RFID Technology and Induction Loop Sensor On Traffic Light System for Emergency Vehicles: A Review

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Abstract

Implementing a traffic light system at a 4-junction using RFID technology integrated with an induction loop sensor can improve traffic flow to clear pathways for emergency vehicles and at the same time reduce traffic congestion. Current literature primarily addresses the capabilities and limitations of RFID and inductive loop sensors separately. For instance, RFID technology has been extensively studied for its potential to enhance vehicle identification and communication, while inductive loops are well-researched for their accuracy in vehicle detection and classification. However, the integration of these technologies has not been thoroughly explored. This absence is significant because combining RFID and inductive loops could offer a more comprehensive solution to traffic management challenges. The integrated system could support RFID's ability to track and communicate with emergency vehicles and inductive loops' precision in detecting vehicle presence, thus optimizing traffic flow and response times, especially during emergencies.

Keywords: Emergency Vehicle, Traffic Light System, RFID, Inductive Loop Sensor, Traffic Congestion

1. Introduction

Traffic congestion continues to pose significant challenges worldwide, necessitating innovative solutions to manage traffic flow effectively. For the time being, most locations in Malaysia continue to alter traffic light sequences using the simple pre-set time counter traffic light system. Since the PCT intervals between each light sequence have been predetermined, this kind of traffic light has only been accessible through programmed sequences. In the meantime, several states in Malaysia now rely on inductive loop sensors but encounter problems with vehicles not stopping on the induction loop and with smaller vehicles not being able to be detected due to induction loop design (Chan, 2023). However, this system primarily addresses traffic congestion but fails to overcome the problem. According to (Rae & Binder, 2024), the widespread adoption of automobiles for commuting purposes brought about a rapid rise in automotive traffic.

According to (Madhavan & Modani, 2020) journal, road traffic injuries are one of the top causes of death for young people worldwide, claiming the lives of over 1.2 million individuals annually. The estimated cost of road traffic injuries to governments is 3% of GDP, and in low- and middle-income nations, it can reach 5%. If nothing is done, it is estimated that by 2030, traffic accidents will account for around 1.9 million deaths annually, making them the seventh most common cause of death. (Abdelfatah, 2016) stated that motorcycle riders account for the majority of fatalities on Malaysian roadways, with over 50% of these deaths occurring in the 16–30 age range. Meanwhile, the largest significant number of motorcycle-related traffic crashes happened to those who are about in the middle of the young adult group, between the ages of 16 and 19, according to data published by (Malaysian Institute of Road Safety Research, 2017) (MIROS). The west coast of Malaysia, which has the biggest population and number of registered motorcycles, has the highest record of motorcycle deaths. The majority of motorcycle fatalities in Malaysia occurred between Saturday to Tuesday, with the highest record between 4 and 10 p.m. at their peak according to (Abdul Manan & Várhelyi, 2012) research.

Besides that, the increasing population has resulted in the rapid growth of vehicles on the roads, leading to an increase in traffic congestion. Traffic congestion not only results in the wastage of time but also causes economic losses. One of the main causes of these issues is ineffective traffic control systems. Conventional traffic signal systems cause delays, congestion, and accidents because they follow preset schedules rather than considering the flow of traffic in real-time. Thus, a more intelligent and effective traffic management system is required, one that can adapt to shifting traffic conditions and maximize traffic flow (Gaikwad et al., 2023). However, the average ambulance response time in 2008, according to studies done at Hospital Universiti Sains Malaysia in Kubang Kerian, Kelantan, Malaysia, was 15 minutes. The average response time decreased to 12 minutes after ten years, yet it is still well below international standards. (Shaharudin Shah et al., 2008) found that in 505 cases, a full 75% still use 8 minutes as the lowest limit ambulance response time.

Traffic light systems integrating RFID and induction loop sensors for emergency vehicle prioritization may contribute to the advancement of traffic light systems and enhance emergency response efficiency.

2. Traffic Light Controller System

This chapter presents a literature review relevant to the research topic, aimed at enhancing understanding in analyzing various studies that examine recent methodologies used in the development of traffic light controller systems (TLCS). This includes systems based on image processing techniques, induction loop technology, LiDAR, and RFID. By synthesizing findings from other researchers and academic journals, the aim is to establish a foundational understanding of the topic while identifying best practices that can minimize redundancy in the research and help achieve optimal results aligned with research objectives.

The TLCS has emerged as a critical area of research due to significant traffic challenges. The complexity of TLCS arises from the integration of various components, including detection systems, adaptive control mechanisms, and communication technologies. These elements work together to enhance traffic management by promoting efficiency, safety, and mobility in traffic flow (Lee & Chiu, 2020).

To address the issue of traffic congestion, a multidisciplinary approach is being pursued with researchers from diverse fields collaborating to identify viable solutions. This chapter explores and evaluates proposed methods and technologies for developing a TLCS, examining various types of controllers, manufactured devices, and different sensor technologies. By analyzing these innovations, valuable insights are offered to inform future developments in this critical area of traffic management.

3. Research of methods applied in the Traffic Light Controller System

3.1 Image Processing Techniques Applied in TLCS

According to a method described by (Susilawati et al., 2023) image processing technique was used to create a traffic signal management system that may alter waiting times based on the situation on the road. The Raspberry Pi 4 was used as the controller in the system's development and to determine the number of vehicles, the system uses cameras to take a picture of the traffic situation, which will then be processed using OpenCV and TensorFlow. The number of vehicles will be transmitted to the web server database for processing as input for the traffic system configuration.

By utilizing a webcam camera as a replacement for the eye and a Raspberry Pi 4 as a digital image processing device that is programmed to calculate the number of vehicles at the junction. The system is programmed to determine those with the most vehicle which indicates the system can change the timing of the traffic lights. The traffic signal will turn green after 10 seconds if there are three vehicles in the queue when it is red. The duration of the green light will be extended by 4 seconds for every additional vehicle in the queue. Figure 1 shows the research block diagram of (Susilawati et al., 2023).

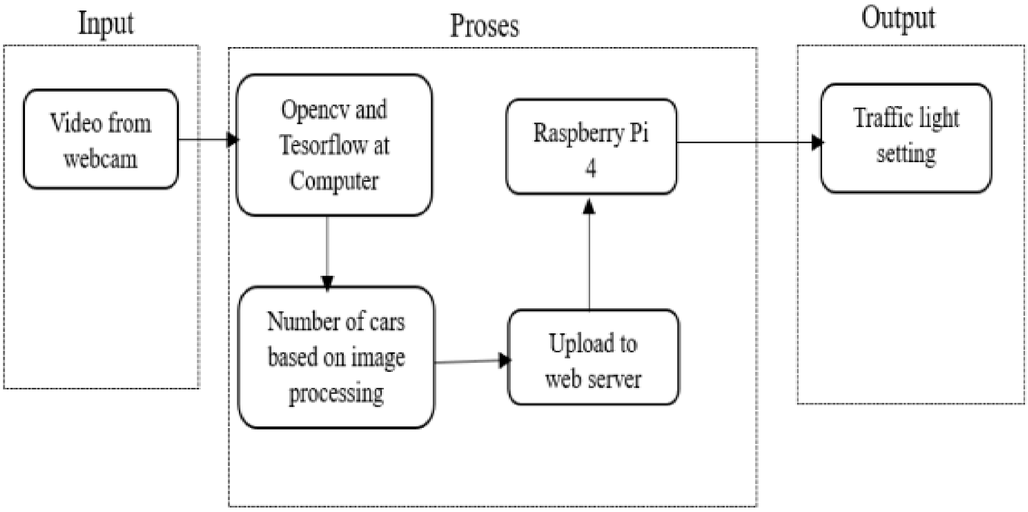


Figure 1. Research block diagram of (Susilawati et al., 2023)

In addition to reducing congestion, (Sakhare et al., 2024) propose an innovative IoT-based traffic control system that uses YOLO for image processing. With the use of video sensors that capture real-time traffic data, the system calculates the average waiting periods for each lane and dynamically adjusts the timing of the signals. Due to the system's flexibility, air pollution and fuel consumption are reduced as traffic flow, congestion, and average waiting times are all improved. The method suggested addresses environmental objectives while addressing urban transportation issues economically and efficiently. The researcher also emphasizes how image processing and the Internet of Things may be used to create intelligent traffic control systems, which will eventually lead to smarter and more liveable cities. Figure 2 shows the general block diagram of (Sakhare et al., 2024) research.

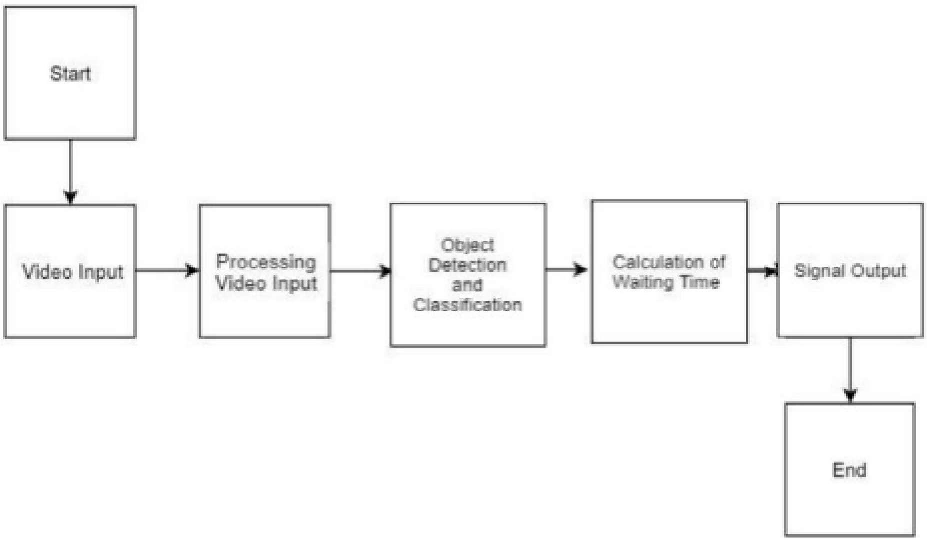


Figure 2. Block diagram research (Sakhare et al., 2024)

Moreover, according to the method described by (Anubhav Mehrotra & Abhinav, 2019) security cameras are used to measure traffic density using MATLAB. A traffic controller and a wireless transmitter are then used to send pictures to the server, which then uses those images to compute traffic density for each sector. The number of vehicles on the route determines the present predefined thresholds employed by the system. According to the amount of traffic on the road, an algorithm was used to establish the duration of a red light for a certain junction lane. The algorithm was sent to the microcontroller and subsequently to the server. Figure 3 shows the research flowchart of (Anubhav Mehrotra & Abhinav, 2019).

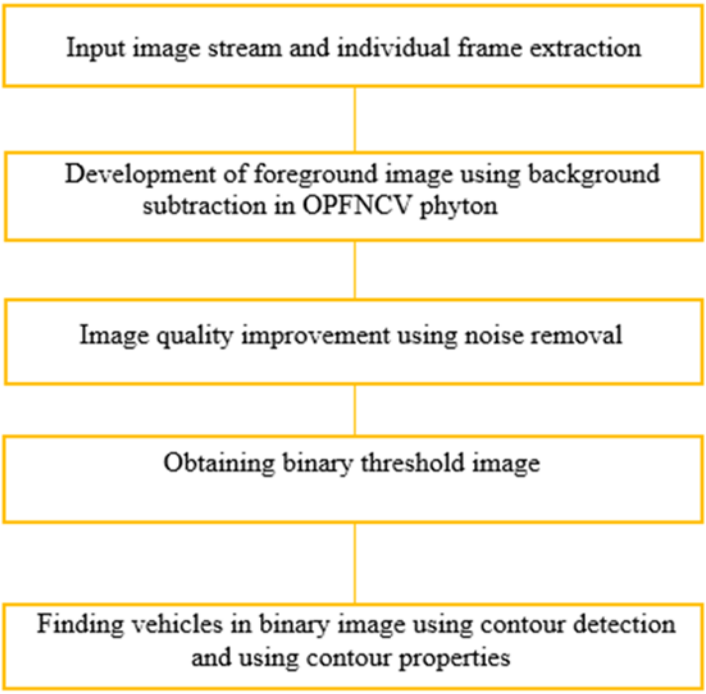


Figure 3. Research flowchart (Anubhav Mehrotra & Abhinav, 2019)

(Javaid et al., 2018) offer an efficient response to the increasing traffic in large cities, where traditional traffic management systems are unable to keep up with the current volume of traffic. To control road traffic situations more effectively and efficiently, a smart traffic management system is proposed, taking into account the most current methodology for traffic management systems. By more efficiently than ever interacting with the local server, it intelligently modifies the signal timing following the traffic density on that specific roadside and controls traffic flow. As it operates even in the event of a centralized or local server failure, the decentralized approach optimizes and effectively utilizes the system. In the event of an emergency, the centralized server alerts the closest rescue department, ensuring immediate human safety. Additionally, the system is made to control traffic on road networks by utilizing RFIDs installed on roadsides, security cameras, and sensors.

The system operates in a distributed way, processing video data at the local server and sensor data at the node level. It then computes average density to control traffic depending on density. Furthermore, it addresses emergency vehicles, including ambulances and fire engines, and provides users with predictive information about the level of traffic on a specific road. Besides that, Figure 4 illustrates the 3-layer system model of (Javaid et al.,

2018) research is divided into three layers data acquisition and collection layer the data processing and decision-making layer, and lastly application and actuation layer.

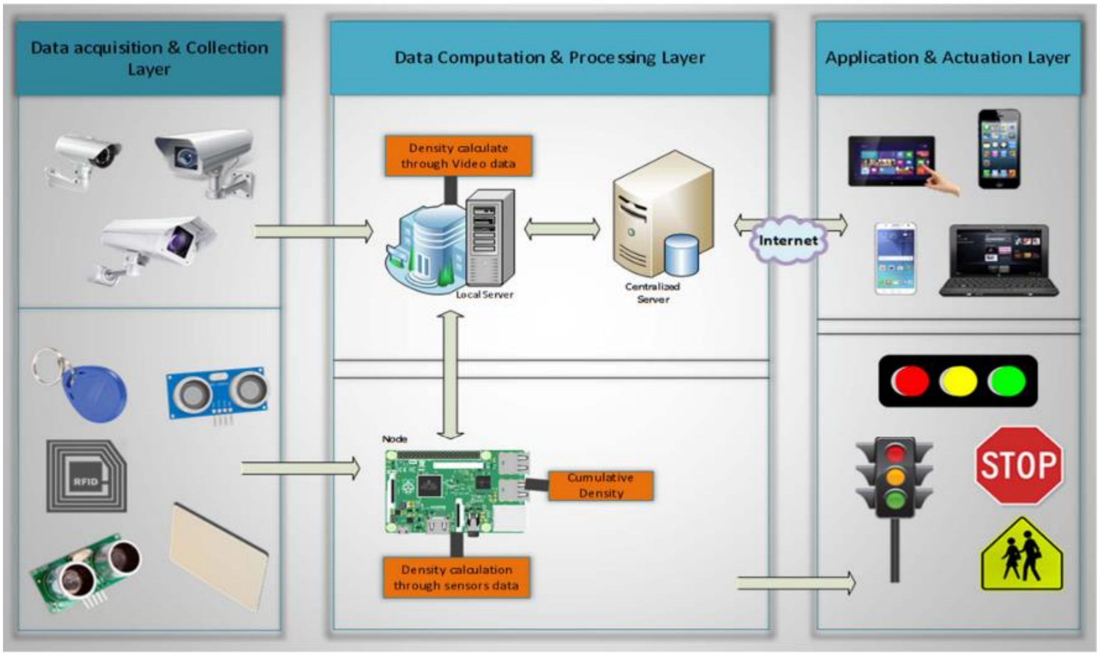


Figure 4. Illustrates the 3 layers system model

According to (Akoum, 2017) the use of real-time image processing to create a smart traffic controller that may be used to find vehicles and provide signals. Many other researchers used a matching method in which a traffic light and camera were installed, and the camera captured a series of images. The captured images are sequentially matched using image matching to set an empty road image as the reference image.

However, (Akoum, 2017) used a filtering method that filtered the image, releasing all waste objects and only showing the cars, and then it clearly showed the number of cars in the image. Figure 5 shows the count and number of tracking vehicles.

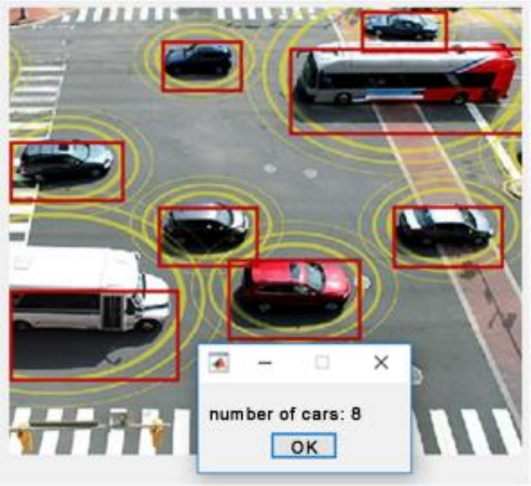

number of cars: 8

Figure 5. The tracking vehicle and the count

Besides that, according to (Kedwan, 2023) the widely utilized traffic control techniques are solved by traffic control employing image processing techniques. The use of timers in automatic traffic control formerly had the disadvantage of wasting time when there was an empty route with a green light. Upon comparison with several edge detection algorithms, it was determined that the Threshold Edge Detector technique for image processing is the most efficient one for traffic control compared to previous techniques. Additionally, because it is less error-prone and more economical than the density-based method, it is more effective.

In addition, the traffic signal timings that are allocated differ significantly based on the traffic density evaluation by image matching. The camera's position when facing the road each time determines how accurate the time due to a single moving camera is calculated. Image processing techniques are the most effective means of controlling the traffic light's status change. Figure 6 illustrates the block diagram of the system described by (Kedwan, 2023).

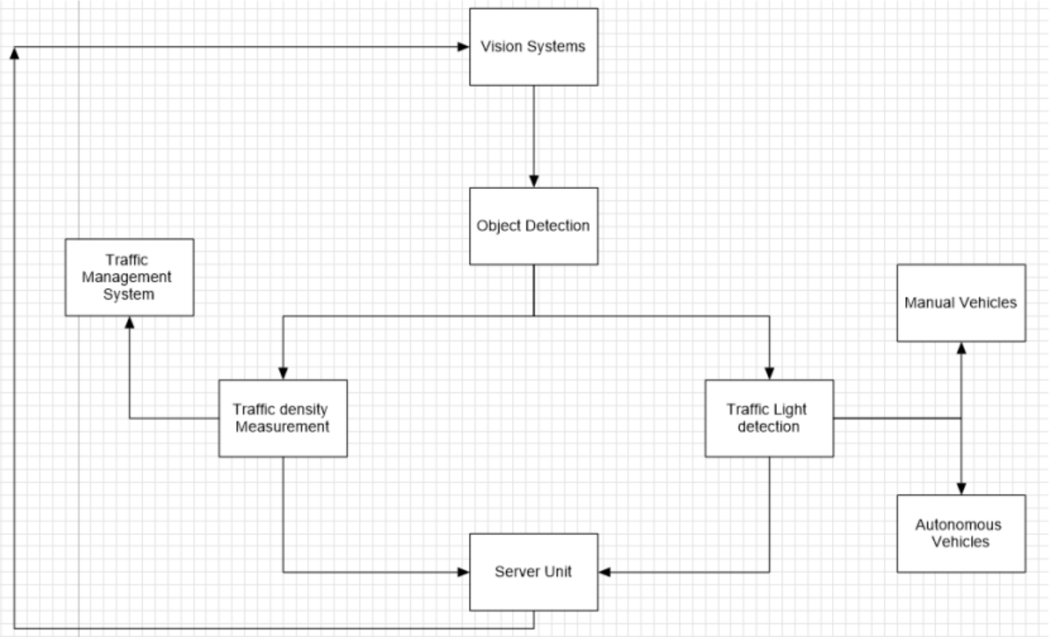


Figure 6. Illustrates the block diagram of the system

Based on (Eddy & Owmya, 2017), an STLCS utilizing image processing techniques to control the traffic light was developed using MATLAB software and an Arduino microcontroller. This system's MATLAB program handles the image processing portion, while the Arduino microcontroller serves as the TLC.

Four webcams are used in the proposed STLCS, which is linked to a computer running MATLAB software. Additionally, MATLAB software was used to process the video frames from each camera utilizing serial image processing techniques for vehicle recognition and counting. The timing algorithm calculates a suitable green period for each lane where the car is to be discharged based on the number of vehicles observed as an input parameter.

Therefore, a collection of LEDs organized in rows and columns is what the LED matrix is as a result. A pixel, or flashing dot that spans the full screen, is created by each component of this row and column arrangement. The vehicle identification method is divided into two groups based on the time mode. In the daytime mode, the subtraction count approach is used. While it would be difficult to count the number of cars in the night mode. Meanwhile, counting the front headlights may be used to estimate the number of automobiles. The algorithm calculates a longer time for this congested route compared to the other less crowded roads if a particular junction has a high traffic density. Figure 7 shows the block diagram of the developed system.

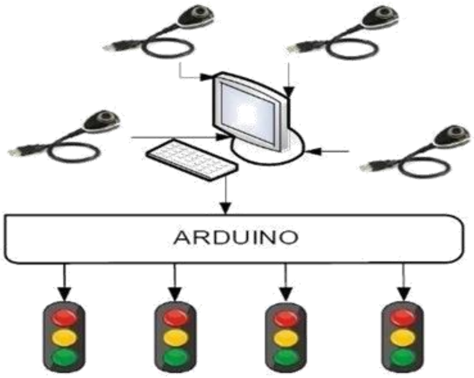


Figure 7. Block Diagram of the Proposed System (Eddy & Owmya, 2017)

According to (Vani et al., 2018), the researcher developed a smart traffic signal system employing image processing techniques. The system's web camera, which was positioned at a specified height, offers real-time surveillance for every intersecting lane. The webcam's real-time traffic frame data is then sent to a computer running MATLAB software for video processing. To determine the traffic density, the number of cars in each lane was determined.

Furthermore, (Vani et al., 2018). noted that it is a major worry nowadays for emergency response unit vehicles to be delayed in traffic, therefore researchers built a component into their system that could identify emergency response unit vehicles like ambulances. As mentioned below, researchers in this study changed the signal priority condition of the traffic light system from high to low priority to address traffic congestion and the presence of emergency vehicles.

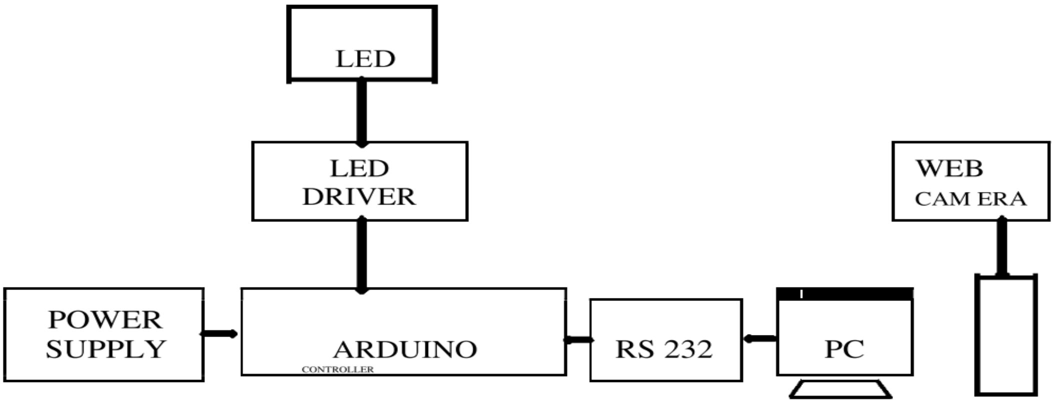


Figure 8. The proposed system block diagram of (Vani et al., 2018)

3.2 Comparison of various aspects of Image Processing Techniques applied in TLS

Table 1. Comparison of various aspects of Image Processing Techniques applied in TLS

Author & Year	Key Details	Method	Advantages	Disadvantages
(Susilawati et al., 2023)	Developed a traffic light management system using Raspberry Pi 4, image processing (OpenCV and TensorFlow) to adjust traffic light timing based on vehicle count. Cameras capture traffic conditions and adjust light timings based on queue length.	Digital Image Processing, Single Shot Detector (SSD), Cascade Classifier OpenCV & TensorFlow	Real-time adjustment of traffic light timings; adaptable to queue lengths; reduces congestion.	Requires camera and processing hardware; dependent on image processing accuracy; potential for delays in response.
(Sakhare et al., 2024)	Introduced a traffic control system based on IoT and image processing with YOLO. It dynamically modifies signal timings based on real-time traffic data, improving traffic flow and reducing waiting times.	IoT-based image processing (YOLO V3)	Reduces congestion and waiting times; lowers pollution and fuel usage; cost-effective.	Potential complexity in IoT integration; requires continuous real-time data processing.
(Anubhav Mehrotra & Abhinav, 2019)	Used security cameras to measure traffic density using Open CV. Traffic controller sends images to a server to compute density and determine red light duration based on predefined thresholds.	Image processing with OTSU bi-modal threshold.	Precise red-light duration based on traffic density; uses existing security cameras.	System depends on image quality and processing speed; may require high bandwidth for image transmission.
(Javaid et al., 2018)	Proposed a smart traffic management system with decentralized control, using ultrasonic sensors, cameras, and RFIDs. The system operates even if a server fails and adapts signal timings based on real-time density data.	Blob detection technique with other distributed sensor-based system	Decentralized and resilient; handles emergencies; provides congestion prediction.	Complex system architecture; may require significant infrastructure and maintenance.
			Efficient vehicle	Performance can be affected by

(Akoum, 2017)	Implemented a smart traffic controller using real-time image processing. The system utilizes edge detection and filtering methods to track and count vehicles, adjusting signals accordingly.	Blob analysis method & Canny Edge Detection Technique	tracking and counting; reduces false positives compared to previous methods.	lighting conditions; requires consistent image quality.
(Kedwan, 2023)	Proposed a traffic control system using image processing and the Threshold Edge Detector technique. This method is cost-effective and reduces errors compared to traditional methods, eliminating the need for additional sensors.	Image processing with Threshold Edge Detector.	Cost-effective; reduces errors; no need for additional hardware; accurate traffic signal control.	Performance may vary with lighting conditions; single camera positioning can affect accuracy.
(Eddy & Owmya, 2017)	Developed an STLCS using MATLAB and Arduino for image processing and traffic light control. The system uses webcams for vehicle recognition and counting, adjusting signal timings based on observed vehicle counts.	Image processing with MATLAB	Real-time vehicle counting and signal adjustment; adaptable on day/night conditions.	Requires multiple webcams and MATLAB software; may be complex to set up and maintain.
(Vani et al., 2018)	Created a smart traffic signal system with real-time image processing using a webcam and MATLAB. The system determines traffic density and adjusts signal timings. It also identifies emergency vehicles to prioritize their passage.	Image processing with MATLAB	Real-time traffic density detection; prioritizes emergency vehicles; reduces congestion.	Performance may be affected by lighting and camera angles; may require robust emergency vehicle detection.

3.3 Induction Loop Applied in TLCS

In the meantime, according to (Ali et al., 2012) a potential solution to this issue is a vehicle detection system that utilizes a new technique involving multiple loop inductive sensors. Test results from a developed prototype demonstrate the effectiveness of this method. The results indicate that the multiple inductive loop system can identify and categorize the number and types of vehicles. This sensor is capable of detecting both large vehicles, such as buses, and smaller ones, like bicycles, making it ideal for varied traffic conditions. The multiple loop system applies to roads regardless of whether traffic is organized or chaotic. Additionally, the data generated by this system is in digital format, making it easy transmission to traffic management centers for real-time use. This developed system supports intelligent transportation system (ITS) implementations in regions with diverse and unmarked traffic, leading to improved management of current roadways and reduced congestion. Figure 9 illustrates the proposed inductive loop system by (Ali et al., 2012).

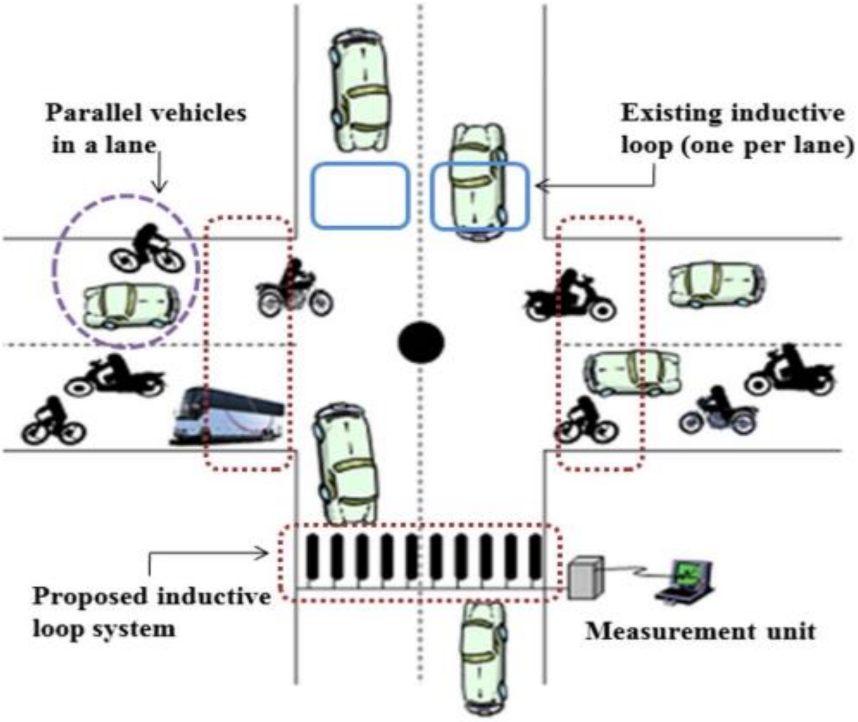


Figure 9. Illustrates the proposed inductive loop system by (Ali et al., 2012)

The experiment done by (Azmi, 2007) is to examine how an inductive loop behaves when an iron core is added to the circuit. Experimental results indicate that the quadrupole loop-type inductor provides the best sensitivity, making it the preferred choice for the sensor circuit. A resonant circuit is employed to enhance the iron detection capability, resulting in a well-designed inductive sensor. This type of sensor, as noted by (Azmi, 2007), is chosen for integration with traffic light controllers because it can detect a wide range of vehicles, from large trucks to small bicycles. It is effective for any vehicle that contains metal, ensuring efficient detection. Moreover, since this sensor identifies metal presence, it helps reduce flow error specifications. In contrast, traditional sensors like motion or ultrasonic types tend to have higher flow error rates, which can be affected by environmental factors like rain. These conventional sensors may misinterpret objects in the sensing area as obstacles, leading to incorrect readings, such as mistaking rain for an obstruction.

Additionally, the traffic light system features six LEDs to indicate two-way lanes and a timer determines the timing for each light sequence. The inductive sensor detects and counts the number of vehicles passing by, relaying this information to the traffic light controller. The controller then decides whether to provide a longer green light duration or to follow a standard light sequence with normal timing delays. A prototype combining the traffic light and inductive sensor has been constructed to showcase the overall performance of (Azmi, 2007) project. Figure 10 illustrates the basic type of inductive loop sensor while Figure 11 illustrates other types of inductive loop sensors.

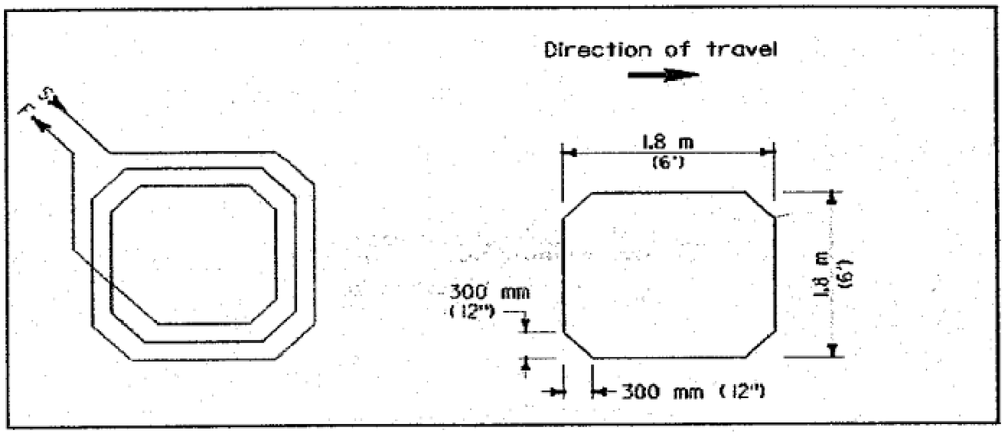


Figure 10. Illustrates the basic type of inductive loop sensor

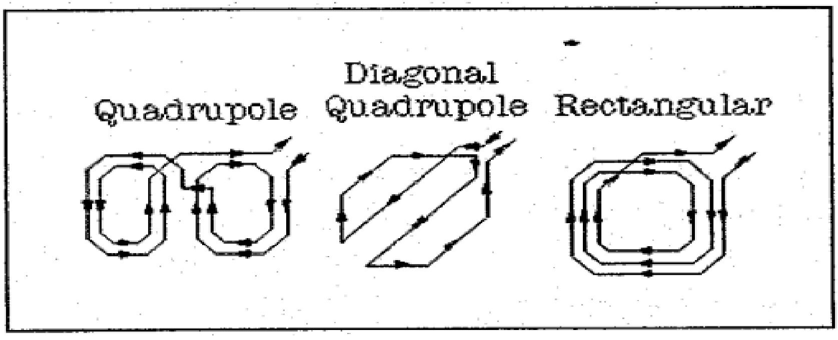


Figure 11. Illustrates other types of inductive loop sensor

According to (Shaithya, 2007), the researcher implemented a traffic light system using the inductive loop detector that is placed below the surface of the roadway which is shown in Figure 12.

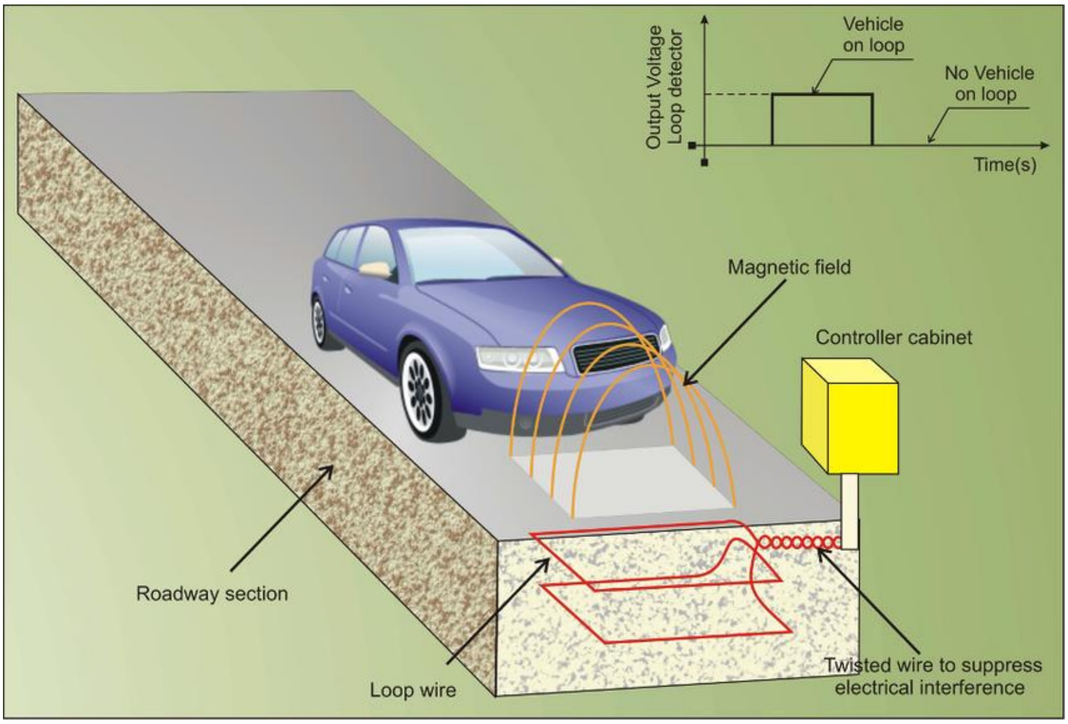


Figure 12. Inductive loop detector that is placed below the surface of the roadway

The researcher noted that the inductive loop operates on AC, allowing the system to function as a tuned electrical circuit, with the lead-in cables serving as the inductive components. When a vehicle enters the inductive loop, the electromagnetic field generated by the AC in the sensor loop induces a small current within the vehicle. According to Lenz’s law, this induced eddy current creates its electromagnetic field that opposes the field from the sensor coil. The presence of this eddy current leads to a reduction in the inductance of the loop (Cecco et al., 1981).

Subsequently, the results indicated that the decrease in inductance results in lower impedance, which triggers the oscillator circuit to send a pulse signal to the data acquisition system, signaling the presence of a vehicle. This information is then used as input for the traffic light control unit based on Figure 13 the block diagram of the inductive loop-based traffic light system.

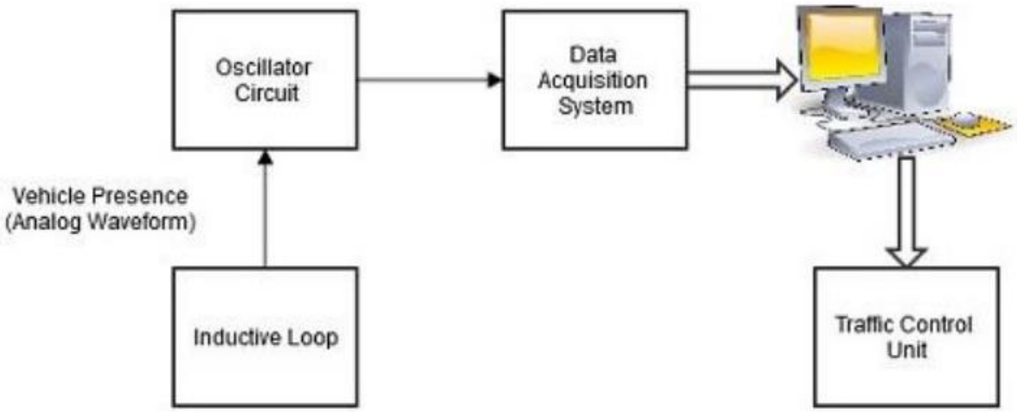


Figure 13. Block Diagram of Inductive Loop-based Traffic Light System

The researcher, (Shaithya, 2007) highlighted that variations in the amplitude of loop inductance within an inductive loop can provide valuable information, including the type of vehicle whether it's a car, bus, or bicycle as well as its speed, count, and length. Consequently, the researcher carried out studies to analyze three different types of inductive loop structures, as illustrated in Figure 14.

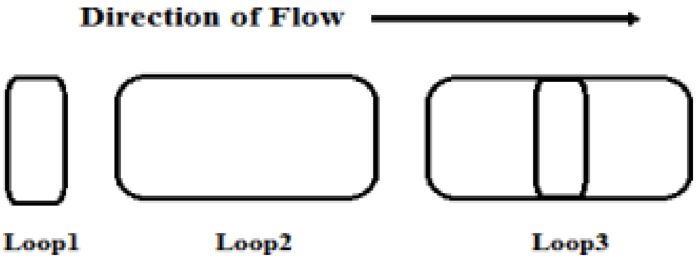
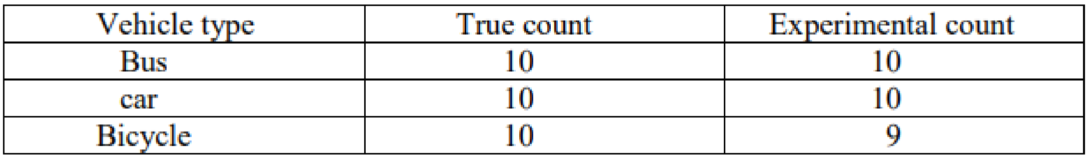


Figure 14. Loop-1 small vehicle detector, Loop-2 large vehicle detector, and Loop-3 new loop detector

Table 2 presents the findings from the researcher, who compared the actual vehicle count with the experimental results obtained using their new Inductive Loop 3 in the traffic light control system. The results indicate that the proposed system can detect vehicles with an accuracy of approximately 97%.

Table 2.Comparison between True Count and Experiment Count using Inductive Loop Detector



Vehicle type	True count	Experimental count
Bus	10	10
car	10	10
Bicycle	10	9

According to (Gajda et al., 2001) in a classification system, identifying the type of vehicle is a crucial parameter for measuring road traffic. Traditionally, strip piezoelectric sensors and video systems have been employed for this purpose. However, it is also feasible to use low-cost inductive loop detectors for vehicle classification. This type of classification system relies on magnetic profiles recorded from the inductive loops, which are sensitive to the dimensions of the loop. In (Gajda et al., 2001) research, discussed the length of the loop in the direction of vehicle movement affects the characteristics of the magnetic profiles for vehicles in different classes. The proposed algorithm in (Gajda et al., 2001) research utilizes signals from inductive loop detectors with appropriately selected dimensions. The study analyzes how loop length influences various characteristics or parameters of the magnetic profile. A higher value of a specific criterion for vehicles across different classes allows for more precise classification. A significant value for two different vehicle types within the same class indicates that it is possible to distinguish between different types within that common category. These findings are associated with a magnetic profile that has been normalized in amplitude and transformed into the vehicle length domain, as illustrated in Figure 15.

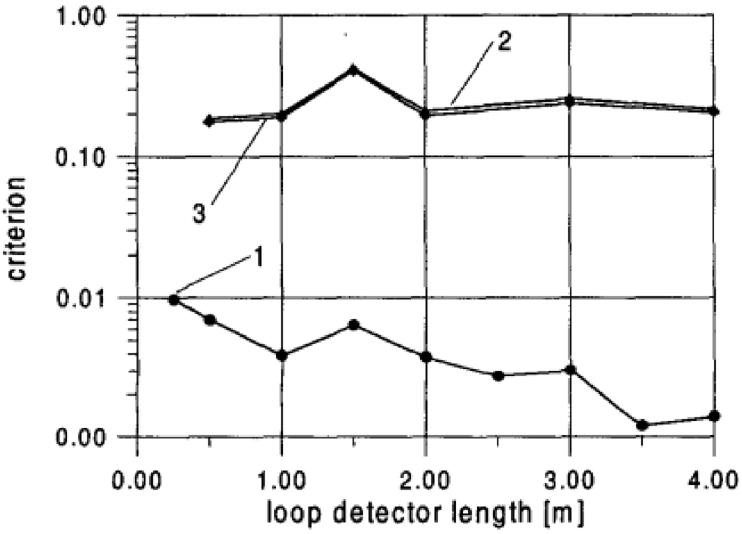


Figure 15. The influence of loop length on criterion 1 for normalized amplitude magnetic profiles in the length domain

The test results show that shorter loops yield higher criterion values. Specifically, a very short loop measuring 10 cm can detect the number of axles and measure the distance between them. This means that such a loop can effectively replace a system that includes two strip piezoelectric sensors and one long loop. Besides that, (Matei et al., 2019) suggested one viable solution is by implementing a virtual inductive loop system. As we know inductive loop detectors have emerged as the most commonly used sensors in traffic management systems. For traffic data collection, (Matei et al., 2019) utilize a “Smart Loop” video sensor, which incorporates presence sensors known as virtual inductive loops, as shown in Figure 16 below.

Figure 16. Smart loop equipment

This smart loop can detect vehicle presence, identify queues in monitored areas, and estimate the circulation speed of vehicles. Hence according to (Matei et al., 2019), road traffic can generally be divided into two categories peak areas and general traffic areas. However, the findings gathered from virtual inductive loops reveal four distinct high-traffic zones: Zone I (early morning), Zone II (mid-peak), Zone III (late afternoon peak), and Zone IV (evening). Using virtual inductive loops to adjust signal plans at junctions is essential for high-capacity intersections, and can accommodate various traffic conditions. Additionally, the calculation of traffic light cycles is based on the number of measurements taken per hour. This allows the virtual inductive loop to generate reports in 5-minute increments, resulting in highly accurate traffic light cycle calculations. Lastly, these loops can be employed to create tailored traffic signal plans for each zone identified as a peak hour.

3.4 Comparison of various aspect in Induction loop sensor applied in TLS

Table 3. Comparison of various aspect in Induction loop sensor applied in TLS

Author & Year	Key Details	Induction Loop Shape	Loop Size	Loop Turn	Loop Type	Advantages	Disadvantages
(Ali et al., 2012)	Developed a multiple loop inductive sensor for vehicle detection. It detects various vehicle types (e.g., buses, bicycles) and is suitable for heterogeneous traffic conditions. The system is digital, aiding real-time traffic management.	Multiple loops in rectangular shape loop	Not specified width, D1 =55 cm and length, D2 = 80 cm and inner loops length, D3 =20 cm	5	Multiple Inductive loop	Detects a wide range of vehicle types; suitable for heterogeneous traffic.	Potential complexity in installation; might require calibration for diverse traffic conditions.
(Azmi, 2007)	Investigated inductive loops with iron cores; chosen quadrupole loop for its sensitivity. The sensor detects all vehicles with metal bodies, reducing flow error compared to conventional sensors. Also used for traffic light control with an astable timer for sequence timing.	Quadrupole loop	Not specified	Not specified	Single Inductive loop	High sensitivity; effective in detecting various vehicle sizes; reduced flow errors compared to other sensors.	Performance can be affected by ambient conditions; may not detect non-metallic objects effectively.

(Shaithya, 2007)	Implemented a traffic light system using inductive loops below the roadway surface. The system detects vehicles based on changes in inductance and generates pulse signals for traffic control. Analysed different inductive loop structures for vehicle detection.	Rectangular loop	Not specified	5	Single Inductive loop	Accurate vehicle detection; improves traffic light control; various loop structures analysed for optimal performance.	Limited by the need for physical installation under the roadway; may be affected by loop placement.
(Gajda et al., 2001)	Discussed vehicle classification using inductive loops, focusing on magnetic profiles and the influence of loop dimensions. Compared to expensive piezoelectric sensors, inductive loops were found to be efficient for vehicle classification.	Various shapes (e.g., long, short)	Variable (1 m – 4 m)	Not specified	Single Inductive loop	Cost-effective; high classification efficiency; adaptable to various loop dimensions.	Classification accuracy dependent on loop size; may require precise calibration to maintain efficiency.
(Matei et al., 2019)	Studied traffic management using virtual inductive loops. Identified four peak traffic zones and emphasized adapting signal plans based on loop data. Virtual inductive loops also help in precise traffic light cycle calculation and creating traffic signal plans.	Not specified	Not specified	Not specified	Virtual inductive loop	Effective for peak traffic zone identification; accurate traffic light cycle calculation; adaptable signal plans.	May require advanced data processing; implementation can be complex in existing infrastructure.

4. Lidar-based traffic light monitoring systems

Recently, lidar technology has advanced significantly in the field of traffic monitoring, largely due to lower costs and high-quality point cloud measurements. (Shirazi & Morris, 2017).One of the key advantages of lidar-based traffic monitoring is its capability to operate at night, as active lidar sensing does not require external illumination (Xiao et al., 2017).

In (Zhang, 2023) research paper, the researcher introduces a cutting-edge 3D lidar-based traffic monitoring system that effectively collects detailed traffic data through an efficient workflow. It measures key traffic parameters, such as vehicle counts, dynamics, dimensions, and types, achieving an impressive vehicle detection accuracy of 94% through both traditional machine learning and deep learning methods. The incorporation of a tracking refinement module has further improved speed measurement accuracy from 0.4 m/s to 0.2 m/s. By combining vehicle detection and tracking, the system enhances the quality of vehicle trajectories in terms of range and continuity, capturing complete vehicle shapes shown in Figure 17.

Moreover, the researcher said that separating object tracking from detection, it reduces trajectory interruptions caused by light occlusion and extends the tracking range, even in areas with weak reflections. However, the system does have limitations, such as unresolved heavy occlusion issues with a single lidar sensor and the inability to achieve real-time monitoring due to unoptimized code and limited computing power, although near real-time processing is feasible. Additionally, identifying vehicles is more challenging compared to video imagery due to the lack of RGB information.

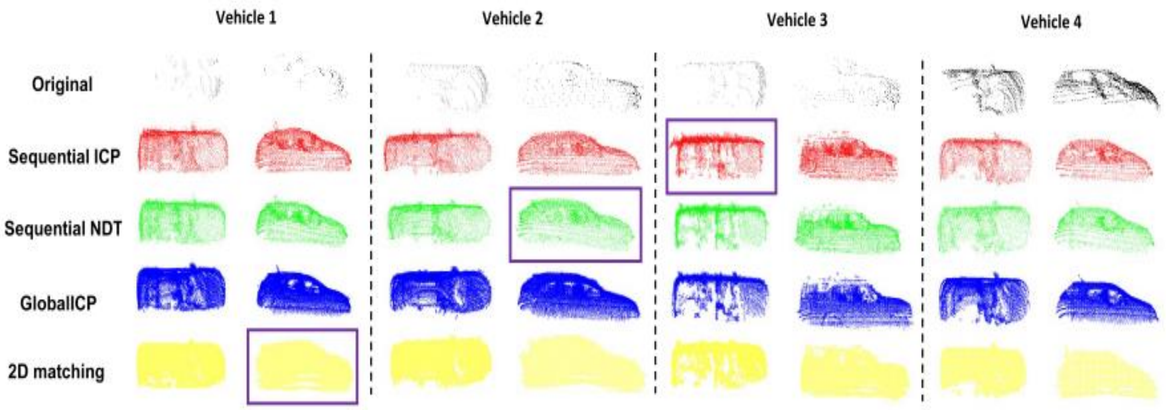
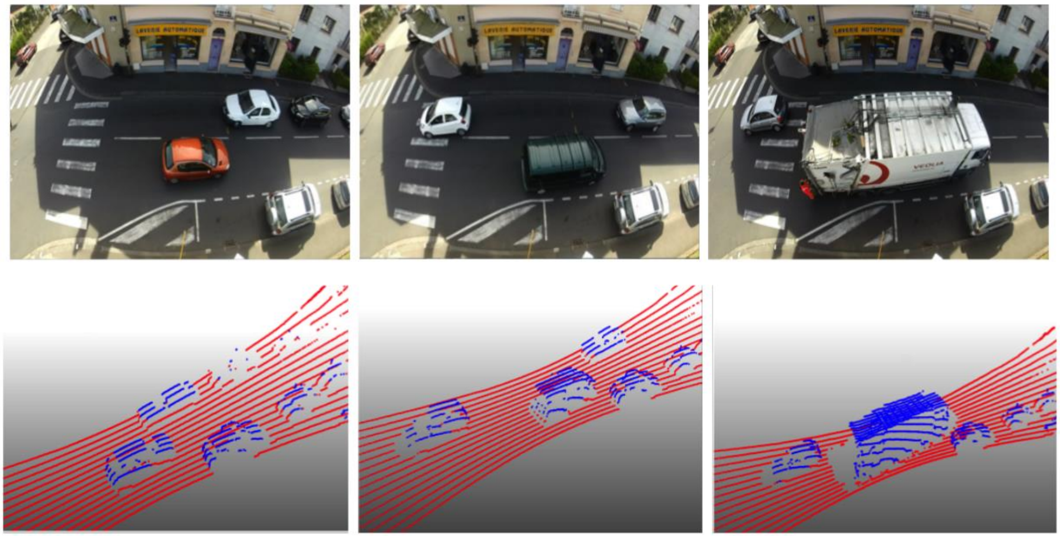


Figure 17. Captured of vehicle types & shape

Despite that, this technology allows for the monitoring of the movements of road users at intersections, which poses challenges of its cost for example, a Robo Sense RS-Ruby Laser Rangefinder with 128 beams costs around $30,714.00 (Zhang, 2023).

Besides that, (Aijazi et al., 2016) proposed a novel method for the automatic detection of vehicles using a compact 3D Velodyne sensor mounted on traffic signals in urban settings. The sensor, positioned at a traffic signal, was designed to detect vehicles at intersections. The 3D point cloud from the sensor was first over-segmented into super voxels, and objects were extracted using a link chain method. These segmented objects were then classified as vehicles or non-vehicles based on geometric models and local descriptors. To validate the proposed method, the researcher carried out an additional experiment where the sensor was positioned vertically at the top of a traffic signal, approximately 8 meters high, at a junction on Rue des Meuniers in Clermont-Ferrand, France. Observations from these trials indicated successful vehicle detection, including motorcycles and buses, in most scans.

However, at greater distances, motorcycles occasionally went undetected due to the scarcity of 3D points. Conversely, at very close ranges specifically when a bus was directly beneath or in front of the sensor the detection algorithm misidentified it as a wall-like structure, leading to a failure in recognizing it as a vehicle as shown in Figure 18 (iii).



(i) (ii) (iii)

Figure 18: Illustrate scenes with vehicle detection in corresponding 3D scans with blue points represent those identified as vehicles.

4.1 Comparison of various aspects of Lidar-based sensor applied in TLS

Table 2. Comparison of various aspects in Lidar-based sensor applied in TLS

Author & Year	Key Details	Technology/System	Advantages	Disadvantages	Useful Aspects
(Zhang, 2023)	Proposed a system that utilizes advanced 3D lidar technology to collect comprehensive traffic information, including vehicle counts, dynamics, dimensions, and types.	3D lidar technology	Vehicle detection accuracy of 94% and improves speed measurement from 0.4 m/s to 0.2 m/s. The system enhances quality by capturing complete vehicle shapes and types.	High-cost, real-time monitoring is limited by unoptimized code and computing power vehicle identification is more complex due to the absence of RGB data.	The system shows great potential for urban traffic monitoring, providing detailed data for a better understanding of traffic behavior and patterns.
(Aijazi et al., 2016)	Introduced a method for vehicle detection using a compact 3D Velodyne sensor mounted on traffic signals. The sensor collected 3D point clouds, which were segmented and classified using geometrical models and local descriptors.	Compact 3D Velodyne sensor	Effective for urban traffic intersections; suitable for real-time vehicle detection.	Rule-based classification; is less effective compared to modern machine learning methods.	Real-time detection; useful for intersection monitoring; practical for urban traffic.

4.2 RFID-based traffic light monitoring systems

In Malaysia, the adoption of RFID technology for the electronic toll collection (ETC) system was officially announced in January 2019 (Lee, 2019). This initiative aimed to enhance the efficiency of ETC, allowing for smoother traffic flow and reducing congestion at toll plazas. Building on this technological advancement, Transport Minister Anthony Loke launched a new special license plate on September 9, 2024, known as RPK or “Rekaan Plat Khas”.

This license plate is specifically designed for electric vehicles, reflecting the government's commitment to promoting eco-friendly transportation. The introduction of the RPK plate is part of a broader strategy to encourage the adoption of electric vehicles in Malaysia facilitate their recognition on the road and the encouragement to the use of RFID technology. Soon, the use of this technology is expected to extend to petrol and diesel vehicles as well (Lim, 2024).

According to (Krausz et al., 2017), radio frequency identification relies on various frequencies for effective interaction between the reader and the tags. The most commonly used frequencies include low frequency (LF) at 125-134 kHz, which has a range of less than 0.5 meters high frequency (HF) at 13.56 MHz, with a range of approximately 1-meter ultra-high frequency (UHF) at 868-956 MHz, which can reach about 4 to 5 meters and microwaves at 2.45 GHz, capable of operating over distances greater than 1 meter.

Moreover, active tags are self-sufficient in terms of power, while passive tags rely only on the energy, they get from the reader to respond. From extremely low-range e-passports or building access control tags to long-range systems of military applications, the communication range drastically varies depending on the kind of tag. An Identec Intelligent Long Range (ILR) system with a communication frequency of 868 MHz in Europe or 915 MHz in North America with tags for a 6 m passive, type i-D and 100 m active, type i-Q range was the RFID utilized in the research conducted by (Krausz et al., 2017).

In (Krausz et al., 2017) research, the long tags were positioned on automobiles and tested in actual traffic situations, the low-range tags were used for indoor testing. The tags weigh 50 g and measure around 131 × 28 x 21 mm, which is quite small size. The amount of internal memory that each tag has might also vary. While some tags contain the memory of many bytes, the simplest tag just has a unique, readable identification. The memory of the applied i-D tags is 64 bytes, and that of the i-Q tags is 8 kB.

During the testing, two different types of antennas were used omnidirectional and directed. The first type can read tags from any direction 360 degrees, while the other type can only read tags within a restricted horizontal and vertical range. The ability of RFID technology to function without a direct line of sight between the tag and scanner is one of its most significant features. The capacity to read and download data from tags in real-world conditions has to be validated because many factors, such as bad weather and obstructions, can drastically reduce signal strength.

(a) Omnidirectional (b) i-D (left) and i-Q (right) Tags

Figure 19. The Indentec Intelligent Long-Range RFID System

A passive tag, an RFID reader, two antennas, a personal computer or control card with a microprocessor, two infrared sensors, a high-speed server with a database system, and an RFID reader make up the system framework described in the research paper (Wen, 2010) as seen in Figure 20. The tag types 1, 2, and 3, and the reader type is an Alien 9780 (915 MHz) shown in Figure 21 were utilized by the researcher. The tags type was passive and were typed once but read several times and powered by RF signal from the reader.

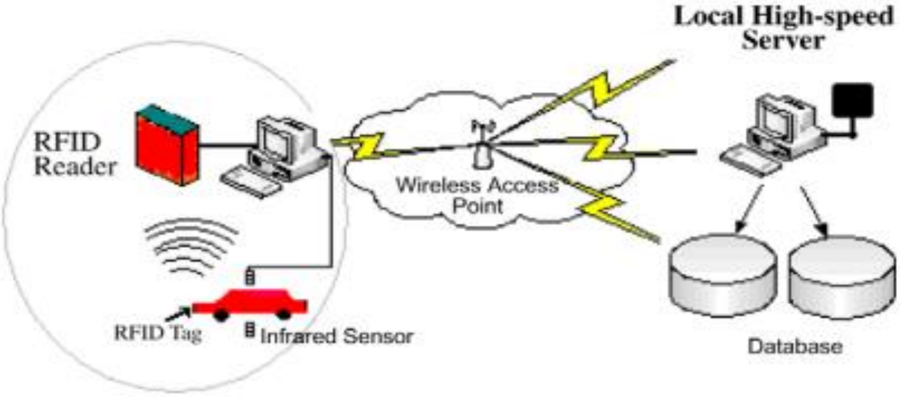


Figure 20. Framework of intelligent traffic management system

Figure 21. The RFID reader and tags, types 1, 2, and 3

To calculate the average speed of a car, the researcher deployed two antennas. The effective sensing angle is 60 degrees as shown in Figure 22. The maximum detected effective distance is 15 m. The researcher used two antennas to measure an automobile's average speed. A 60-degree angle is the effective sensing angle. 15 m is the greatest detected effective distance. Two antennas are separated by twelve meters. The researcher thus determined that d = 12. Speed ¼ d t1-t2, where t1 is the detected time of antenna 1 and t2 is the discovered time of antenna 2, is the formula used to compute vehicle speed. The distance between the antennas is represented by d. Calculating the vehicle's speed is simple because the separation between antennas 1 and 2 is known. The speed of the vehicle is recorded for thirty samples, and the average speed is calculated by the system. The speed of the automobile can be measured by the researcher using just one antenna. Therefore, if one knows the initial and final times that an automobile was identified, t1 and t2, as well as the diameter of the circle (d = 2 radius), which is the detected antenna distance, determining the car's speed is rather simple.

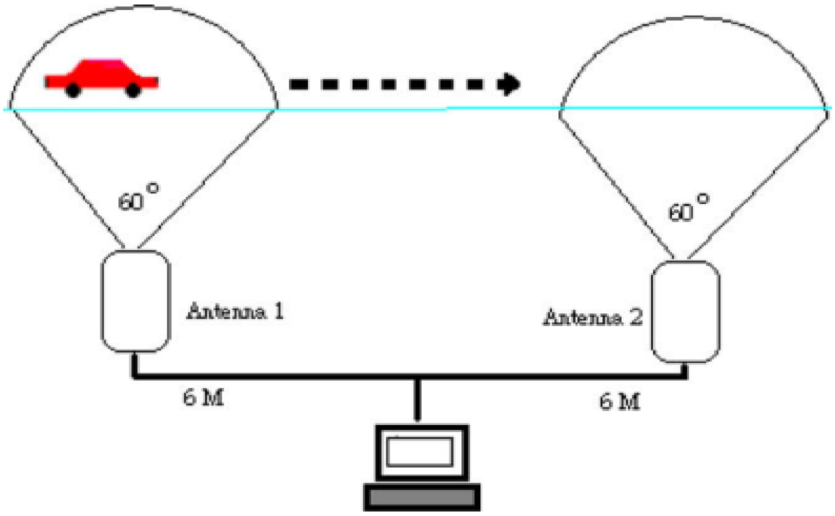


Figure 22. Antenna sensing angle and distance between antenna 1 and 2

To assess the maximum detection distance and the maximum automobile speed, the researcher put up an experiment. According to Figure 23, the researcher discovered that Type 1 can be accurately read at a distance of 2.5 meters, Type 2 at a distance of 10 meters, and Type 3 at a distance of 10 meters. Of course, at the greatest distance, 11.7 m Types 2 and 3 can be detected. Types 2 and 3 do differ slightly from one another, though 7 out of 10 times, Type 2 can be correctly read, and 9 out of 10 times, Type 3. To see how fast a speed might be noticed, the researcher then set up the system on Shi-Yaun Road in Taoyaun County, Taiwan.

The maximum automobile speed was limited to 68 km/h due to the speed limit on the road. Figure 24 displays the average proper sample result after 30 tests. Type 1 only read at 60 km/h, whereas Types 2 and 3 could be measured at 68 km/h. The researcher said that if the test vehicle's speed is insufficient, 68 km/h is already beyond the posted speed limit in an urban location, and automobiles are rarely seen traveling faster than 68 km/h in cities.

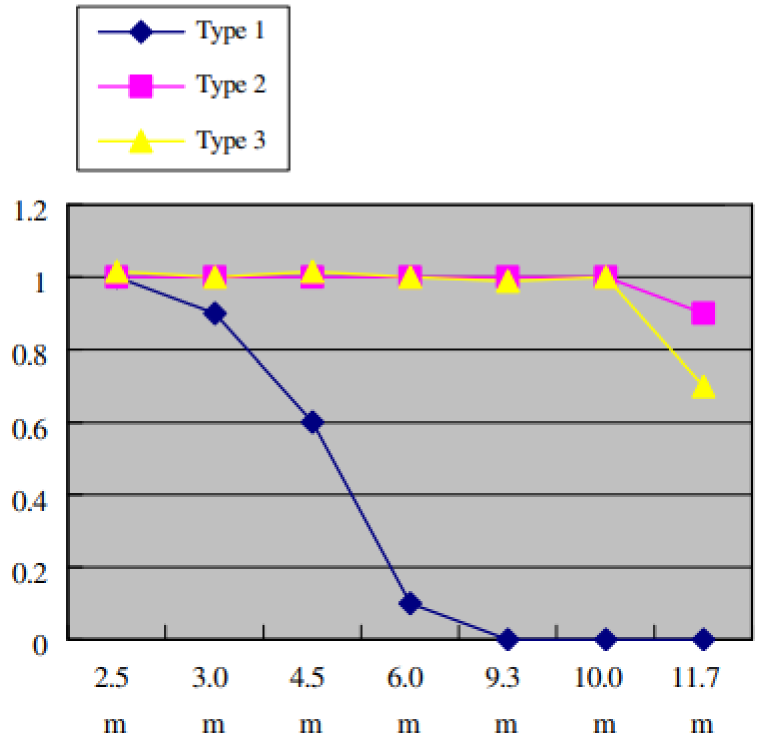


Figure 23. The maximum detected distance among tags

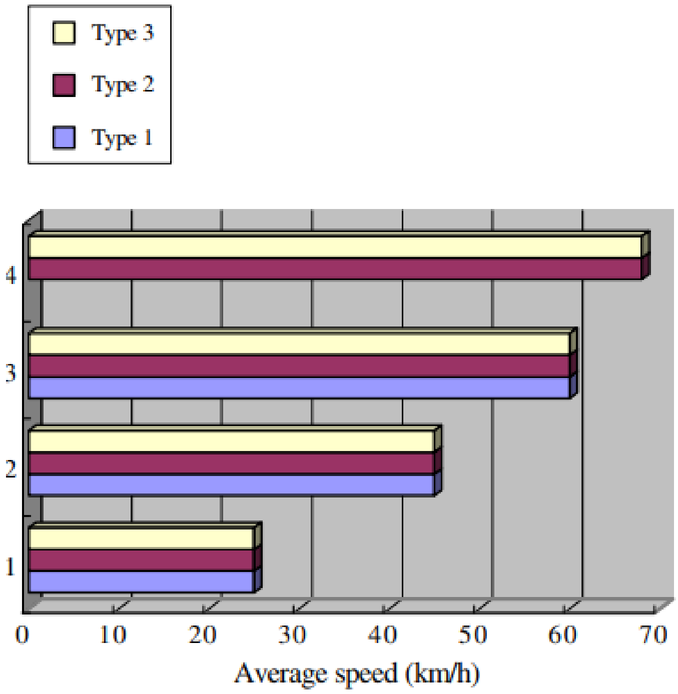


Figure 24. The valid detected average speed

Similar to other methodologies, in (Qiu & Xiao, 2014) research each RFID tag contains information about a specific object and is usually attached to it. An RFID reader can access this information without needing to touch the object. The reader transmits the data to a computer system through a standard network interface for analysis and processing shown in Figure 25.

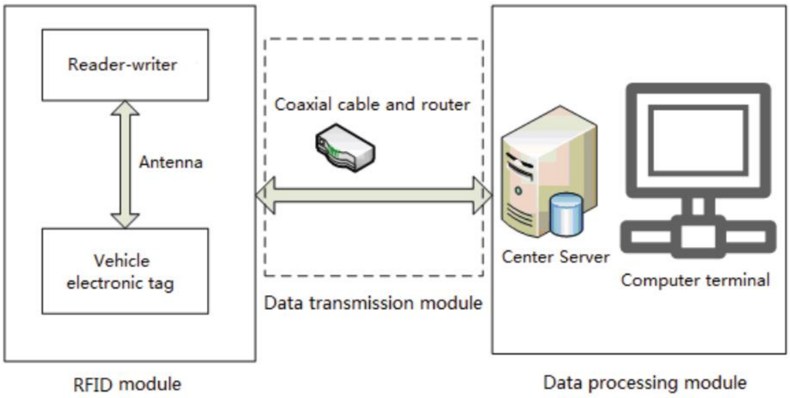


Figure 25. The traffic monitoring system of (Qiu & Xiao, 2014)

Moreover (Qiu & Xiao, 2014) states that the complex road environment puts more demands on wireless transmission. Wireless communication may be impacted by environmental, traffic flow changes, and changing temperatures but by reviewing the features of wireless transmission requirements for transportation it is possible. In (Qiu & Xiao, 2014) research, they went for an electronic tag that is passive due to its ability for waterproof, anti-shock, and anti-collision. Also, it has a 1–10 m identification range and is flexible to change. The long-range integration reader that was utilized is DLC 6890 shown in Figure 26. The reading distance of the reader is at least 12 meters, and it is a directional antenna reader. The researcher said that the reader is quite good at avoiding interruption and it offers a range of interfaces for communication and an operating frequency of 915MHz.

Figure 26. RFID reader Model DLC6890

In (Qiu & Xiao, 2014) research explains that the communication between the tag and reader is a crucial part of the software design, acting as their communication protocol. The reader is stationed at various intersections, while each vehicle carries a tag that moves with it. Tags that are out of the reader's range stay inactive, but when they come within range, they are powered up and activated. Once activated, the tags send their stored information like vehicle details and license plate numbers to the reader.

During the simulation, the intersection signals and tag information are simplified. This communication is simulated using Proteus and Keil C, with two AT89C52 microcontrollers representing the tag and the reader shown in Figure 27. The tag activates when a switch is turned on, sending confirmation and vehicle data to the reader through a serial port. The reader then forwards this information to a data processing center. The researcher ran four simulation experiments in Proteus, following the principles of both the hardware and software design and the results demonstrated that the proposed design was viable.

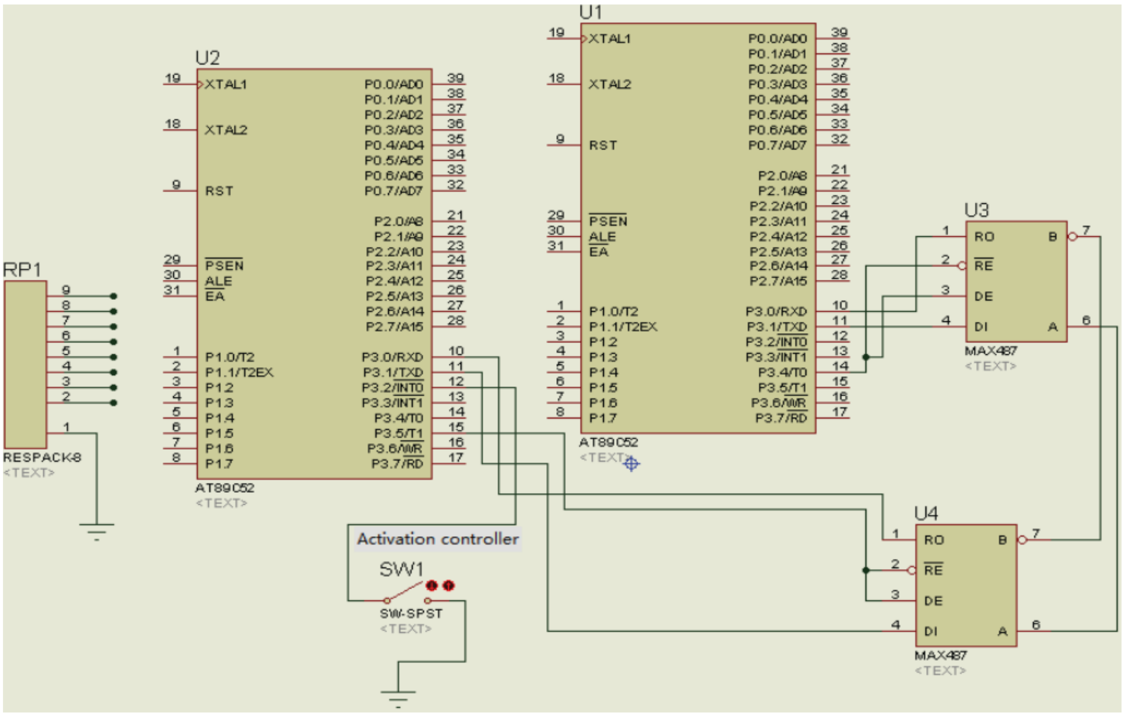


Figure 27. The simulation diagram of AT89C52, tag & reader

Furthermore, the Vehicle Traffic Congestion Estimation (VTCE) research topic by (Al-Naima & Hamd, 2012) uses an Alien ALR-9800 Enterprise RFID reader type shown in Figure 28 because it satisfies the majority of the specifications for RFID hardware, including operating at UHF frequency, supporting Ethernet connections, having multiple antenna ports, and having a multi-static antenna. The hardware and software components comprise the two sections of the VTCE project. Microsoft SQL Server 2008 R2 Management Studio is used to build the massive database system, while Microsoft Visual Basic 2010 is used to construct the software section. The Rifidi Platform and the Roads and Traffic Intersections Simulator (RTIS) are used to mimic RFID readers, which make up the hardware portion. Rifidi is a software that functions as a hardware reader and mimics an RFID system.

Figure 28. ALR-9800 Developer's Kit

The researcher designed an RTIS software shown in Figure 29 that mimics the real-world motions of cars, with RFID tags and the network of roads that includes traffic intersections. The VTCE's system architecture is displayed in Figure 30. The two RFID readers, four antennas on each reader, and RFID tags fastened to every car make up the majority of this system. Every branch has two installed RFID antennas that can immediately scan from both cars in opposing directions and record the necessary information for each vehicle.

Activate Cars
- ☑ Red Car
- ☑ Yellow Car
- ☑ Green Car
- ☑ Blue Car
- ☑ Black Car
- ☑ White Car
- ☑ Chocolate Car

100

Figure 29. The Roads and Traffic Intersections Simulator (RTIS)

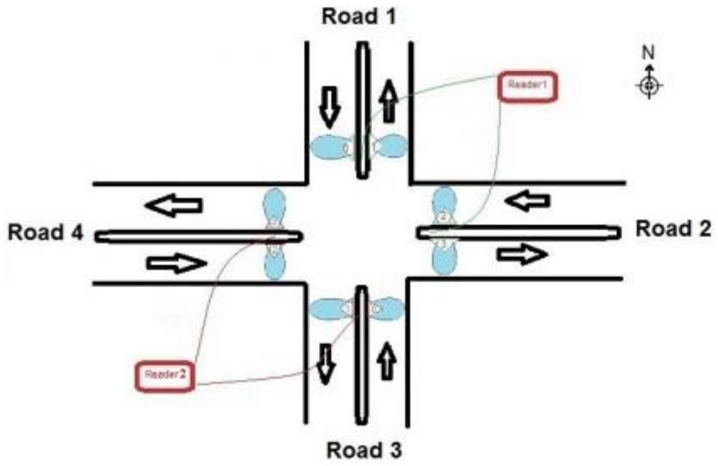


Figure 30. The architecture of VTCE based on RFID

The two RFID antennas are conveniently spaced apart and situated on the road's median island, close to the traffic crossroads. The antennas' RF do not overlap because of the architecture for positioning the antennas. The direction of a vehicle's journey from entrance to exit will be known in the Central Computer System (CCS) based on the sequence in which the identical tag ID is received from two separate antennas. The VTCE system design will track the direction of travel for every car at each traffic intersection in real-time. Figure 31 shows how the CCS relates to the RFID readers and the database.

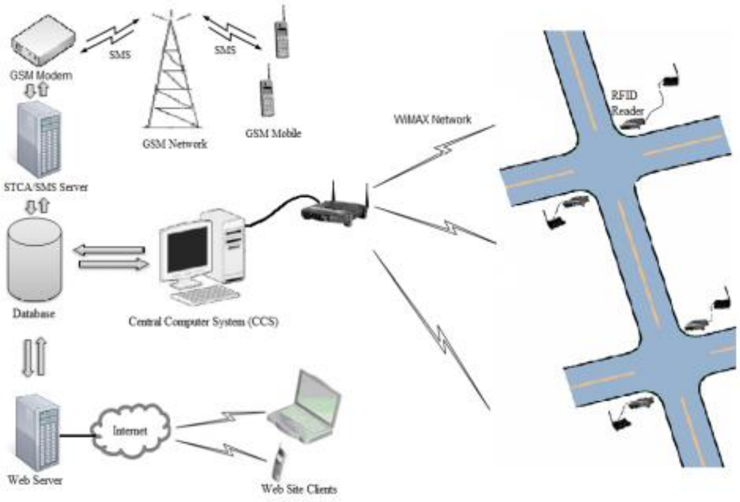


Figure 31. The layout of the VTCE environment

(Yu et al., 2011) research presents an electronic tag that is attached to every car on the road and a reader is deployed. The type of electronic tag design that was used by the researcher was :

(a) Compact and low weight for easy installation in a car.
(b) Low power consumption to avoid using too much of a vehicle's power.
(c) Adequate RAM to store vehicle-related data.
(d) Robust security and dependability to fend off intrusions, malfunctions, and self-harm.
(e) Inexpensive enough to be widely adopted in all automobiles.

Figure 32 illustrates the active electronic tag's operation. A communications chip uses an IC module operating at 433MHz, which has improved diffraction ability and an effective range of roughly 15 meters.

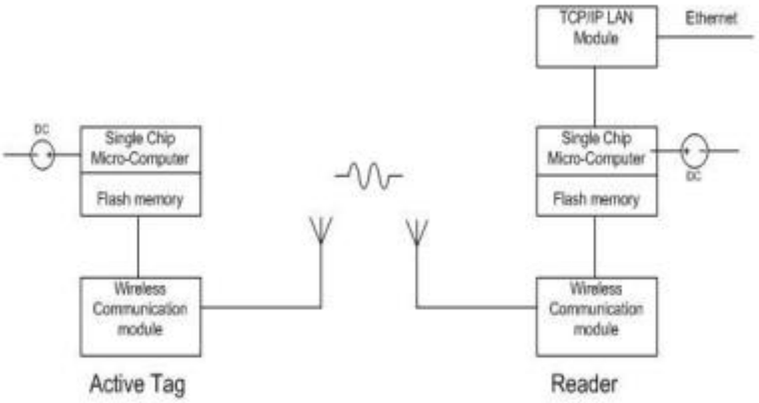
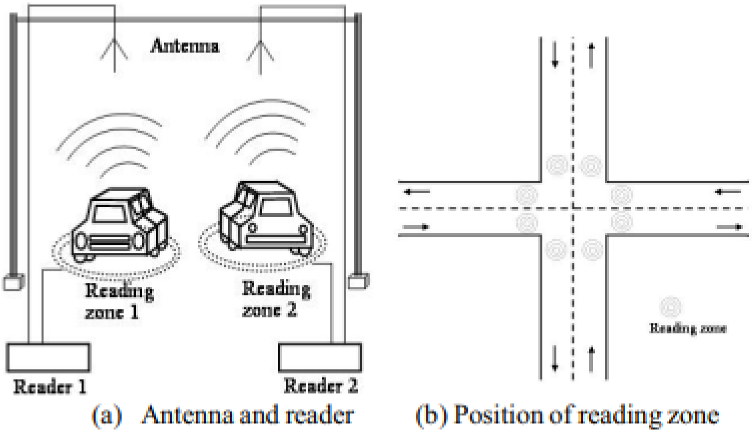


Figure 32. A principal diagram of electronic active tags and readers

The wireless transmitter module CC1100 and SCM C8051F920 microcontrollers serve as the foundation for the electronic tag and reader. A low-power, high-speed microcontroller unit (MCU) with 32KB of programmable flash memory and the security feature on the flash memory that can prevent unauthorized modifications and data erasure in a single-chip UHF transceiver for low-cost, low-power wireless applications by using CC1100. A highly customizable modem is integrated into its RF transceiver and modem that can transmit data at up to 500 kbps.

The vehicle information such as the license plate number, type of vehicle, tag ID, and vehicle characteristics can all be recorded by the tags. The tag is round and weighs less than a few grams. The tags are set inside a car by immediately connecting 12V DC power to the car. To gather vehicle data from tags in real-time at a traffic junction and transmit it over LAN to the local server in the base station, readers are deployed there. As seen in Figure 33, two sets of readers are installed at each branch's lane to read vehicle information from the two directions, respectively.



(a) Antenna and reader (b) Position of reading zone

Figure 33. Illustration of readers at a cross-intersection

A directional transmitting antenna, used by a reader, only picks up data from cars that are traveling in a certain area of the road. Near the beginning of a branch, on the pole's crossbar, is where the reading antenna is mounted. Every reader has a single reading zone, and it only activates to read an electronic tag when a car moves within that zone. This avoids the situation when an electronic tag is read by several readers and identifies the location of the associated vehicle.

However, every regularly operating vehicle at a junction may be detected twice, once upon entering the intersection and once while exiting it. This means that the researcher will be able to determine the origin and destination of a car. The following is how the working principle operates. The directional transmitting antenna activates and sends a request to the electronic tag when a car moves within the reading zone. The data in the electronic tag is delivered to the reader once the vehicle's electronic tag receives a request. Two steps are taken to prevent illegal information leaking to safeguard the security and privacy of data in electronic tags.

(a) Before the electronic tag transmits the data, it must verify the reader's consent.
(b) Encrypting the data transmission between the tag and the reader is required.

Once a reader receives data from a passing vehicle, the system checks the vehicle's status and automatically enters the vehicle's ID, position, time, speed, and other pertinent information into the local traffic status database. Upon identifying an unusual occurrence, the system would promptly dispatch an alert. In the meantime, the system allows for the uploading of data to the center server, vehicle flow statistics, and online vehicle information queries as shown in Figure 34.

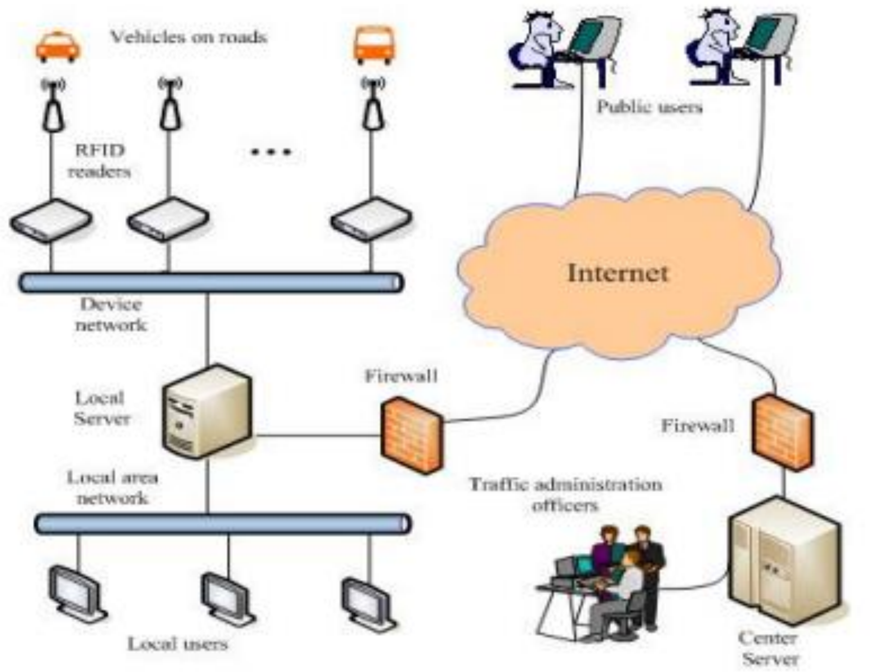


Figure 34.System structure of urban traffic IOT

In contrast, another system is created following the idea of IoT by (Vong et al., 2011) and is implemented in this study through the use of radio-frequency identification technology. The RFID tag, the RFID reader, and the back-end system make up the three main components of the RFID system. Every vehicle has an RFID tag fitted to collect data on emissions and the RFID reader serves as a data receiver to exchange information with the tags. Then the government uses the back-end system to keep an eye on the data. In this way, the data is transmitted and collected from the tag to the back-end system through the reader.

In (Vong et al., 2011) research, the data about emissions from a vehicle's exhaust system is collected using RFID tags. The exhaust pipe usually has two lambda sensors shown in Figure 35 to monitor the air-fuel ratio. Nitrogen oxides are produced more when this ratio is too high while, hydrocarbons and carbon monoxide are produced more when it is too low.

Knowing this ratio is essential to comprehending emissions. However, RFID tags hold digital data, while lambda sensors give low voltage signals (0 to 1V). The voltage signals from the lambda sensors are converted into digital data using an analog-to-digital converter (ADC) so that the data to be saved on the RFID tag.

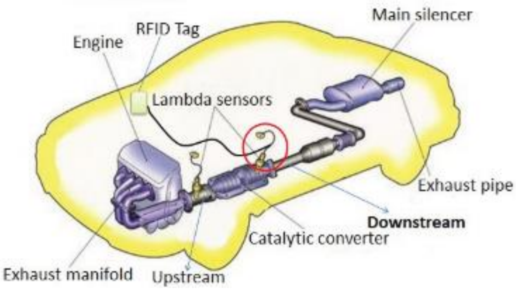


Figure 35. The vehicle emission system

To address this issue, the researcher created the RFID tag prototype with ADC which is seen in Figure 36. An RFID module and an ADC with a wire interface make up the majority of the prototype. First, the ADC converts the signals from the lambda sensors, after which the cables carry the signals to the RFID module where they are stored.

Figure 36. Prototype of the RFID Tag

The information system's essential station is the RFID reader since it is responsible for gathering and transferring all data. To transfer the data to the back-end system, an RFID module must detect the radio frequency signal from the RFID tag, and a 3G module must communicate the data as well. For the RFID module and the 3G module to communicate, a data transfer interface module is also required. An RFID reader prototype is constructed using these fundamental parts and is shown in Figure 37.

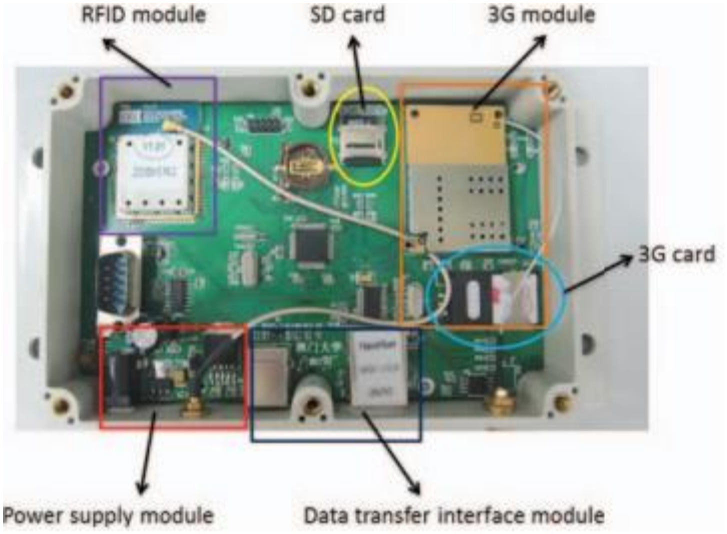


Figure 37. Prototype of the RFID reader

Along with the three necessary modules RFID, 3G, and data transfer interface, the designed RFID reader also includes a power supply module that supplies the reader with a voltage of 6V and an SD card that stores the reader IP and configuration settings so that the system doesn't have to be reset when the reader is restarted due to power outages. The RFID module's monitoring range is 50 to 150 meters, and its carrier frequency is 24 GHz, which is comparable to the microwave band.

Later, experiments were conducted by the researcher in an open area of approximately 200 square meters to assess the efficiency of the information system. A five-meter-high pole was built up to represent traffic lights, as seen in Figure 38, to replicate a road condition. Vehicles carrying the intended RFID tag would operate in this zone. The back-end system was set up in a separate room, and an RFID reader was mounted to the pole.

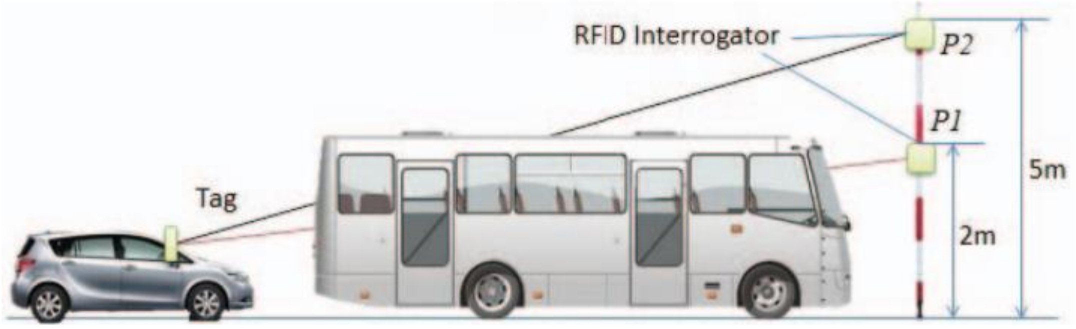
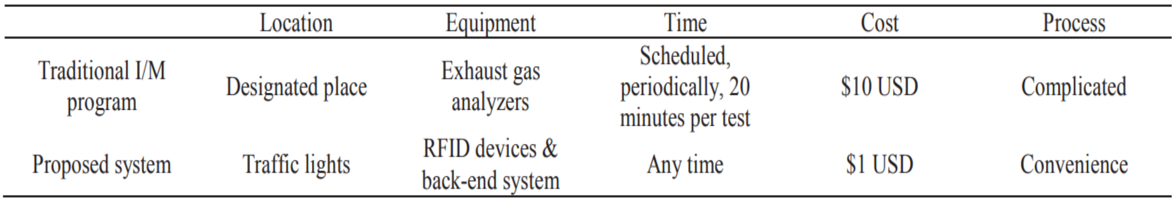


Figure 38. Simulation of the road situation

Additionally, five tests were used to examine the interaction between the vehicle and the traffic light, the tag position test, the obstruction test, the effective distance test, the effective inspected vehicle number test, and the reliability test. These tests are intended to show if the reader can detect the RFID tag (vehicle emission data) and whether the reader can indicate the accuracy of the tag reading. The suggested information system was compared with the conventional Inspection and Maintenance (I/M) program, which is summed up in Table 3, based on the experimental findings by the researcher. Consequently, it is demonstrated that the suggested system for vehicle emission inspection is more efficient, practical, and cost-effective than the conventional Inspection and Maintenance (I/M) program.

Table 3. Comparison between traditional I/M program and the proposed system by (Vong et al., 2011)



	Location	Equipment	Time	Cost	Process
Traditional I/M program	Designated place	Exhaust gas analyzers	Scheduled, periodically, 20 minutes per test	$10 USD	Complicated
Proposed system	Traffic lights	RFID devices & back-end system	Any time	$1 USD	Convenience

4.3 Comparison of various aspects of RFID technology applied in TLS

Table 4. Comparison of various aspects of RFID technology applied in TLS

References	Topic	Reader Type	Antenna Type	Tag Type	Power Source	Read Range (m)	Frequency	Speed (Km/h)
(Krausz et al., 2017)	Radio Frequency Identification in Supporting Traffic Safety	Identec Intelligent Long Range (ILR)	Directional & Omni Directional	Active & Passive	Internal Battery & External Reader	Not specified	UHF 915 MHz	Not specified
(Wen, 2010)	An intelligent traffic management expert system with RFID technology	Alien 9780	Directional	Passive	External Reader	2.5 - 10	UHF 915 MHz	60 - 68
(Qiu & Xiao, 2014)	The Design and Simulation of Traffic Monitoring System Based on RFID	DLC 6890	Directional	Passive	External Reader	12	UHF 915 MHz	Not specified
(Al-Naima & Hamd, 2012)	Vehicle Traffic Congestion Estimation Based on RFID	Alien ALR-9800	Directional	Passive	Not specified	Not specified	UHF 915 MHz	Not specified
(Yu et al., 2011)	An RFID Electronic Tag based Automatic Vehicle Identification System for Traffic IOT Applications	Not specified	Directional	Active	Internal Battery	15	Not specified	Not specified
(Vong et al., 2011)	Application of RFID Technology and the Maximum Spanning Tree Algorithm for Solving Vehicle Emissions in IOT	Customize & Not specified	Customize & Not specified	Active	Internal Battery	50 - 150	Microwave Band 24 GHz	Not specified

5. Conclusions

Existing research often overlooks the practical challenges associated with deploying such integrated systems in real-world scenarios. The complexities of installation and operation of a system that combines RFID and inductive loops are not well-documented. This lack of practical insight poses a barrier to the effective implementation of these technologies in actual traffic management settings. Understanding these challenges is essential for translating theoretical benefits into practical applications.

There is limited knowledge about how integrated systems perform under various traffic conditions. Most studies focus on evaluating RFID and inductive loops separately, without considering how their combined functionality might handle different traffic scenarios, such as varied traffic densities and emergencies. This gap leaves a void in understanding how an integrated approach could adapt to and improve its performance. To address these gaps, research should be taken to prioritize developing a practical framework for integrating RFID and inductive loop sensors, along with conducting real-world tests to assess their combined performance. By filling these gaps, future studies can pave the way for more effective, efficient traffic flow, safety, and overall system responsiveness, particularly in critical situations requiring emergency vehicle prioritization and in managing high traffic volumes in traffic management systems.

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