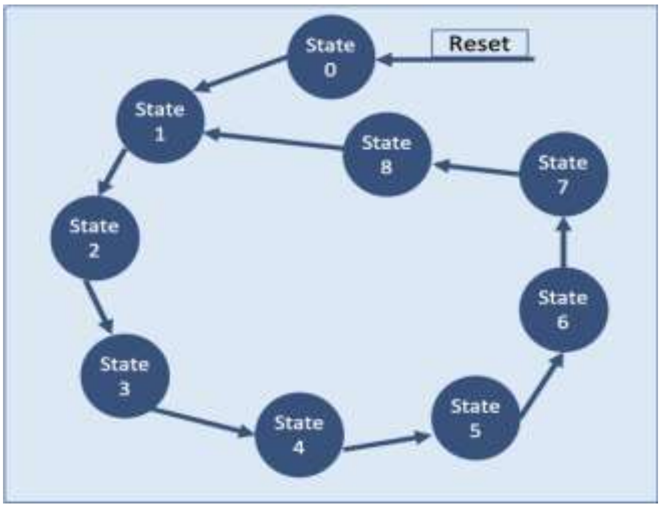


Figure 6. State transition diagram for the Fixed-Time mode

3.6 Decision Making

The decision making algorithm employs three thresholds to categorize traffic density into low, medium, high and very high in a manner similar to that developed in [13]. During the current cycle, the system captures the queue lengths for all the roads. Any appropriate vehicle detection system can be used. The individual roads are then placed in a descending order of queue lengths. The road with the longest queue is designated the major road for that cycle and allocated the maximum cycle time. The green-time for the ith traffic signal (t_i) in seconds is calculated using Eq.(1).

$$t_i = \frac{t_w}{N-1}\,\sigma \quad (1)$$

Where N is the number of unique green states in a cycle. t_w is the preset value for the maximum wait time in seconds. σ is a unitless quantity denoting the queue length factor. Thus, σ = 0.25 for low traffic density, σ = 0.50 for medium traffic density; σ = 0.75 for high traffic density; and 1 for maximum traffic density. Here traffic density is measure in queue length.

4. PROTOTYPING AND TESTING

A prototype of the system was designed, implemented and tested. The central processing unit is a Digilent Spartan-3E from Xilinx shown in Figure 7. The 4 input push buttons were used to simulate the vehicle detectors and the first 6 of the 8 input switches were used to simulate the different roads (i.e. North – South, East-West, South – North, West-East, North – East and South – West respectively). For example, to simulate a high queue length on the North – South road, switch 1 is switched on and button 3 is pressed.

Figure 7. Digilent Spartan-3E from Xilinx

Communication between the controller and the cloud is established using the ESP8266 WIFI-Module shown in Figure 8. This enables the controller to send the current state of the system to the cloud database and also retrieve commands during the remote operation through an adaptor.

Figure 8. The ESP8266 WIFI-Module

The FPGA was programmed using VHDL on the Modelsim platform. The complete assemble of the prototype is shown in Figure 9. This is built to mimic the test case which is shown in Figure 2. The existing system is a fixed-timing system with the green-time of 60 seconds for T1 and T3, and 22 seconds for all T2, T4, T5 and T6. The existing controller is not very efficient and has led to car waiting times as high as 6 minutes and long queue length on the West – East and East – West roads during rush hour. The actuated mode of this design solves this problem by allocating more green-time to these roads during rush hours.

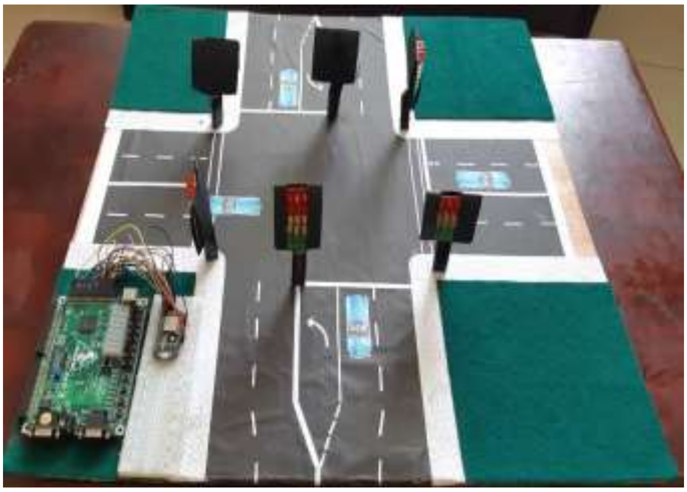
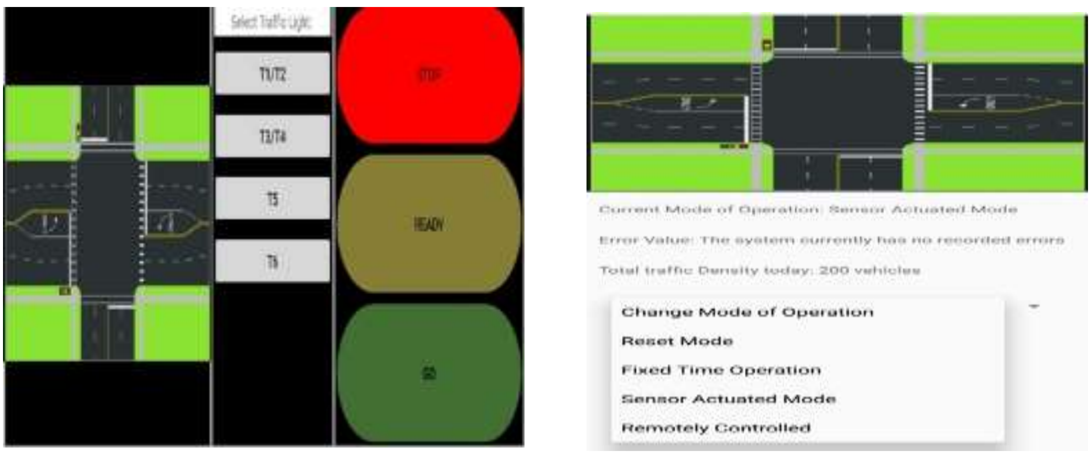


Figure 9. The Complete prototype of the Intelligent Traffic Controller with Remote Control Mode

The remote control software is an android application which communicates with the controller hardware through a cloud database. An operator must first get registered by the administrator and login to the system before gaining access to the control interface. The interface displayed in Figure 10 (a) enables an authorized personnel to control the state transitions remotely. The interface shown in Figure 10 (b) enables the operator to switch modes or reset the system.



(a) (b)

Figure 10. The remote control interface.

5. CONCLUSION

An intelligent traffic system has been designed and implemented. A prototype of the system has been built and tested. Currently, the prototype is showcased in the College of Engineering Innovation Center, Kwame Nkrumah University of Science and technology, Kumasi - Ghana. Next improvement will incorporate surveillance cameras to enable remote viewing for remote control and secondly will use the cloud database for coordination of traffic flow through adjacent intersections.

CONFLICT OF INTERESTS

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

REFERENCES

[1] Yasin H. Modelling and Control of Hybrid Vehicle. *International Journal of Innovative Technology and Interdisciplinary Sciences*, 2019; 2(3); 212-222.

[2] Rehman Y. A., Khan A. and Tariq M. Modeling, design and analysis of intelligent traffic control system based on integrated statistical image processing techniques, in *2015 12th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, Islamabad 2015, p. 169–174.

[3] Ramzanzad M. and Rashidy Kanan H. A new method for design and implementation of intelligent traffic control system based on fuzzy logic using FPGA, *13th Iranian Conference on Fuzzy Systems (IFSC)*, Qazvin 2013, p. 1–4.

[4] Lahade S. V and Hirekhan S. R. (2015) Intelligent and adaptive Traffic Light Controller (IA-TLC) using FPGA.

[5] El-Medany W. M. and Hussain M. R. (2007) FPGA-based advanced real traffic light controller system design.

[6] Chen Y. R., Chen K. P. and Hsiung P. A. Dynamic traffic light optimization and control system using model-predictive control method, *IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, Rio de Janeiro 2016, p. 2366–2371.

[7] Li N., Xiong G., Song W., Gong J. and Jiang Y. A micro-intelligent traffic behavior test platform using visual information processing, *in 2nd International Conference on Measurement, Information and Control*, Harbin 2013, p. 1475-1478.

[8] Nellore K. and Hancke G. P. Traffic management for emergency vehicle priority based on visual sensing," *Sensors (Switzerland)*, 2016; 16 (11); 1892.

[9] Heung T. H., Ho T. K. and Fung Y. F. Coordinated road-junction traffic control by dynamic programming, *IEEE Transactions on Intelligent Transportation Systems*, 2005; 6(3); 341-350.

[10] Bhate S., Kulkarni P., Lagad S., Shinde M. and Patil S. (2018) IoT based Intelligent Traffic Signal System for Emergency vehicles.

[11] Elkhatib M. M., Adwan A. I., Alsamna A. S. and Abu-Hudrouss A. M. Smart traffic lights using image processing algorithms, *IEEE 7th Palestinian International Conference on Electrical and Computer Engineering (PICECE)*, Gaza 2019, p. 1-6.

[12] Gaikwad O. R., Vishwasrao A., Pujari P. K. and Talathi T. Image Processing Based Traffic Light Control. *Int. J. Sci. Eng. Technol. Res.*, 2014; 3(4); 1010-

1014.

[13] Kaviani R., Ahmadi P. and Gholampour I. A new method for traffic density estimation based on topic model, *Signal Processing and Intelligent Systems Conference (SPIS)*, Tehran 2015, p. 114-118.

[14] Fu W., Wang J., Lu H. and Ma S. Dynamic scene understanding by improved sparse topical coding. *Pattern Recognition*, 2013; 46(7); 1841-1850.

[15] Lin L. T., Huang H. J., Lin J. M. and Young F. F. A new intelligent traffic control system for Taiwan. *9th International Conference on Intelligent Transport Systems Telecommunications (ITST)*, Lille 2009, p. 138–142.

[16] Sehgal V. K., Dhope S., Goel P., Chaudhry J. S. and Sood P. An embedded platform for intelligent traffic control. *Fourth UKSim European Symposium on Computer Modeling and Simulation (EMS)*, Pisa 2010, p. 541–545.

[17] Saha S. Automated Traffic Law Enforcement System: A Feasibility Study for the Congested Cities of Developing Countries, *International Journal of Innovative Technology and Interdisciplinary Sciences*, 2020; 3(1); 346-363.