Smart Traffic Light Control System

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Abstract— **Traffic light control systems are widely used to monitor and control the flow of automobiles through the junction of many roads. They aim to realize smooth motion of cars in the transportation routes. However, the synchronization of multiple traffic light systems at adjacent intersections is a complicated problem given the various parameters involved. Conventional systems do not handle variable flows approaching the junctions. In addition, the mutual interference between adjacent traffic light systems, the disparity of cars flow with time, the accidents, the passage of emergency vehicles, and the pedestrian crossing are not implemented in the existing traffic system. This leads to traffic jam and congestion. We propose a system based on PIC microcontroller that evaluates the traffic density using IR sensors and accomplishes dynamic timing slots with different levels. Moreover, a portable controller device is designed to solve the problem of emergency vehicles stuck in the overcrowded roads.**

Keywords—Traffic light system; microcontroller; XBee wireless communication; IR sensor; traffic density

I. Introduction

Traffic lights, developed since 1912, are signaling devices that are conceived to control the traffic flows at road intersections, pedestrian crossings, rail trains, and other locations. Traffic lights consist of three universal colored lights: the green light allows traffic to proceed in the indicated direction, the yellow light warns vehicles to prepare for short stop, and the red signal prohibits any traffic from proceeding [1].

Nowadays, many countries suffer from the traffic congestion problems that affect the transportation system in cities and cause serious dilemma. In spite of replacing traffic officers and flagmen by automatic traffic systems, the optimization of the heavy traffic jam is still a major issue to be faced, especially with multiple junction nodes [2]. The rapid increase of the number of automobiles and the constantly rising number of road users are not accompanied with promoted infrastructures with sufficient resources. Partial solutions were offered by constructing new roads, implementing flyovers and bypass roads, creating rings, and performing roads rehabilitation.

However, the traffic problem is very complicated due to the involvement of diverse parameters. First, the traffic flow depends on the time of the day where the traffic peak hours are generally in the morning and in the afternoon; on the days of the week where weekends reveal minimum load while Mondays and Fridays generally show dense traffic oriented from cities to their outskirts and in reverse direction respectively; and time of the year as holidays and summer. Secondly, the current traffic light system is implemented with hard coded delays where the lights transition time slots are fixed regularly and do not depend on real time traffic flow. The third point is concerned with the state of one light at an intersection that influences the flow of traffic at adjacent intersections. Also, the conventional traffic system does not consider the case of accidents, roadworks, and breakdown cars that worsen traffic congestion. In addition, a crucial issue is related to the smooth motion through intersections of emergency vehicles of higher priorities such as ambulances, rescue vehicles, fire brigade, police, and VIP persons that could get stuck in the crowd. Finally, the pedestrians that cross the lanes also alter the traffic system.

The conventional traffic system needs to be upgraded to solve the severe traffic congestion, alleviate transportation troubles, reduce traffic volume and waiting time, minimize overall travel time, optimize cars safety and efficiency, and expand the benefits in health, economic, and environmental sectors. This paper proposes a simple, low-cost, and real time smart traffic light control system that aims to overcome many defects and improve the traffic management. The system is based on PIC microcontroller that controls the various operations, monitors the traffic volume and density flow via infrared sensors (IR), and changes the lighting transition slots accordingly. Moreover, a handheld portable device communicates wirelessly with the traffic master controller by means of XBee transceivers in order to run the appropriate subroutines and allow the smooth displacement of emergency vehicles through the intersection.

II. Intelligent Traffic Control System

The design of intelligent traffic control system is an active research topic. Researchers around the world are inventing newer approaches and innovative systems to solve this stressful problem. Models based on mathematical equations are applied to estimate the car waiting time at a junction, the number of cars in the waiting queue, the extension of the waiting cars along the lane, the optimal timing slots for green, yellow, and red lights that best fit the real and veritable situation and the efficient combination of routing. In fact, the mutual dependencies between nearby intersections lead to a complicated formulation with cumbersome parameters. These parameters are accidental, hazardous, dependent, and the worse point is the variance of these parameters with time. Thus, finding a dynamic, consistent, and convenient solution is quite

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impossible. Researchers from different disciplines are collaborating to explore feasible solutions that reduce traffic congestion. Therefore, various methodologies are constantly proposed in the literature and many techniques are implemented profiting from the technological advances of microcomputers, recent manufactured devices and sensors, and innovative algorithms modeling, as much as possible, the complication of traffic lights.

The IR sensors are employed in numerous traffic systems [3-7]. The IR transmitter and the IR receiver are mounted on either sides of a road. When an automobile passes on the road between the IR sensors, the system is activated and the car counter is incremented. The collected information about the traffic density of the different roads of a junction is analyzed in order to modify dynamically the delays of green light at the lane having the significant traffic volume. The whole system could be controlled by PIC microcontroller [1-2, 4-5] or even by PLC [8-9].

To inform the traffic system about the arrival of the emergency vehicles toward the junction, they are supported by RF emitters [10-12] that send warning signals to RF transceivers disposed at every traffic light intersection. The triggering sequences of the traffic lights are modified correspondingly in order to provide a special route to the emergency vehicles. Other researchers [13] use the Global Positioning System (GPS) to communicate with the traffic light controllers and send preemption signals. The ambulance was equipped with both RF to communicate with traffic light controller and the GSM module to report to hospital doctors about the patient status and to receive messages concerning the kind of therapy or first aid recovery that should be done to the injured patient [14].

Many works [15-16] predict the density of the traffic based on image processing methodology. But these techniques require the acquisition of good images whose quality are weather dependent, especially with the rain and the fog. Other researchers use sophisticated algorithms to model the various states of the traffic such as fuzzy logic [17] and genetic algorithms [18].

Most published works are dedicated to one junction or intersection where the influence of the adjacent intersections is not examined. Thus, the situation becomes more complicated and widely dependent. Further efforts should be made to achieve complete modeling, monitoring, and control for multiple synchronized junctions.

III. System Design

The designed smart traffic light control system corresponds to a junction of 4 mono directional roads in the form of "+" as shown in Fig. 1. We aim in the first place to investigate the technologies of the existing systems and seek the most appropriate employed devices. We try also to test the proposed integrated design as architecture, hardware, and software. Next step will be an extension of the suggested traffic light system to a bidirectional "+" junction with various routing configurations. Our research target involves the management of traffic light systems for multiple adjacent bidirectional roads.

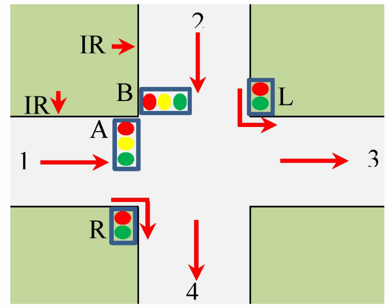

Fig. 1. Intersection of 4 monodirectional roads

The intersection in this primary work is equipped with two traffic lights of three colors, labeled A and B, associated to the car flow coming from roads 1 and 2. Two traffic lights of two colors labeled R and L are integrated to designate the right and left deviation, respectively. Two pairs of IR transmitters and receivers are mounted on either side of roads 1 and 2.

A. Traffic light configurations

In the proposed smart traffic light system, two configurations are presented: the first arrangement allows the flow of automotive from road 1 forwardly to road 3 as well as the turning to the right to follow road 4, while the second one permits the cars to move from road 2 directly toward road 4 or shift to the left to pursue road 3.

The disposition of cars transitions between the roads takes into consideration the crossing of pedestrians. Table 1 illustrates the states of the traffic lights labeled A, B, L, and R during the two configuration modes. The terminology adopted is formed of three fields: traffic light-color lights states. For example, A-G ON designates that the green light of the traffic light A is illuminated. The phase I of the first configuration corresponds to the activation of the green light of the traffic light A and traffic R where the cars parking at road 1 are crossing the intersection. The phase II agrees with the warning for stop position where only the yellow light of the traffic light A is turning on for 5 s. during this configuration, the red lights of the traffic light B and L are ON. In the second configuration, the lights illuminations are reversed.

B. Density traffic light and IR sensors

The major problem of the existing traffic light systems is that the transition timing slots are fixed within the code.

TABLE I. Traffic Light Configurations During the Two Modes of Operation

First configuration		**Second configuration**	
Phase I	***Phase II***	***Phase I***	***Phase II***
A-G ON A-Y OFF A-R OFF	A-G OFF A-Y ON A-R OFF	A-G OFF A-Y OFF A-R ON	A-G OFF A-Y OFF A-R ON
B-G OFF B-Y OFF B-R ON	B-G OFF B-Y OFF B-R ON	B-G ON B-Y OFF B-R OFF	B-G OFF B-Y ON B-R OFF
R-G ON R-R OFF	R-G ON R-R OFF	R-G OFF R-R ON	R-G OFF R-R ON
L-G OFF L-R ON	L-G OFF L-R ON	L-G ON L-R OFF	L-G ON L-R OFF

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A similar system is unable to solve the situation where the traffic congestion is only observed from one direction. This state is frequently detected in many cities where employees from outskirts are driving in the morning to the city downtown and returning home in the evening. In addition, when the flow of cars approaching the intersection roads increases during the traffic peak hours or decreases during night, the green light activation should be extended or reduced respectively. Therefore, IR transceivers mounted on either side of roads are used to detect the passage of cars through it. The IR transmitter generates continuously and regularly a 38 kHz square wave signal while the IR receiver connected to the traffic master controller receives the signal and remains inactivated. When an automobile traverses the road between the IR transceivers, the IR radiation bounces and the system is activated. This activation process is analyzed by the traffic master controller where the car density counter is adjusted. Then, the traffic master controller, which is equipped with PIC microcontroller, responds to the acquired data. Actually, three modes of lighting transition slots are suggested: the normal mode, the traffic jam mode, and the soft traffic mode. The shifting between these three modes is done dynamically and in real time. In fact, the number of counted cars in the phase I of a given configuration affects directly the green light period in the next phase I of the proceeding configuration. The timing slots of the different modes are depicted in Table 2. The three timing slots associated to the normal, jam, and soft modes of traffic are respectively 30, 50, and 15 s. These levels are assigned by the code and can be adjusted by the software. For normal mode, the phase I of each configuration is equal to 30 s. However, if road 1 reveals jam traffic and road 2 shows soft traffic then the period of phase I of the first configuration will be 50 s. In contrast, the period of phase I of the second configuration will be 15 s.

It is noted that during the first configuration, the cars of road 1 are moving to their destination while the cars of road 2 are stacked and parked. Furthermore, when phase II of the first configuration starts, the IR sensor of the road 1 begins the car counting from zero.

C. *Emergency vehicles*

One of the substantial situations in the traffic light system concerns the passage of emergency vehicles as higher priorities through the roads junction. An emergency vehicle includes ambulances, rescue vehicles, fire brigade, police, and VIP persons that could get stuck in the traffic congestion. This issue may cause several problems that depend on the injury of patient transported, person accident, fire buildings, robbery, and many various critical situations. It is mandatory to implement a technique to solve this predicament.

TABLE II. TIMING SLOTS ACQUIRED BY EACH CONFIGURATION AND ACHIEVED FOR THE THREE MODES OF TRAFFIC

Traffic Modes	**Configuration**	
	Phase I	***Phase II***
Normal traffic	30	5
Jam traffic	50	5
Soft traffic	15	5

A handheld portable device at the disposition of the traffic officer is proposed in order to command the traffic master controller. Indeed, the portable controller could be adjusted to be mounted on emergency vehicles or implemented in the traffic control center. The portable device is supported by two push buttons labeled EA and EB. The EA button is pressed when the emergency vehicle arrives at the intersection from the side of traffic light A, that is from road 1. Due to this action, the phase I of the first configuration is set and the green light timing slot is shining unlimitedly to provide sufficient time to the stacked vehicle to traverse the intersection. Next, the EA button is pressed again to return to the normal mode, where the yellow light of the traffic light A is ON for 5 s to warn the drivers that traffic light B will be closely triggered. If the elapsed time exceeds 4 minutes and the EA button is still operating for many causes, the system is automatically actuated and initiates the second configuration. The EB button applied to the traffic light B achieves similar process. If the two buttons are pressed simultaneously, the priority is given to the button EA.

IV. ELECTRONIC COMPONENTS

The circuit of the smart light traffic control system is implemented based on various electronic components that include: the Programmable Intelligent Controller (PIC) 16F877A microcontroller, an LCD display device, XBee transceivers, a pair of IR sensors, push buttons (EA, EB, and 1 to 4), and many colored LEDs that represent the three lights (red, green, and yellow) of the traffic lights A and B associated with the roads 1 and 2 as well as the two lights (red and green) for the traffic light R and L associated with the deflection to the right and left in the direction of roads 3 and 4.

A. *Microcontroller PIC 16F877A*

The PIC 16F877A [19-23], a family of Harvard architecture microcontrollers made by Microchip, is an integrated circuit (IC) consisting of a simple Central Processing Unit (CPU), RAM, ROM, and EEPROM memories. It contains also clock, timers, A/D converters, and five input/output ports. On the other hand, its 35 instructions make it easy and simple to program. Moreover, its power consumption is low and it has a wide operating voltage range (2 V to 5.5 V) while its input clock operates at up to 20 MHz.

The pin configuration of the PIC 16F877A microcontroller is shown in Fig. 2 where 5 bidirectional input/output ports can be classified as: A is a 6-bit general purpose port which can be also configured as Analog to Digital converter (A/D); B, C, and D are 8-bit general purpose ports, while port E is only 3-bit port. These ports are used to input data that may be generated from keypad, sensor, push button, switch, etc. or to present command signals or data to output devices such as LCD, 7-segment, LED, motor driver, relay, etc.

Each port has its own associated TRIS register. The configuration of these TRIS registers is to select the data transfer direction between the microcontroller and the different peripheral devices through the ports. When a TRIS register is cleared, its corresponding port acts as output, otherwise it operates as input.

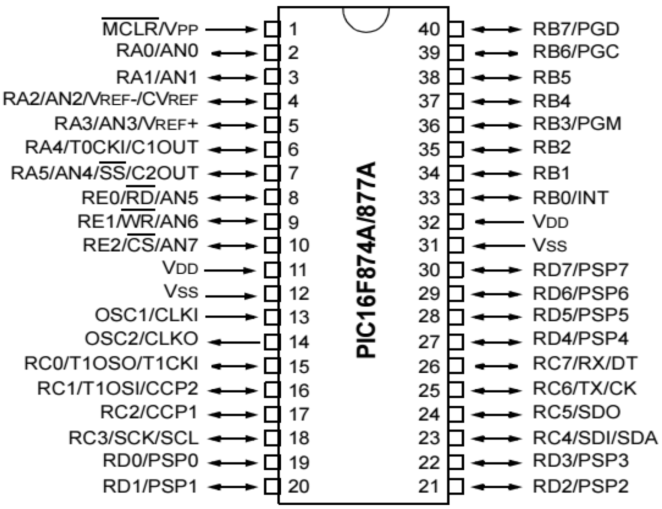

Fig. 2. Pin configuration of the PIC 16F877A microcontroller

On the other hand, many microcontroller port pins can be extended to perform incremental functions and operate specific purposes. The PIC microcontroller is backed up by the Universal Synchronous Asynchronous Receiver Transmitter (USART) module that permits the PIC to communicate with wide range of devices.

B. *LCD display*

Liquid Crystal Display (LCD) [24] is a power economical, tenuous, flat-panel display, simply programmable, and can be used in many digital and electronic circuits. It employs a matrix structure in which the active element forming the pixel cell is located in the intersection of two electrode buses. Particularly, the 16x2 LCD used in the implemented prototype is able to display data over 2 lines, each of 16 characters.

Actually, two types of registers are used to configure the LCD; the command register is recommended for the control instructions as LCD initialization, clearing the screen, setting the cursor position, and controlling display. While the data register holds the ASCII code of the characters that are promptly appeared on the display.

C. *IR sensor*

An infrared sensor is an electronic device implemented to detect obstacles or to differentiate between objects depending on its feature. It is generally harnessed to measure an object heat or its motion [25]. The IR sensor emits or receives the infrared radiations (430 THz – 300 GHz) that are invisible for the human eye. The LED (Light Emitting Diode) may act as an IR emitter while the IR detector is a photodiode component which is sensitive to IR light having the same frequency as the emitted radiation. The concept of operation is simple: when IR radiation of the LED reaches the photodiode, the output voltages change according to the magnitude of the IR light.

D. *XBee transceivers*

The XBee transceiver module, Series 2, allows creating complex mesh networks based on ZigBee firmware [26]. It admits a safe and simple full duplex communication between microcontrollers through serial port data transfer. The XBee features (2 mW output, 120 m range, built-in antenna, 250 kbps max data rate, and 8 digital IO pins) are suitable for our objective. Moreover, XBee is supported by point-to-point communication adequate for using one traffic light controller and corroborative also by multi-point network compatible for using multiple traffic controllers. In the XBee configuration, the component connected to portable controller runs as server whereas that linked to traffic light controller fills in the host mode. The XBee characteristics give immunity against interference from neighboring systems and avoid the interaction of closer systems which prohibit the interruption in their services.

V. HARDWARE DESIGN

The smart light traffic control system is composed of two separate devices: the traffic master controller and the handheld portable controller. Fig. 3 shows the hardware implemented circuit of the smart traffic controller using the Proteus software.

The traffic master controller is mounted with the traffic lights at the roads intersection and is responsible for the lighting transition and their timing slots. Its implemented design circuit includes: the PIC 16F877A microcontroller, the three lights (red, green, and yellow) of the traffic lights A and B associated to the roads 1 and 2, the two lights (red and green) for the traffic light R and L associated with the deflection to the right and left in the direction of roads 3 and 4, the two IR receivers to measure the traffic volume, the XBee transmitter system, and other basic components. The traffic master controller provides the duration and the schedule of the two configurations and their dedicated phases for different modes of traffic. It determines the status of the different lights by commanding the triggered switches connected to the PIC ports. The microcontroller is also connected to IR detectors whose output voltages are responsible of shifting the counter of the cars arriving at the intersection. Finally, the XBee module receives the command orders form the portable controller and calls the corresponding emergency subroutines.

The portable controller commands the traffic master controller by means of XBee transceiver that communicates wirelessly with the other XBee component. A PIC 16F877A constitutes the hardware core of the portable controller. It is connected, in addition to XBee, to the buttons EA and EB that start up the emergency subroutines.

An LCD screen is employed to notify the user if the mode of emergency is operating and which emergency procedure is currently running. We propose also a password of 6 digits formed by the combinations of 4 digits from 1 to 4 in order to supply the portable controller by a certain security level [27]. The total number of arrangements is 4096 possibilities. The role of security code is to prevent unauthorized persons from accessing to the smart light system.

VI. CONCLUSION AND PERSPECTIVES

The traffic light issue is obviously a critical problem that worries citizens and governments. The influence of low efficient conventional traffic system affects the economic, health, financial, and environmental domains.

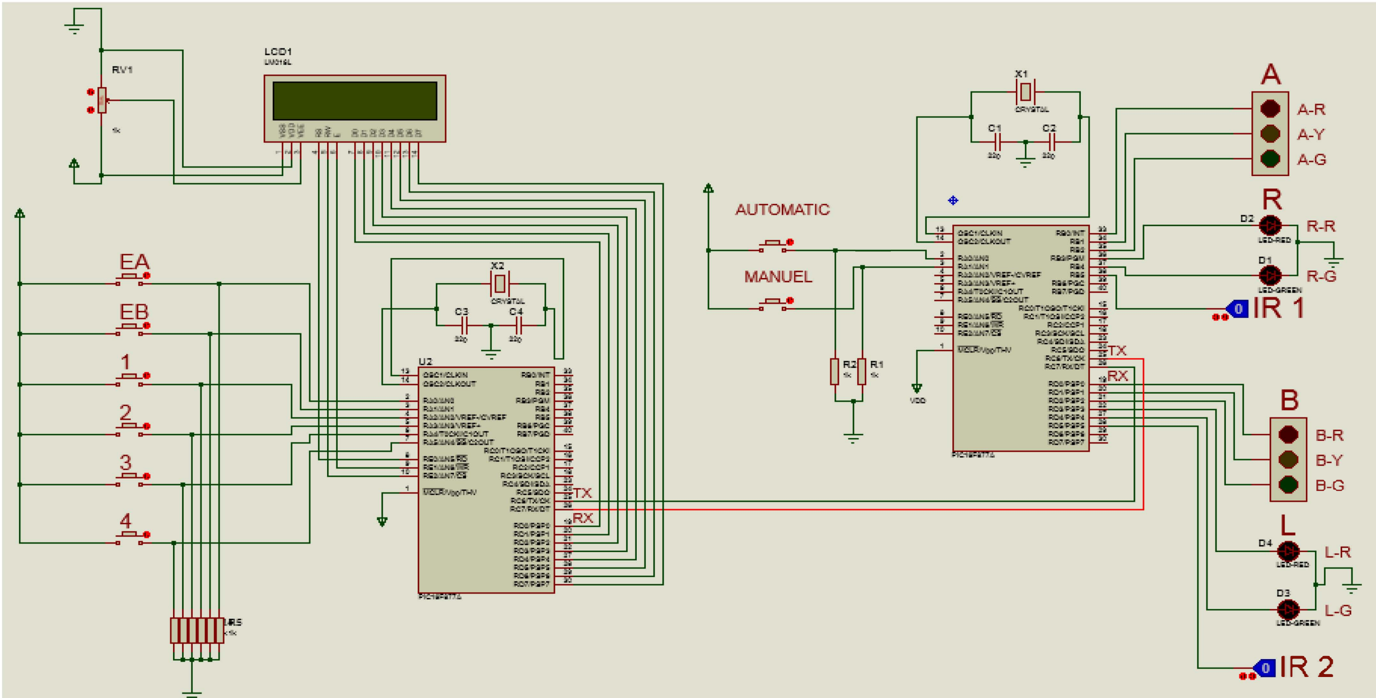

Fig. 3. Block diagram of the circuit designed by Proteus software. The handheld portable controller hardware is is disposed at left while the traffic master controller implementation is shown at the right.

The transportation system trouble and the bad monitoring may cause car accidents, traffic jam, and roads congestion that put heavy loads on businesses and works.

The advancement of technologies and the miniature of control devices, appliances and sensors have given the capability to build sophisticated smart and intelligent embedded systems to solve human problems and facilitate the life style. Our smart traffic light control system endeavors to contribute to the scientific society to ameliorate the existing traffic light systems and manage the flow of automobiles at the intersections by implementing innovated hardware and software design systems.

The proposed smart traffic system consists of a traffic light controller that manages the traffic lights of a "+" junction of mono directional roads. The system is capable of estimating the traffic density using IR sensors posted on either side of the roads. Based on this information, the time dedicated for the green light will be extended to allow large flow of cars in case of traffic jam, or reduced to prevent unnecessary waiting time when no cars are present at the opposite route. The system is complemented by portable controller for the emergency vehicles stuck in the traffic. By means of secure communication using XBee wireless system, the portable controller triggers the traffic master controller to the emergency mode and provides an open path until the stuck emergency vehicle traverses the intersection.

The designed system is implemented, realized electronically, and tested to ensure complete validation of its operations and functions. The current design can be promoted by monitoring and controlling an intersection with double roads. Future improvements can be added such as pedestrian crossing button, delay timing displays, as well as car accident and failure modes. The integration of different traffic controllers at several junctions will be investigated in the future in order to accomplish a complete synchronization. To study the system performance, traffic data can be recorded and downloaded to computer platform where statistical data analysis studies could be applied to better understand the traffic flows between the intersections. Finally, traffic light controller could be powered by solar power panels to reduce grid electricity consumption and realize green energy operations.

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