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SMART TRAFFIC LIGHT SIMULATION

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Abstract

With the rapid growth of urbanization and increasing vehicle density, efficient traffic management has become a major challenge. Conventional traffic signal systems operate on fixed time intervals, leading to traffic congestion, longer waiting times, and increased pollution. To overcome these limitations, this project presents a Smart Traffic Light Simulation System that dynamically controls traffic signals based on real-time traffic conditions.

The proposed system uses a hybrid approach for traffic detection. An ultrasonic sensor is employed to detect vehicle density in the North South direction, while a camera-based vision system is used to analyze traffic flow in the East–West direction. Vehicle detection and counting are performed using Python with OpenCV and YOLO-based object detection techniques. An Arduino Uno microcontroller controls the traffic signal LEDs and ensures safe signal transitions through serial communication. Additionally, environmental sensors such as the DHT11 temperature and humidity sensor and the MQ-135 air quality sensor are integrated to monitor surrounding conditions at the intersection.

By combining sensor-based detection, computer vision, and intelligent decision-making, the system effectively reduces traffic congestion, minimizes waiting time, and improves overall traffic efficiency. The proposed model supports the development of smart and sustainable traffic management systems for future smart cities.

Keywords:*Smart Traffic Light System, Traffic Density Detection, Computer Vision, YOLO, Arduino Uno, Ultrasonic Sensor, IoT, Air Quality Monitoring, Real-Time Traffic Control.*

1.0 Introduction

Traffic congestion has become a serious challenge in modern cities due to the rapid increase in the number of vehicles and the continued use of traditional fixed-time traffic signal systems. Conventional traffic lights operate on predefined timing cycles without considering real-time traffic conditions, which often leads to unnecessary waiting times, increased fuel consumption, air pollution, and driver frustration. Several studies have highlighted that fixed-time traffic control systems are inefficient under varying traffic conditions and contribute significantly to urban traffic problems [10].

To overcome these limitations, smart traffic management systems have emerged as an effective solution. These systems utilize real-time traffic data, intelligent decision-making, and automation to regulate traffic flow more efficiently. Research shows that adaptive traffic signal systems based on traffic density can significantly reduce congestion and improve road utilization compared to traditional methods [9].

The proposed Smart Traffic Light Simulation System is designed to dynamically control traffic signals based on real-time traffic conditions at an intersection. The system adopts a hybrid traffic detection approach, where an ultrasonic sensor is used to monitor vehicle density in the North–South direction, while a camera-based vision system analyzes traffic flow in the East–West direction using computer vision techniques. Vehicle detection and counting are performed using Python and YOLO-based object detection, which has proven effective for real-time object detection and traffic analysis [3], [4].

An Arduino Uno microcontroller is used to control traffic signal LEDs and ensure safe signal transitions through red, yellow, and green phases. In addition to traffic management, the system integrates environmental sensors such as temperature, humidity, and air quality sensors to monitor surrounding conditions at the intersection. Similar sensor-based monitoring systems have been widely adopted in smart city applications for improving traffic efficiency and environmental awareness [10]. By combining sensor-based detection, computer vision, and intelligent control, the proposed system provides an efficient, scalable, and smart solution for modern traffic management systems and future smart city applications.

1.1 Literature Survey

Smart traffic management has gained significant attention due to increasing urban traffic congestion and limitations of traditional fixed-time signal systems. Various researchers and technology platforms have contributed to the development of intelligent, sensor-based, and vision-based traffic control systems.

The Arduino Uno microcontroller is widely used in embedded system applications due to its simplicity, low cost, and ease of integration with sensors and actuators. According to Arduino documentation [1], Arduino Uno supports real-time control and serial communication, making it suitable for traffic signal control and automation systems. Many smart traffic projects rely on Arduino for controlling signal LEDs and interfacing with external sensors.

Computer vision has become an essential component in modern traffic monitoring systems. The OpenCV library provides a comprehensive set of tools for image and video processing, enabling real-time object detection and tracking [2]. OpenCV has been extensively used in traffic surveillance applications to analyze vehicle movement, density, and flow using camera input.

One of the most influential advancements in real-time object detection is the YOLO (You Only Look Once) algorithm. Redmon and Farhadi [3] proposed YOLO as a unified, single-stage object

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detection model capable of detecting objects with high speed and reasonable accuracy. This approach is well suited for real-time traffic analysis where fast vehicle detection is required. Further improvements were introduced in YOLOv4, which achieved better detection accuracy and performance optimization, making it suitable for real-world applications such as traffic monitoring and surveillance [4].

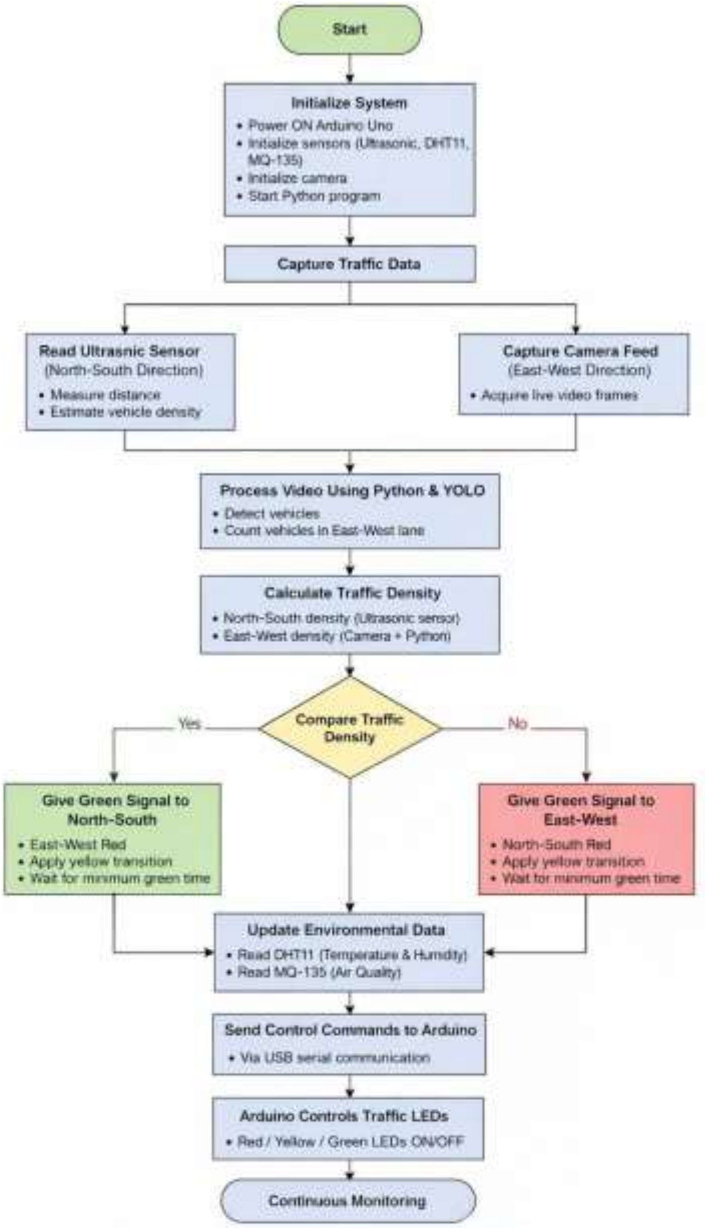
Sensor-based traffic detection also plays a vital role in smart traffic systems. The HC-SR04 ultrasonic sensor is commonly used for distance and obstacle detection. As described in the Adafruit Learning System [5], ultrasonic sensors provide reliable vehicle presence and distance measurement, making them useful for estimating traffic density on specific lanes.

Environmental monitoring is another important aspect of smart city traffic systems. The DHT11 sensor is used to measure temperature and humidity, providing environmental context at traffic intersections [6]. Similarly, the MQ-135 gas sensor is capable of detecting air quality levels by sensing harmful gases, which helps in monitoring pollution caused by vehicular emissions [7]. These sensors support the integration of traffic management with environmental awareness.

The Python programming language plays a key role in implementing intelligent traffic systems due to its simplicity and extensive library support. Python documentation [8] highlights its suitability for data processing, computer vision, and machine learning applications. Python is widely used with OpenCV and YOLO for vehicle detection and traffic analysis.

Several researchers have proposed intelligent traffic control systems using image processing and IoT technologies. Mittal and Bhandari [9] presented a smart traffic light control system based on image processing techniques to dynamically adjust signal timings according to traffic density. Their work demonstrated improved traffic flow compared to traditional fixed-time systems. Similarly, Sharma and Kaur [10] proposed an IoT-based intelligent traffic signal system aimed at smart city applications, emphasizing real-time monitoring, automation, and reduced congestion.

2.0 Methodology



Flowchart of Smart Traffic Light Simulation System

The Smart Traffic Light Simulation System operates by collecting real-time traffic data and dynamically controlling traffic signals. Initially, the Arduino Uno, sensors, camera, and Python program are initialized. Traffic density in the North–South direction is measured using an ultrasonic sensor, while live video from the East–West direction is captured through a camera.
Vehicle detection and counting are performed using Python with the YOLO object detection algorithm. Traffic density from both directions is calculated and compared to determine signal priority. The direction with higher traffic density is given the green signal, while the other direction remains red, with a yellow transition applied for safety.

Environmental data such as temperature, humidity, and air quality are monitored using DHT11 and MQ-135 sensors. Control commands are sent to the Arduino via serial communication, which

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controls the traffic signal LEDs. The system continuously monitors traffic conditions to ensure efficient and adaptive traffic signal operation.

3.0 Results

Fig. 1. Smart traffic light simulation setup

Fig. 2. Vehicle detection using YOLO algorithm

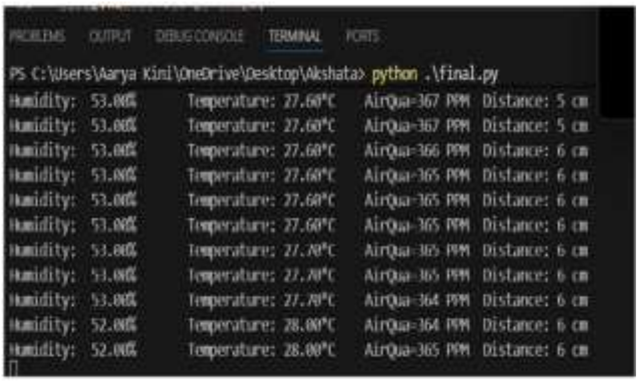

Fig. 3. Ultrasonic sensor distance measurement

Fig. 4. Vehicle detection using video

3.1.1 Traffic Density Detection and Signal Control Efficiency

The analysis shows that the system efficiently handled real-time traffic density detection and traffic signal control without conflicts or data inconsistency. Vehicle density was detected using a camera-based vision system and ultrasonic sensor input with minimal delay. Based on the detected traffic

density, signal timing was adjusted automatically to manage traffic flow effectively.
Compared to traditional fixed-time traffic signal systems, the automated signal control reduced unnecessary waiting time and minimized congestion. This resulted in smoother traffic movement and better utilization of road infrastructure.

3.1.2 System Interaction and Traffic Signal Operation

The system allows smooth interaction between sensors, the Arduino controller, and traffic signal LEDs in a simple and reliable manner. Sensor data is continuously collected and processed, and corresponding signal actions are triggered without manual intervention. Traffic signals change based on real-time conditions, ensuring proper lane prioritization.
This direct coordination reduces human dependency and improves traffic regulation. During testing, the system was found to be stable and responsive, even with continuous traffic flow changes.

3.1.3 Vehicle Detection Accuracy and Decision Reliability

The computer vision-based vehicle detection module provided accurate and consistent vehicle count results. The YOLO-based object detection model successfully identified vehicles from video input and supported real-time decision-making. The detected traffic density values were reliable and suitable for dynamic signal control.
Although the system currently focuses on vehicle counting, the observed results indicate that it effectively supports intelligent traffic decision-making, especially at busy intersections.

3.1.4 Environmental Monitoring and Sensor Data Support

The integration of environmental sensors such as temperature, humidity, and air quality improved the overall functionality of the system. Sensor data was continuously monitored and displayed through the serial interface, providing additional situational awareness at traffic intersections.
This feature supports future enhancements related to pollution monitoring and traffic safety. The environmental data collected was stable and matched expected values during testing.

3.1.5 Overall System Performance Discussion

The experimental results confirm that the Smart Traffic Management System improves traffic efficiency when compared to traditional traffic control methods. By integrating vehicle detection, sensor-based monitoring, and automated signal control into a single platform, the system reduces congestion and manual effort.
The unified structure allows easy deployment at multiple intersections, making the system suitable for scalable smart city traffic solutions. Overall, the system demonstrates strong potential for real-world implementation.

4.0 CONCLUSION

The Smart Traffic Light Simulation is an intelligent system designed to improve traffic management

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at intersections. It goes beyond fixed-time signal control by using real-time traffic detection through sensors and camera analysis to adjust signal timings dynamically. Unlike traditional traffic systems, it adapts to changing traffic conditions and prioritizes congested lanes within a single automated setup. Built using modern sensing and control technologies, it offers a future-ready solution for safer, smarter, and more efficient traffic control.

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