


Optimizing Traffic Flow: Utilizing IR and Load Cell Sensors for Cost-Effective Traffic Congestion Alleviation at Smart City Intersections [†]

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Abstract: Cities face a significant challenge due to increasing traffic congestion and the rising number of vehicles. Developed countries have introduced smart traffic management systems as a solution to mitigate congestion and improve traffic flow. These systems employ various techniques such as image processing, radar sensing, ultrasonic and microwave detectors, and other sensors. However, each of these methods has its drawbacks, including susceptibility to weather conditions, high costs, and low accuracy. Intelligent traffic control methods like inductive loop detection, wireless sensor networks, and video data analysis have proven to be efficient. However, they suffer from lengthy installation processes and high installation and maintenance expenses. In response to this issue, this article proposes a system that can detect lane density and adjust traffic signal timers accordingly to optimize traffic flow. The proposed system utilizes IR sensors and load sensors to calculate the density of each lane at an intersection, and an RFID system is implemented to accommodate emergency response vehicles. This system is centered around an ATmega 2560 chip. To demonstrate the effectiveness of the proposed approach, real-time experiments were conducted on a scaled-down model of the system. The results showed promising outcomes. The authors argue that this system could serve as a cost-effective and efficient solution for managing traffic in cities, particularly in Pakistan.

Keywords: road traffic congestions; IR sensor; load sensor; smart traffic management; RFID



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1. Introduction

Due to the increasing number of vehicles on the road, traffic networks are becoming increasingly complicated and inconvenient. The result is gridlock and traffic bottlenecks, which considerably impact the economy, the environment, and public health. Since one of the simplest necessities in the modern world is speedy mobility, people use all sorts of transportation, including cars and motorcycles. The number of vehicles in cities is expanding at a faster rate than the growth rate of the transportation infrastructure, resulting in serious traffic congestion. In order to guarantee smooth vehicular traffic flow, assist vehicles and pedestrians crossing intersections, and prevent accidents, traffic management systems are primarily employed. The existing traffic management systems, however, operate on fixed schedules and are not based on traffic density. Controlling traffic congestion becomes a challenge when traffic signals have set timing delays. Furthermore, the existing timer-based system does not have the ability to accommodate emergency vehicles. The existing traffic management infrastructure, therefore, needs upgrading in order to address ever-increasing traffic congestion issues. In light of the above, this article proposes a straightforward, affordable, and real-time junction traffic management system. The proposed system measures the

number of vehicles depending on traffic density using IR sensors and load sensors before setting timers for signals in the lanes. The solution also caters to the issues brought on by the arrival of emergency vehicles.

2. Literature Review

For several years, traffic control systems have extensively relied on the use of surveillance devices and video monitoring [1]. However, video monitoring methods require high-quality images and video data; the clarity of the images obtained using cameras is, in most cases, not independent of weather, particularly in rain and fog. Nonetheless, in a traditional camera-based junction traffic management system, the images from a traffic junction are transformed into a grayscale image followed by contouring, which helps to ascertain the number of cars present. But since this method is time-consuming, expensive, and computationally demanding, it is not an ideal choice in a real-world scenario. Moreover, it is impractical to manually review the enormous amount of data generated by video and still-image cameras. Nonetheless, the computer vision-based camera system has several handy use cases in automatic vehicle detection and counting in the unsupervised video of highways, including monitoring action at traffic intersections to identify traffic jams and then predicting the traffic to help with traffic regulation [2]. By contrast, the proposed system does not require any cameras; instead, load cells measure the load and sense whether it is a vehicle or pedestrian, and an IR sensor detects if anything surrounds them. There are several other vehicle monitoring systems cited in the literature, such as radar-based traffic monitoring systems [3] and ultrasonic wave detection systems [4]. However, these methods and the sensors therein are expensive, challenging to install, have a limited range, and require additional maintenance costs. Moreover, these sensors in most of the aforementioned methods are prone to external disturbances, such as metal barriers close to roads that can interfere with radar devices [5].

Inductive loop detection [6] is another method mentioned in the literature where an insulated wire is placed in a cutout in the road, and when a vehicle passes over or stops on the wire, it changes the wire's induction and frequency. An electronic unit in the controller cabinet sends a signal to the controller to indicate the vehicle's presence, passage, occupancy, and number. However, reliability problems can occur due to poor connections, sealant applications in pull boxes, poor pavement conditions, and frequent road digging. A summary of the most commonly used sensors frequently employed in traffic tracking systems includes unpowered acoustic devices [7], pressure sensors [8], photoelectric methods [9], detection using inductive loops [10], and metallic sensors [11]. This article, however, focuses on the deployment of a load cell, infrared, and RFID-based road junction traffic management system.

The rest of the article is structured as follows: Section 3 introduces the prototype model and confers upon its working principle. In Section 4, the focus is on the fabrication of the model. Section 5 entails a concise deliberation. Section 6 concludes the article.

3. Methodology

The proposed system has two main sensing devices that can sense vehicle density in a lane: infrared (IR) and load cells. It is proposed that a set of three sensors be placed alongside each lane in order to determine traffic density in a reliable manner. The brain of the entire system is an ATmega 2560 microcontroller. The microcontroller incorporates sensor inputs and appropriately prioritizes the lanes. It also decides when to illuminate lane traffic indicator lights. The microcontroller also receives data from the radio frequency identification (RFID) tag readers, thereby identifying the tags on emergency response vehicles. The microcontroller then gives the lane with the incoming emergency vehicle the highest priority, using these data as input. The microcontroller is also able to continuously monitor the system for any potential malfunctions. Either an external battery or a power adapter can be used to power the entire system.

3.1. Default Working Logic

Figure 1 displays the operational schematic of a density-based traffic signal system at a typical four-way junction. Four lanes—L1, L2, L3, and L4—pass through a single intersection. A set of three load cells and IR sensors are present in each lane. These devices are able to gauge the lane density. Load sensors are triggered by the weight of the vehicles that can be parked on top of them. The microcontroller assumes a low value if detected values from the load sensors fall below a predetermined minimal weight. In this case, it is safe to assume that a pedestrian is standing atop the sensor. On the other hand, if the controller receives values above the pre-determined threshold, the detected values can be interpreted as automobiles. Similarly, infrared sensors are placed alongside each lane for redundancy, and they help identify any obstruction that is positioned in their field of view. However, IR sensors have a predetermined maximum range; if an obstacle is detected within that range, the device treats it as a vehicle and gives the controller a high signal. The controller, on the other hand, receives a low indication if there is not an obstruction within the predetermined area. Consequently, it can recognize cars that are parked in front of them. The main sensors in the proposed system are RFID and load sensors. The inclusion of IR sensors is made solely to enhance the effectiveness of the load sensors. The working principle of the system is as follows:

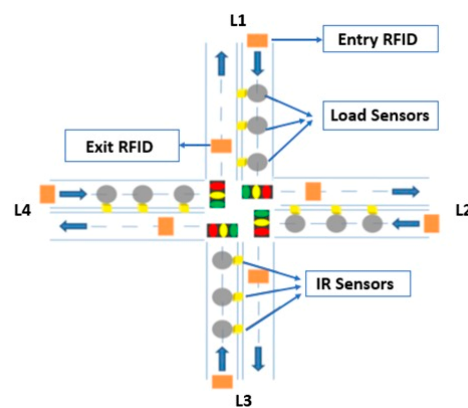


Figure 1. Density-based system intersection diagram.

- The system first determines the density of lane L1 using the sensor values for that specific lane. The output from each sensor is categorized as either high or low. If all three sensors output a high value, the lane is considered to have a high density, and the timer for the green light of that lane is set to the maximum amount.
- The timer setting is set to moderate in cases where the situation is classified as a medium density, i.e., only two out of three sensors output a high value.
- Lastly, if the output of only a single sensor is high, it is considered a low-density situation, and the timer is set to a lower number.
- The timer before the green light is set to zero if there happens to be no traffic on the lane, i.e., all three sensors output a low value.
- Once checking L1 has been completed, the algorithm looks for lane L2 after the timeout and performs similar operations to it. After L2, the system examines L3, then L4, and finally L1 once again. This cycle is repeated infinitely.

3.2. Provision for Emergency Response Vehicles

This system has a total of eight RFID readers, of which four are used to watch over emergency response vehicles as they arrive, and two are used to determine their exit. Since emergency vehicles have the right of way, it is important to give priority to the RFID output over the density check. This system constantly checks the lane entrance for RFIDs to recognize the entry of emergency service vehicles. RFID tags are installed on every emergency car, and the controller receives data regarding each tag. No matter how densely

populated the other lanes are, a lane always receives the highest priority whenever the entrance RFID identifies emergency service vehicles. As soon as the RFID at the entrance is triggered, the exit RFID is activated. This state is maintained until the emergency vehicle passes by the exit RFID. The system continues to operate based on densities only after an emergency response vehicle has left the junction.

3.3. Transitioning between Default and Emergency Modes

The flowchart for the density-based traffic signal system is shown in Figure 2 [12]. In the illustration, L represents the lane number, and R stands for the emergency vehicle. R is initially set to 0, and until an emergency service vehicle is detected, it remains so. R can be in one of four states depending on which lane the emergency response vehicle is in as it approaches the signal: 1, 2, 3, or 4. The fact that R is not equal to 0 shows that an emergency vehicle is approaching the intersection. Regardless of their densities, all other lane signals change to red while the one with the emergency vehicle remains green [13]. R does not become 0 until the emergency car has passed the intersection, at which point the density-checking system is activated.

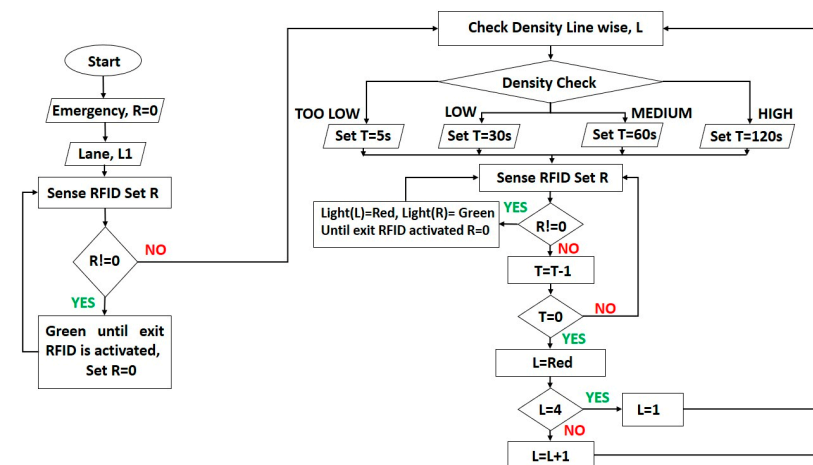


Figure 2. Flow chart of density-based traffic management system.

In the density check, L is initially set to 1, examining the front lane. The density of the lane, which can be high, middle, low, or zero, determines how long the timer runs. The timer is set to 120 s in the case of a high density, 60 s for medium density, 30 s for low density, and 5 s for zero density. This is conducted to allow cars parked outside of the designated stop areas or on zebra crossings to leave the junction. The lane signal turns green as soon as the timer is set, and the timer begins counting down. The number of L is then increased by 1, i.e., the density of the next lane is examined, and the procedure is repeated exactly. Eventually, the cycle is repeated again and again.

4. Fabrication

Fabricating a model for traffic flow using load cells and IR sensors involves careful planning, installation, and calibration of the sensors and data processing equipment. It also requires expertise in programming and data analysis to accurately interpret data collected from the sensors.

First of all, it is important to determine the size and layout of the model. Deciding on the size and layout of the model includes deciding on the number of lanes, the width of each lane, and the position of the load cells and IR sensors. Once the layout and size are determined, the installation phase begins. The load cells are placed underneath the road surface in each lane of the model. It is imperative that the load cells be placed at regular intervals along the lane to measure the weight of passing vehicles. After that, the installation of the IR sensors above the road surface in each lane of the model is carried

out. The IR sensors are placed at regular intervals along the lane to detect the presence of passing vehicles. Finally, a set of four RFID tags is installed at the entrance and exit of every lane to cater to emergency vehicles.

After the installation, all the sensors are connected to the microcontroller using the appropriate circuitry. The microcontroller is able to read the weight measurements from the load cells and the obstacle signals from the IR sensors. The microcontroller stores data or sends it to a computer for further processing and analysis. The various steps involved in sensor installation and testing are shown in Figure 3.

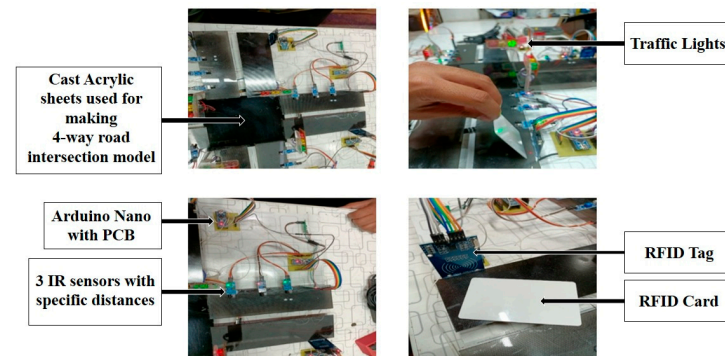


Figure 3. Sensor installation and testing.

Final Model

Figure 4 shows the completed model for a typical four-way junction. On each side of the junction, three IR sensors and three load cells are installed. At the entry of every road, RFID tags are placed to cater to any emergency vehicle. At the exit, there are also RFID tags placed, which give a signal to the system that the emergency vehicle has exited the junction. After the emergency vehicle exits, the RFID tag senses it, and then the density-based system takes over. In this manner, the flow of traffic is regulated.

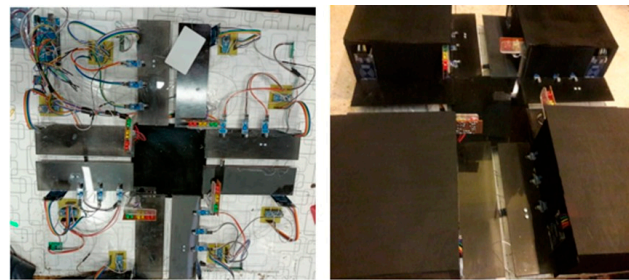


Figure 4. Final four-way road intersection model.

5. Discussion

The viability of a traffic management project utilizing load cells and IR sensors relies on the application of specific requirements and an implementation strategy. Load cells can gauge the weight of vehicles crossing a particular location, which can be advantageous for traffic monitoring and categorization. IR sensors can detect the presence or absence of vehicles, as well as measure their velocity and distance. To ensure the success of a traffic management project using load cells and IR sensors, it is important to carefully evaluate the specific application requirements, select appropriate hardware and software components, and develop a robust implementation plan that addresses potential challenges and risks. Working with experienced professionals and consulting with relevant stakeholders, such as local authorities, traffic engineers, and transportation planners, can also help ensure the success of the project. Table 1 lists major traffic management solutions and their relative disadvantages. Similarly, the advantages of the proposed method are outlined in Table 2.

Table 1. Disadvantages of the existing traffic management system.

Technique	Disadvantages
Image processing	Weather dependent, i.e., does not work properly in rain and fog
Radar detector	Expensive: the performance affected by metal barriers around the road
Ultrasonic detector	Limited testing distance
Piezoelectric sensor	Sensitive to vibration and acceleration
Inductive loop	Sensitive to temperature fluctuations
Magnetic detector	Magnetic field is affected by external ferromagnetic material
Microwave detector	Radiations are hazardous for health, and they consume more energy
Photoelectric detector	Over a long period of time, the lens becomes contaminated

Table 2. Advantages of the proposed system.

Sensor	Advantage
Load cells	Load cells are used for quick and precise measurements. Compared to other sensors, load cells are affordable and have a longer life span
IR sensors	IR sensors have a low cost and require minimum power to operate
RFID	RFID is inexpensive and reliable; it can check the entry and exit of any emergency vehicle and control the signals accordingly

6. Conclusions

The implementation of a density-based traffic signal system in urban areas can effectively reduce the time wasted by adjusting the signal timer based on traffic densities. This system also benefits emergency service vehicles by prioritizing their passage through intersections. One of the major advantages of this system is that it addresses the issue of multiple entrances for emergency service vehicles from different lanes. Smart traffic management systems have numerous advantages over traditional traffic management systems. The system design contains an ATmega 2560 chip as its brain, which stores data obtained from sensors and executes them using appropriate programming to model the density-based traffic flow system by prioritizing emergency vehicles for efficient and safe traffic flow. The prototype model discussed in the paper is found to be scalable for real-world implementation at an actual junction. By using real-time data and advanced algorithms, smart traffic management systems can optimize traffic flow and reduce delays, resulting in shorter travel times and reduced fuel consumption. Additionally, smart traffic management systems can improve safety by reducing the number of accidents caused by traffic congestion and the risk of collisions at intersections.

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