

Intelligent transportation system leveraging Internet of Things (IoT) Technology for optimized traffic flow and smart urban mobility management

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Abstract

Metropolitan cities worldwide face severe traffic congestion due to a significant increase in vehicles, despite inadequate road infrastructure. Conventional traffic signaling systems, relying on manual or time-based control, are inefficient and lack real-time data, leading to delayed emergency response times, fuel waste, and health issues. To address this, a smart traffic management system is proposed, utilizing real-time data from sensors or Google Maps to optimize traffic light control at junctions. This system aims to efficiently manage signaled intersections, leveraging IoT technology and comparative data analysis to develop an algorithm that adapts to dynamic traffic conditions. This approach offers opportunities for advancements in traffic management, detection technology, and flexible optimization techniques through automated learning.

Keywords: Internet of things; IoT sensor; Intelligent Transportation System; Real Time Optimization; Smart Traffic Management

1. Introduction

The rapid increase in urbanization presents a complex global issue that requires diverse solutions. Urban populations have grown as more people migrate to cities. The United Nations estimates that by 2030, about 4.9 billion people will live in urban areas. This growth brings challenges such as pollution, traffic congestion, and resource management. The rise of the Internet of Things (IoT) has led to a large number of devices connected to networks, continuously collecting and transmitting data for further analysis. With advancements in deep learning, many applications now use these

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techniques to analyze collected data, enabling "intelligence" and "automation." Consequently, leveraging data analysis and IoT infrastructure, "Smart Cities" have emerged, encompassing smart grids, smart transportation, smart manufacturing, smart buildings, and more. [1,2,3,4].

Transportation systems are an indispensable part of people's daily life. Since the population living in urban areas has increased, the world will thus witness explosive growth in motor vehicles, which will have a detrimental impact and contribute to traffic congestion, noise pollution, road accidents, and other issues [5].

To address these challenges, this research proposes a smart traffic management system that utilizes real-time data, IoT technology, and advanced analytics to optimize traffic flow and improve urban mobility. The system aims to efficiently manage signaled intersections, prioritize emergency vehicles, and provide a signal-free path for crisis vehicles. Unlike traditional methods that rely on limited data from sensors, this system utilizes GPS tracking data and references like Google Maps and Bing Maps to accurately determine real-time traffic situations and optimize traffic light control. The proposed system also addresses the critical issue of emergency vehicle movement in congested intersections. By using radio wave signaling, crisis vehicles can be detected and prioritized, ensuring a signal-free path and avoiding traffic congestion. The system's order of precedence prioritizes ambulances, fire trucks, and police vehicles, considering the combination of multiple emergency vehicles approaching from different directions. This project aims to develop a comprehensive and efficient smart traffic management system, overcoming the limitations of traditional methods and providing a scalable solution for urban transportation challenges.

2. Review of Related Works

Researchers worldwide have endeavored to develop efficient smart traffic management systems, sharing a common goal of optimizing traffic flow and reducing congestion. While their objectives align, each study has contributed unique insights and innovations, collectively advancing the field. Building upon existing works, newer systems are being developed to provide even better solutions, demonstrating the ongoing pursuit of excellence in smart traffic management.

X. Li et al [6] proposed various IoT based Traffic Management systems that utilize sensors and real time data to optimize traffic flow. These systems have been shown to reduce congestion and improve travel times .J.Wang et al.[7] explored the use of traffic signaling systems that adapt to real time traffic conditions. These systems have been found to reduce congestion and improve traffic efficiency.

Y. Zhang et al [8] Implemented GPS tracking based real time traffic management system, He used GPS tracking data to develop real time traffic management systems .These systems have been shown to improve traffic flow and reduce congestion

H. Lee et al [9] proposed and implemented Radio wave signaling for emergency vehicle priority in smart traffic management. He used Radio wave signaling to prioritize emergency vehicles in traffic management systems . This approach has been found to reduce emergency responses times and improve traffic safety.

S. kumar et al. [10] Smart Traffic Management systems: A literature review of smart traffic management systems highlighted the importance of real time data , IoT technology, and adaptive signaling in optimizing traffic flow

3. Components

The smart traffic management system consists of several components, including:

Radio signal detector, Radio waves transmitter, Ultra-sonic sensor/Hall Effect sensor, Raspberry Pi, Light Emitting Diode (LED) and python programming language for the software development of the project.

3.1. Radio Signal Detector

Radio signal detectors are devices that receive and process radio waves, consisting of an antenna that receives radio waves, an RF amplifier that boosts signal strength, a tuner that filters specific frequencies, a detector that extracts information from signals, an audio speaker that outputs audio signals (optional), and other components that enable effective signal processing and analysis [11, 12].

In a smart traffic management system, radio signal detectors play crucial roles such as detecting signals from emergency vehicles to prioritize their movement, enabling vehicle-to-infrastructure communication for real-time traffic data collection, and providing traffic signal priority to public transport vehicles. These detectors also enhance safety by quickly identifying accidents or breakdowns and improve overall traffic flow and efficiency. The implementation involves surveying and planning key locations, installing hardware, developing software for signal processing, testing and calibrating the system, and performing regular maintenance and upgrades. This integration ultimately leads to improved traffic flow, enhanced safety, and greater efficiency in public transport [12].

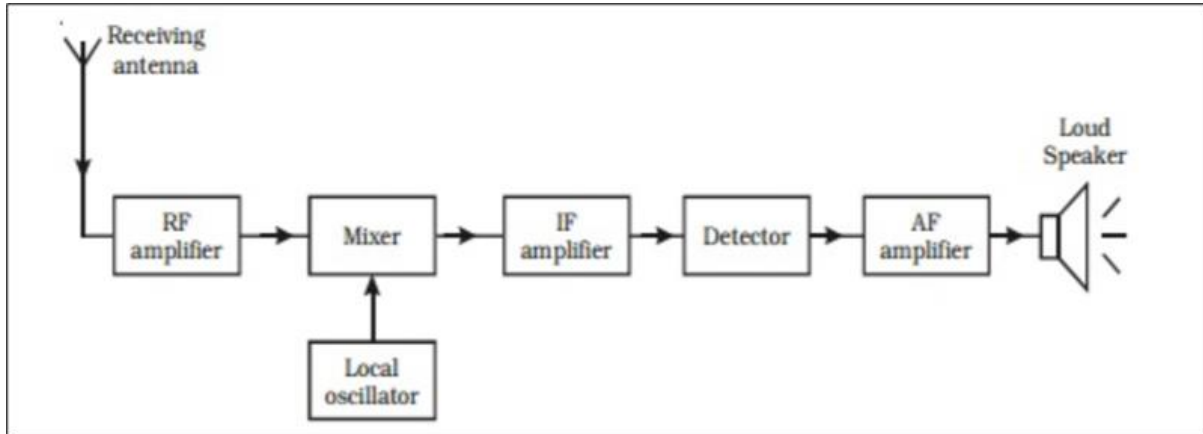


Figure 1 Radio Signal Detector

The radio signal detector receives and processes radio waves, extracting information and amplifying the signal to be heard through a speaker. This component plays a crucial role in detecting radio signals transmitted by emergency vehicles, enabling the smart traffic management system to prioritize their passage[12].

3.2. Hall effect sensor

<p>Figure 2a Working principle of Hall effect sensor</p>	<p>Figure 2b Hall effect sensor</p>

A Hall effect sensor is a device that uses the Hall effect principle to measure magnetic fields and detect magnetism, rotation, or position [13]. It consists of a semiconductor material with three terminals, including a current source, a voltage source, and an output terminal [14]. When a magnetic field is present, the sensor generates a voltage output that is proportional to the strength of the magnetic field [15].

Overall, Hall Effect sensors are reliable and versatile devices used in various industries, including automotive and industrial automation.

3.3. RASPBERRY PI

Raspberry Pi is a small, low-cost, and highly capable single-board computer that has revolutionized the world of computing and electronics. It's a tiny PC that can fit in the palm of your hand and is widely used in various applications, including: Robotics and Automation, IoT Projects, Home Automation e.t.c. [16]

Raspberry Pi boards come in different models, such as Raspberry Pi 4, Raspberry Pi 3, Raspberry Pi Zero, and more. They are equipped with features like: Processor (CPU), Memory (RAM), Storage(SDcard), USB ports, HDMI port, Ethernet port, Wi-Fi and Bluetooth connectivity[16].



Figure 3 Raspberry pi

Raspberry Pi is an excellent tool for learning, prototyping, and building innovative projects, and its affordability and versatility have made it a popular choice among hobbyists, students, and professionals alike. When building a traffic management system, Raspberry Pi's small size, low power consumption, and flexibility make it an ideal component for collecting and processing real-time traffic data, controlling traffic signals, and integrating with various sensors and infrastructure, leading to improved traffic flow and reduced congestion.[16]

3.4. LIGHT EMITTING DIODE (LED)

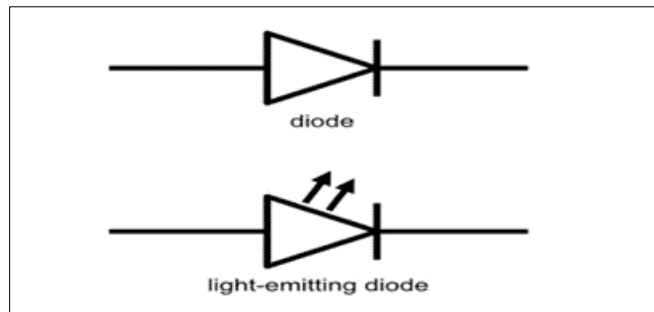


Figure 4 Light Emitting Diode

A Light Emitting Diode (LED) is a type of semiconductor device that converts electrical energy into visible light. LEDs are widely used in various applications, including:

- Lighting: LEDs are used in lamps, bulbs, and other lighting fixtures due to their energy efficiency and long lifespan.
- Indicators: LEDs are used as indicators in electronic devices, such as power buttons, status lights, and warning lights.
- Displays: LEDs are used in display screens, such as LED TVs, LED scoreboards, and LED video walls.
- Automotive: LEDs are used in car lights, brake lights, and interior lighting.
- Signage: LEDs are used in advertising signs, traffic signs, and other types of signage.

LEDs offer several advantages, including energy efficiency, long lifespan, durability, environmental friendliness, and design flexibility, making them a superior choice over traditional lighting sources. In the context of a traffic management system, LEDs are used in traffic lights, pedestrian signals, and other signage to provide clear and visible indications to drivers and pedestrians.

4. Methodology

The proposed smart traffic management system utilizes a real-time sensor-based approach to optimize traffic flow. The methodology is outlined in the following steps:

- **Sensor Data Collection:** Real-time traffic density data is collected from sensors deployed on the road.
- **Cloud Storage:** The collected data is stored in the cloud for processing and analysis.
- **Microcontroller Processing:** The data is fed into a microcontroller, which determines the optimal signal timing for each lane based on the current traffic conditions.
- **Emergency Override:** In the event of an emergency, the sensor data is directly fed into the microcontroller, interrupting the normal signal cycle and initiating an immediate signal change.

This methodology enables real-time adaptation to changing traffic conditions, optimizing traffic flow and reducing congestion. The basic flowchart in figure [5] illustrates this process, providing a visual representation of the system's logic.

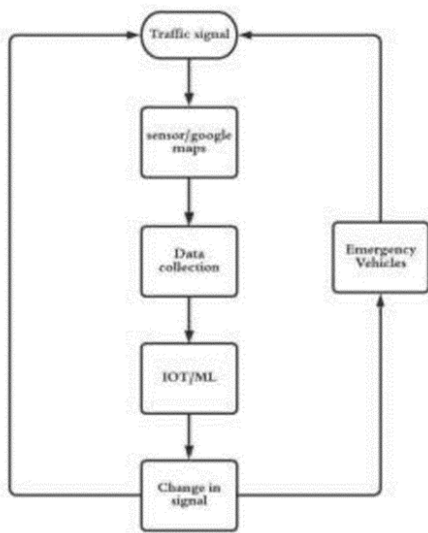


Figure 5 Process Flow Chart

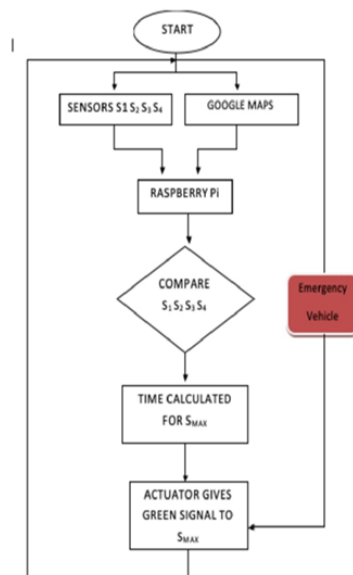


Figure 6 Data Collection

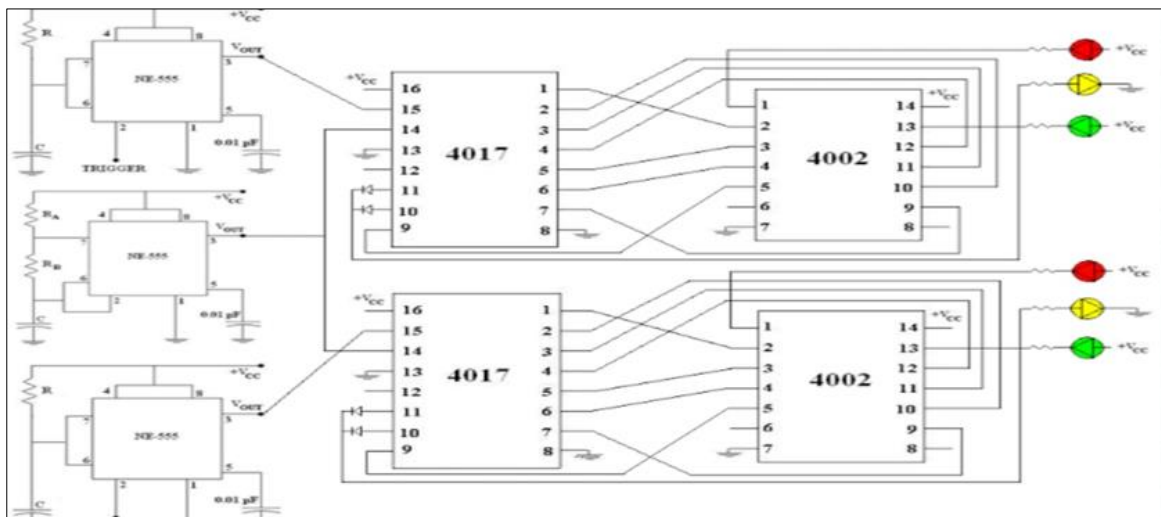


Figure 7 Circuit Diagram of the Traffic Management System

4.1. Sensor Data Collection

Real-time traffic density data is gathered from sensors installed along the road network. These sensors are designed to detect the presence and movement of vehicles in specific lanes or sections of the road.

4.1.1. Cloud Storage

The collected sensor data is transmitted to and stored in cloud-based storage systems. Cloud storage facilitates centralized data management, allowing for scalability, accessibility, and efficient processing of large volumes of data.

4.1.2. Microcontroller Processing

A microcontroller, such as a Raspberry Pi, receives the real-time traffic data from the cloud storage. The microcontroller's role is to process this data and make real-time decisions regarding optimal traffic signal timings for each lane or direction at intersections.

Based on the current traffic conditions (detected through sensor data), the microcontroller calculates and adjusts the duration of green signals to minimize congestion and maximize traffic flow efficiency.

4.1.3. Emergency Override

In cases of emergencies, such as the detection of an ambulance or other emergency vehicles using specialized sensors (like radio wave detectors), an emergency override mechanism comes into play. The microcontroller receives immediate input from these emergency detection sensors, bypassing the normal signal cycle. It swiftly changes traffic signals to prioritize the passage of emergency vehicles, ensuring prompt response times and clearing the path efficiently.

5. Results

5.1. Initial stage

To simulate a four-way intersection, we utilized four separate breadboards, each representing a different direction. Three hall effect sensors were strategically placed on three sides, accompanied by a green and red LED light on each side. All terminals from these sensors and lights were connected to the GPIO pins of a Raspberry Pi. The system continuously gathers real-time data from all sensors, identifying the direction with the highest traffic volume. The green light is then allocated to this identified direction while the other three directions remain red. As vehicles clear each side, the program dynamically evaluates the next highest traffic volume among the remaining directions. This cycle ensures equitable distribution of green lights among all four sides over subsequent iterations.

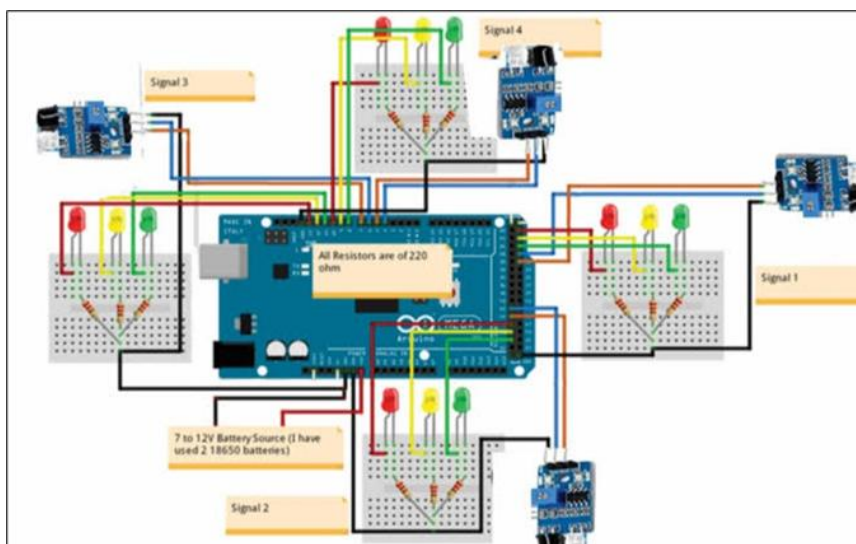


Figure 8 Prototype of the smart traffic management system

5.2. Subsequent stage

When the autonomous traffic control system activates, it integrates data from various sensors including ultrasonic and radio wave detectors. The control unit collects data from sensors S1 to S4, determining the direction with the highest traffic volume and the respective traffic distances. The Raspberry Pi computes the optimal duration for each green signal release based on this data. After each cycle, excluding the last two sensors, the system re-evaluates and assigns green signal preference to the direction with the highest traffic distance compared to the other sensor values. This iterative process continues until each direction at the intersection has received at least one green signal in the initial loop.



Figure 9 Working Model of The Traffic Management System

In scenarios where radio wave detectors detect an approaching emergency vehicle, an alert triggers within the system. The control unit monitors the radio wave signal and, as the emitter nears within 500 meters of the junction, halts all ongoing processes. The system then prioritizes the direction in which the emergency vehicle is approaching, immediately switching signals to red for other directions and granting green to the emergency vehicle's path. In cases where multiple emergency vehicles approach from different directions, precedence is given to ambulances, followed by fire trucks and police vehicles. If two or more emergency vehicles approach from one direction and one from another, priority shifts to the direction with multiple emergency vehicles

```

1      import RPi.GPIO as GPIO
2      from time import sleep
3
4      # Define pin numbers
5      hallpin1 = 8
6      hallpin2 = 10
7      hallpin3 = 12
8      hallpin11 = 22
9      hallpin12 = 24
10     hallpin13 = 26
11     hallpin21 = 38
12     hallpin22 = 40
13     hallpin23 = 37
14     hallpin31 = 31
15     hallpin32 = 29
16     hallpin33 = 23
17     LED1 = 16
18     LED2 = 18
19     LED11 = 32
20     LED12 = 36
21     LED21 = 35

```

Figure 10 Arduino Interface for Traffic I/O variable declaration of the project

The Python script on the Arduino interface controls an LED-based traffic management system using a Raspberry Pi, utilizing hall effect sensors to detect magnets and manage traffic flow by turning on corresponding LEDs based on the number of detected magnets.



```

project.ino
: +
if GPIO.input(hallpin1):
    a1 = 1
    print("magnet 1 detected")
else:
    print("magnet 1 not detected")

if GPIO.input(hallpin2):
    a2 = 1
    print("magnet 2 detected")
else:
    print("magnet 2 not detected")

if GPIO.input(hallpin3):
    a3 = 1
    print("magnet 3 detected")
else:
    print("magnet 3 not detected")

print("-----")

if GPIO.input(hallpin11):
ole

```

Figure 11 Working Procedure on Arduino Interface.

6. Discussion

This traffic management system integrates hall effect sensors, LED lights (red and green), and Raspberry Pi microcontrollers. The Raspberry Pi hosts Python programming that regulates the timing of LED lights. Hall effect sensors are positioned at regular intervals along road surfaces to detect vehicle presence up to their respective placements. It is suggested that all emergency vehicles be outfitted with radio wave transmitters, enabling radio detectors at junctions to recognize their presence. Radio wave detectors are installed at each junction to detect signals emitted by emergency vehicle transmitters. Raspberry Pi microcontrollers stationed at junctions collect data from various sensors, compute required timings, and activate LED lights accordingly for specified durations

7. Conclusion

This intelligent traffic management system leveraging Hall effect sensors, LED lights, Raspberry Pi microcontrollers, and radio wave detectors demonstrates a novel approach to optimizing traffic flow and prioritizing emergency vehicle passage. By integrating sensor data and radio wave detection, the system dynamically adjusts traffic light timings to minimize congestion and ensure swift passage for emergency vehicles. This innovative solution has the potential to significantly reduce response times, enhance public safety, and improve overall traffic efficiency in urban areas.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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