Real-time Dynamic Traffic Light Control System with Emergency Vehicle Priority

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Abstract. Traffic light control systems are widely used to monitor and control vehicles’ flow to provide a smooth and orderly flow of traffic by controlling which lane should be granted to pass through the intersection point without compromising on safety standards. However, a conventional traffic light system handles neither dynamic traffic flow nor the prioritization of emergency vehicles (EVs). Consequently leads to congestion as the conventional traffic light grants underutilized road lanes to have the equal cycle length as a congested lane and possibly causes an accident and delay when multiple EVs are approaching the intersection. This paper proposes an intelligent system that dynamically adjusts the cycle length for each of the lanes at an intersection based on the vehicular density and grants the different types of EVs to pass through the intersection point by assigning different priorities. The system consists of three modules, the traffic light control module, the emergency Radio-frequency identification (RFID) module and the internet module. The traffic light control module detects vehicular density using ultrasonic sensors and assigns a dynamic set of cycle length based on the individual lane density condition. The emergency RFID tags are installed on different types of EVs based on the preset priority weights. The internet module allows the dynamic traffic light system to be controlled by authorized personnel in a real-time application.

Index Terms- Emergency Vehicle Priority, Internet of Things (IoT), Smart Traffic Light System, Vehicle Density Detection

1. Introduction
The world population presently stands at 7.8 billion, and the demographers expect the 8 billion milestones in 2023, with the global population projected to reach 10 billion by 2056 [1]. Specifically, Malaysia’s population is projected to be at 32.7 million in 2020, having reached 32.5 million milestones in 2019 [2]. The rapid increase of the population’s size, mainly in the major cities such as Kuala Lumpur and the continually rising number of road users, are not attended with the enhanced transportation system, thus causing severe traffic congestion.

Critical traffic congestion not only leads to substantial economic lost [3] but also has negative impacts on the quality of community life [4]. According to the report in [5], working-class Malaysians are estimated to waste about 1 million wasted hours annually stuck in traffic congestions per day, and it can be translated to a total RM 10 billion up to RM 20 billion annually. The report has also confirmed a few factors that contribute to the billions wasted, such as the
extra amount of petrol used in stop-go traffic, the effects of additional carbon emissions on the environment and society and loss of valuable time. Further, the studies conducted in [6–8] discuss health issues affected by the carbon dioxide (CO$_2$) emitted by vehicles, and the contaminated air creates another disturbance to the community such as obesity that can affect their life productivity [8].

Most of the busy cities, including Kuala Lumpur, continuously utilize conventional traffic light systems programmed at a pre-timed control consisting of a series of fixed intervals and keep repeating a preset constant cycle [9]. If one of the lanes is empty, the conventional traffic light system remains to run the identical light sequence, which is inefficient and waste as the other more congested lanes should be considered to have a longer time to relieve the traffic congestion. A density-based traffic light control system with GSM-based remote override is designed in [10] to reduce very long queues of vehicular traffic at the cross-road junctions and eliminate conflicting authority between the green light for the motorists, pedestrians and emergency vehicles. Meanwhile, [11] focuses on several simulations based on symmetry models, implemented in practical cases to streamline vehicle density and reduce traffic congestion.

With the conventional traffic system, users on the road must respond quickly to emergency vehicles (EVs), i.e., ambulance, fire engine, police vehicles, to save the person's lives and property. However, [12] reports 82.9% of the 98% respondents had at least one experience of failing to respond when EV approached public roads. The lanes that have emergency vehicles must be given higher priority in designing the system to keep the emergency vehicle safe and smooth without causes an accident, as traffic lights in another junction turn red to stop the flow of the other non-priority vehicles. [13] proposes a traffic system by extending the green period or cutting off the red period to facilitate the EV passing through the intersection and assigns different weights of priorities to different types of EV. Thus the signal controller can react effectively in the case of multiple EVs at the same intersection.

Intelligent transportation systems need to be developed and implemented, especially in major cities, to replace the incompetent conventional traffic light system. Studies in [14–16], propose an intelligent management system for traffic control systems based on different approaches and configurations. The authors in [14] studies and develop a traffic light controller electronic circuit with a centralized control topology, and the proposed system can communicate with other wireless network traffic lights supported by the Internet of Things (IoT). Meanwhile, [15] integrates the IoT and big data into the proposed system to acquire data in a real-time application and provide a solution through predictive analytics. Further, [16] proposes a modern traffic control system using connected vehicle technology under VANET configuration with an integrated approach of solving general traffic-related issues in a high volume traffic gateway.

The current traffic light implementation also relies on users to report service faults of the traffic light system. Real-time monitoring of the traffic light system would allow maintenance workers to know when the traffic light system is non-operational. By allowing the control room to know the traffic light's current status in real-time, authorities can react faster to a faulty traffic light system. Non-operational traffic lights may cause heavier congestions and unsafe driving conditions as there is no signaling system.

This paper proposes a dynamic traffic light control system with emergency vehicle priority that can be controlled in real-time. Three modules as been considered in this design, i.e., the traffic light control module, the emergency Radio-frequency identification (RFID) module and the internet module. To make the traffic system more efficient and energy saving, we implement vehicular density detection at the intersection equipped with ultrasonic sensors and dynamically assign a cycle length based on the individual lane condition. The emergency RFID module is to be installed on an emergency vehicle. Once the emergency vehicle is detected at the junction, priority will be given to the lane with the EVs. The internet module allows the traffic light to be controlled by authorized personnel in a real-time application.
The rest of the paper is outlined as follows. The next section provides a system model for a real-time dynamic traffic light control system with EVs priority. In section 3, we illustrate the results in three modules: the traffic light control module, the emergency RFID module, and the internet module to confirm the proposed system model’s advantages. Finally, section 4 states a conclusion of the work.

2. System model
This paper proposes a system that intelligently adjusts traffic light system response based on the emergency vehicle priority and vehicular density for each of the lanes at the traffic light junction in a real-time application. Motivated by the fact that the traffic light system’s electrical energy can be wasted mostly during the idle traffic and non-congested traffic, we propose an intelligent system as illustrated in Figure 1. The system is set to be on idle mode if no vehicle is detected at the lanes. As soon as a vehicle is detected, the system will be in an active mode and invoke three different proposed approaches based on real-time traffic conditions and emergency vehicle priority weights, i.e., invoke dynamic traffic light system with priority for emergency vehicle lane, invoke dynamic traffic light system based on vehicular density, and invoke the conventional traffic light system.

Instantly when an EV is detected at any of the lanes; the highest priority will be given to that particular lane. The traffic light system users will be alarmed, and the green light will be turned on until the EV is safely passed through the intersection. The vehicular density for each of the lanes is considered in the later approaches. If all the lanes are occupied with high vehicular

![Flowchart of Dynamic Traffic Light Control System](image-url)
density, then the conventional traffic light cycles will be invoked. Otherwise, the traffic light cycles depend on the vehicular density and occupied lanes. In this approach, each of the active lanes’ cycle length is based on the traffic density, i.e., longer green time for the lane with higher traffic density. For instance, if traffic is detected at one or two lanes, the lanes with detected vehicles will be activated and alternately served based on the traffic density. In contrast, the lane without any vehicle is ignored from the sequence.

![Block Diagram of the proposed Real-time Dynamic Traffic Light Control System with EV Priority](image)

**Figure 2.** Block Diagram of the proposed Real-time Dynamic Traffic Light Control System with EV Priority.

Figure 2 illustrates the block diagram of the proposed dynamic traffic light control system with EV priority that consists of three modules, i.e., the traffic light control module, the emergency RFID module and the internet module. The traffic light detects vehicular density using ultrasonic sensors and assigns a dynamic set of cycle length based on the lane density condition. The emergency RFID module with a preset weighting factor information must be installed on the individual EVs to handle different types of EVs approaching the intersection. The internet module allows the traffic light to be controlled by an authorized person. Arduino Uno is used as a microcontroller to manage and control the proposed approaches.

Figure 3 illustrates the traffic light control module’s schematic diagram, which consists of ultrasonic sensors. Each of the ultrasonic sensors consists of two main components, the sender and the receiver. The HC-SR04 Ultrasonic Module has four pins, Ground, VCC, Trig and Echo. Ground and VCC pins of the module need to be connected to the ground and the 5 volts pins on the Arduino Board, respectively and the trig and echo pins to any Digital I/O pin on the Arduino Board.

The schematic diagram of the emergency RFID module shows in Fig. 4. The emergency RFID consists of two main components, a transponder is installed to the EV to be identified, and a transceiver is embedded in the traffic light control system. The transponder is a passive device and contains a microchip that stores and processes information of the EV and an antenna to receive and transmit a signal. In this research, we consider multiple types of EVs with different weights of priorities. We preset the weights of priorities and store this information in the individual transponder. Hence the transceiver can interpret which EV has a higher priority; thus, the system can decide which lane should be granted to pass through the intersection.
Figure 3. Schematic diagram of Traffic Light Control Module

point. The transceiver consists of an RF module and an antenna that generates a high-frequency electromagnetic field, causing electrons to move through the transponder’s antenna and subsequently power the chip. The powered chip inside the transponder then responds by sending its stored information back to the transceiver in the form of another radio signal. The change in the RF wave is detected and interpreted by the reader, sending the data out to a computer or microcontroller. The RC522 RFID Reader module is designed to create a 13.56MHz electromagnetic field to communicate with the RFID tags (ISO 14443A standard tags). The reader can communicate with a microcontroller over a 4-pin Serial Peripheral Interface (SPI) with a maximum data rate of 10Mbps. It also supports communication over I2C and UART protocols. The module comes with an interrupt pin, and the module will alert the traffic light system when the EVs with transponder approaching the transceiver. The operating voltage of the module is from 2.5 to 3.3V. The logic pins are 5-volt tolerant, so we can easily connect it to an Arduino without using any logic level converter. The RC522 module has eight pins, i.e., VCC, RST, GND, IRQ, MISO/ SCL/ Tx, MOSI, SCK and SS/ SDA/ Rx. The VCC pin supplies the module’s power from 2.5 to 3.3 volts, while the RST pin is an input for reset and power-down. The GND is the ground pin and needs to be connected to the GND pin on the Arduino. The IRQ pin is an interrupt pin that does the vital task of alerting the microcontroller when the EV with an RFID transponder comes into the traffic light intersection. MISO / SCL / Tx pin acts as Master-In-Slave-Out when SPI interface is enabled, acts as a serial clock when I2C interface is enabled and acts as serial data output when UART interface is enabled. MOSI (Master Out Slave In) is SPI input to the RC522 module. SCK (Serial Clock) accepts clock pulses provided by the SPI bus master, i.e., Arduino. Lastly, the SS/ SDA/ Rx pin works as signal input when the SPI interface is enabled, works as serial data when the I2C interface is enabled and works as serial data input when the UART interface is enabled.

Figure 5. Schematic diagram of Internet Control Module

For Internet Control Module, the NodeMCU V2 ESP8266 is used to allow data transfer between the Arduino and the Android Application. The Arduino communicates through serial communication with the NodeMCU V2 ESP8266; it sends real-time traffic data to the Android Application. The NodeMCU V2 ESP8266 also enables the traffic light to be controlled by authorized personnel in a real-time application. In a critical situation, the authorized personnel can also control and hand-over the system to avoid serious accidents and delays in real-time without wasting time going to the concerned junction.
3. Results and discussion

Figure 6 shows the output of ultrasonic sensing module testing. The ultrasonic sensing module is capable of calculating the density of the vehicles for each of the lanes. The testing shows that if only a single lane is detected to have several vehicles (active mode) while the others are empties (idle mode), only the traffic light for the active mode is lighted up as green until all the vehicles passed through. The testing also shows that when two lanes are detected to have traffic flow, the system only calculates cycle length for these two lanes and alternately allows traffic flow between the two lanes while the other empty lane remains red light. When all the lanes are occupied, the traffic light system acts as a standard traffic light with the cycle length depends on vehicle density at each of the lanes. As a result, the proposed intelligent traffic light system provides an efficient traffic flow, reducing traffic congestion time.

Figure 7 shows the output of the RFID module testing. The RFID module is used to detect the EV that approaching the traffic light junction or intersection. The testing shows that as soon as the EV installed with the RFID is detected, the proposed intelligent traffic light system will alarm the traffic users and immediately turn green to grant the EV to pass through the junction while the other lanes will turn red. The RFID also stores the preset weight priority information if multiple EVs are approaching the intersection simultaneously. In the testing, we limit our
Figure 6. Traffic Light Control Module (Ultrasonic Sensor)

EVs to two different EVs because of the limited budget, and we preset their weighting priorities. If the two EVs from the different lanes are approaching the traffic light system simultaneously, the higher priority EV will be served first, then the lower priority EV. In a critical situation such as numerous EVs approaching the intersection, the authorized personnel can hand over the system through the internet module.

Figure 7. Emergency RFID Module (RFID Reader)

Figure 8 shows the output of the internet module’s testing that confirms the proposed intelligent traffic light system by showing real-time response status in the Remote XY application. The Wi-Fi module act as a data transfer medium and an application interface between the Arduino and the android smartphone. When the Arduino is powered, the traffic light starts the operating system, and the Arduino starts updating the traffic light conditions’ status to the Wi-Fi module. Once the smartphone is connected to the Wi-Fi module’s access point, RemoteXY starts to operate, and authorized personnel can remotely monitor and control the proposed traffic lights system.

However, from our observation, we noticed that the proposed traffic light system is not suitable for use in high traffic density areas. Computer Vision Traffic Light would be more suitable for future work to be implemented in high traffic density areas. [17] shows that Computer
Figure 8. Internet Control Module (Node MCU): Testing of two junction traffic light with RemoteXY application

Vision Traffic Light generates an average reliability of 92.83% in the daytime and 85.77% in the night time. The Computer Vision Traffic Light would also be easily integrated with traffic light cameras that catch road users who attempt to pass the traffic light when the traffic light is red. Furthermore, to enhance our system in real practice, we suggest that the system use the optimization technique. The optimization approaches have been proposed in our published work in different research background areas, i.e., [18–25]. Optimization techniques are proved to be superior methods to find an optimal solution for the chosen objective function subject to a list of constraints to be satisfied. For instance, we can propose to minimize the delay time at the traffic light intersection with the given constraints such as vehicular density, multiple EVs priority satisfaction and pedestrians safety preferences.

4. Conclusion
The proposed dynamic traffic light control system with EV priority can be effectively used in a real-time application. This system could bring a significant improvement in human beings’ daily life and could help to save a life. There is a feature in the application that helps the city’s emergency services such as emergency medical service, firefighting, and police to use the emergency feature in the application to bypass the traffic light in the city. The unique emergency mode featured in the proposed system gave emergency blinking just before the EVs would pass the intersection to notify the traffic users to avoid accidents and delays. Internet of Things (IoT) helps human beings to live in a comfortable and timely style.

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