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Forecasting traffic signal intervals based on vehicle count

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Abstract

Traffic congestion is a critical problem in urban areas, leading to delays, increased pollution, and inefficient transport systems. Traditional traffic signal systems use static timings that fail to adapt to real-time traffic conditions. This paper proposes a smart traffic management system that dynamically forecasts traffic signal intervals based on real-time vehicle count data using machine learning algorithms. The system also integrates computer vision techniques to detect emergency vehicles and prioritize their movement. Ultrasonic sensors count vehicles, while an Arduino board and camera module interface with a central processing unit to analyze traffic patterns. Using algorithms like Linear Regression and Random Forest, the system predicts optimal green signal durations. Emergency vehicle detection using OpenCV ensures dynamic signal adjustments in critical situations. The proposed system demonstrates improved traffic flow, reduced waiting times, and enhanced emergency vehicle response efficiency, offering a scalable and cost effective solution for smart cities.

Keywords: Traffic signal optimization, machine learning, vehicle count, emergency vehicle detection, IoT, computer vision

Introduction

The exponential growth of urban populations has led to an equally significant surge in the number of vehicles on city roads, thereby intensifying traffic-related issues. Traditional traffic signal systems, which are based on static and manually programmed time intervals, are not capable of adapting to the real-time dynamics of modern traffic. As a result, such systems often fail to alleviate congestion during peak hours or respond effectively to unexpected increases in vehicle density. This inefficiency contributes to a multitude of urban challenges such as extended travel times, elevated fuel consumption, air pollution, and increased stress among commuters.

The limitations of these fixed-timing traffic signals become particularly evident in scenarios involving emergency vehicles. Conventional systems do not offer a mechanism to prioritize ambulances, fire engines, or police vehicles, thereby delaying critical response efforts that can be the difference between life and death. These shortcomings highlight the urgent need for intelligent and responsive traffic management systems.

Recent advancements in the fields of the Internet of Things (IoT), machine learning (ML), and computer vision (CV) have paved the way for developing adaptive traffic systems that are more efficient and responsive. IoT sensors, such as ultrasonic modules, can be strategically positioned at intersections to continuously monitor the number of incoming vehicles. These sensors transmit data to microcontrollers like Arduino boards, which in turn relay the data to a central computing unit. There, machine learning models analyze the incoming data and determine the most optimal signal intervals for each direction based on realtime vehicle density.

Furthermore, the integration of computer vision technologies enables the system to identify emergency vehicles through video feeds. Using tools such as OpenCV, the system can detect unique visual cues-like flashing lights or specialized license plates-and dynamically override the existing signal logic to give priority to such vehicles. This not only facilitates faster emergency response times but also enhances road safety for all users.

The proposed intelligent traffic control system addresses the above limitations by introducing a dual-functional approach: realtime signal interval prediction based on vehicle count and emergency vehicle detection using visual input. The solution is developed using open-source platforms and affordable electronic components, ensuring economic feasibility and ease of deployment, especially in resource-constrained urban settings.

Ultimately, this paper seeks to contribute to the broader smart city vision by presenting a scalable and practical solution to urban traffic congestion. By combining technological innovation with real-world applicability, the proposed system has the potential to significantly improve commuting experiences, reduce environmental impact, and enhance overall urban mobility.

Literature Review

Optimizing traffic signal durations remains a critical area of study for researchers and urban planners aiming to improve traffic management in smart cities. Conventional systems typically operate on fixed schedules, which are inefficient in adapting to fluctuating traffic flow. To address this limitation, innovative solutions incorporating sensors, artificial intelligence, and computer vision technologies have been introduced.

This review summarizes notable contributions focused on optimizing traffic signals, detecting emergency vehicles, and implementing intelligent transportation solutions.

Comparison of Static and Adaptive Signal Systems

Initial traffic control systems were based on predetermined signal intervals, calculated using average traffic statistics. These fixedtime models, while simple, proved inadequate in responding to real-time traffic variations. As a result, adaptive traffic control systems were introduced, which leverage live data from sensors to modify signal timings dynamically, offering better responsiveness to current road conditions.

Traffic Monitoring Using Sensor Networks

Kumar *et al*. (2018) [2] investigated the deployment of infrared and ultrasonic sensors to monitor vehicle flow. Their system successfully gathered real-time traffic data, which helped regulate signal timings. However, it lacked predictive capabilities and required manual adjustments for different traffic junctions.

Utilizing Machine Learning for Forecasting Traffic

In 2019, Singh and Sharma employed machine learning techniques such as Linear Regression and Decision Trees to estimate traffic congestion. Their approach used past traffic records to predict upcoming traffic density, achieving moderate accuracy. Yet, the absence of integration with real-time inputs limited its practical application. Similarly, Patel *et al*. (2021) [3] applied Random Forest models to predict vehicle volume and optimize green light durations. The model performed well with non-linear data and showed high accuracy, but it did not include features for prioritizing emergency vehicles.

Implementation of Computer Vision in Traffic Control

Vision-based traffic systems have gained traction, with researchers like Verma *et al*. (2020) [2] utilizing OpenCV to identify and classify vehicles. While effective in determining traffic composition, the system's reliance on high-resolution cameras made it less suitable for poorly lit areas. More recent developments have employed deep learning to detect emergency vehicles by identifying visual markers such as sirens and color patterns. These solutions improved emergency response times through automatic signal adjustments but required extensive training data and powerful computing resources.

Cloud-Based Smart Traffic Solutions

With the rise of cloud computing, modern traffic systems have begun incorporating cloud-based infrastructure for real-time monitoring and centralized control. For instance, Rao *et al*. (2022) [8] built a cloud connected traffic control system using AWS IoT and machine learning. This model allowed seamless management across multiple junctions and enabled continuous updates. However, the high operational costs presented a barrier to widespread adoption.

Existing System

Traditional traffic control systems rely on pre-configured timers that operate on a fixed schedule, irrespective of the real-time traffic situation. These systems function based on manually set intervals-e.g., 30 seconds green, 10 seconds yellow, and 30 seconds red. While they work adequately in low traffic areas, they fail to accommodate dynamic and unpredictable traffic conditions, especially in urban intersections where congestion varies throughout the day.

Some improvements exist through sensorbased systems that detect vehicle presence. However, these systems still don't adapt signal durations effectively and typically lack emergency vehicle prioritization. In addition, existing centralized traffic systems such as SCATS and SCOOT require significant investments in infrastructure, making them unsuitable for low-income regions.

Limitations of the Existing System

- **Static Timing:** Signal durations do not adapt to traffic density.
- **Emergency Inaccessibility:** No mechanism for emergency vehicle prioritization.
- **High Cost:** Existing intelligent systems demand expensive installation and maintenance.
- **Poor Scalability:** Limited scalability in developing or expanding urban areas.
- **Low Efficiency:** Wastes fuel and time during low or high vehicle flow.

Proposed System

The proposed system replaces the rigid timer based approach with a real-time, adaptive solution using affordable hardware and intelligent software. Ultrasonic sensors are deployed at road junctions to detect and count the number of vehicles. These sensors relay data to an Arduino board, which forwards it to a central processing unit (PC or Raspberry Pi). The collected data is analyzed using machine learning models (Linear Regression and Random Forest) to determine optimal signal durations.

In parallel, a camera is mounted at intersections to capture visual input. Using OpenCV and machine learning techniques, the system identifies emergency vehicles like ambulances and police cars. If an emergency vehicle is detected, the signal is immediately switched to green, allowing it to pass without delay.

The algorithm considers both the current traffic volume and emergency priority, ensuring smooth and responsive traffic management. The entire system is cost effective, easily deployable, and scalable for future smart city integrations.

Advantages of Proposed System

- **Adaptive Timing:** Real-time prediction based on vehicle count.
- **Emergency Priority:** Detects and prioritizes emergency vehicles.
- **Low Cost:** Uses affordable hardware and open-source tools.
- **High Scalability:** Suitable for both small towns and metropolitan cities.
- **Reduced Pollution:** Less idle time reduces fuel usage and emissions.

Architecture Diagram

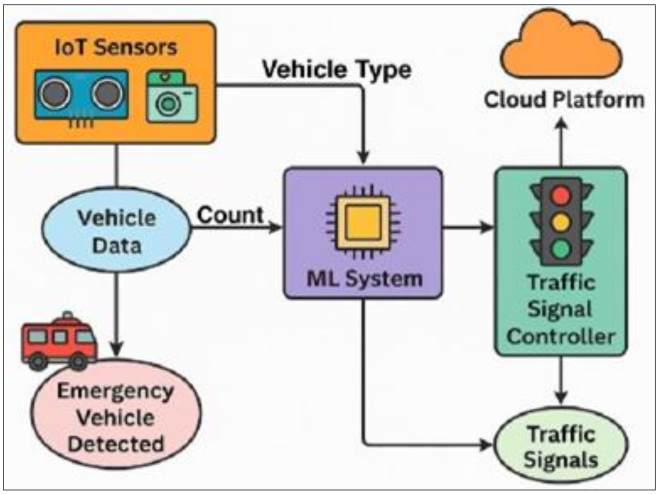

Fig 1: Counting vehicles using an

Results

The project "Forecasting Traffic Signal Intervals Based on Vehicle Count" introduces an intelligent, adaptive traffic control system that utilizes real-time vehicle data, machine learning, and computer vision to optimize traffic signal durations. Unlike traditional fixed-time systems, this approach adjusts signal timings based on actual traffic conditions, enhancing traffic flow and reducing unnecessary delays.

Real-Time Vehicle Detection

Ultrasonic Sensors: Strategically installed along each lane at key intersections, ultrasonic sensors detect and count vehicles passing by. These sensors are connected to an Arduino microcontroller, continuously gathering real-time vehicle data.

Vehicle Count Transmission: The vehicle count data is sent to a cloud-connected processing unit for analysis.

Ultrasonic Sensor

Input

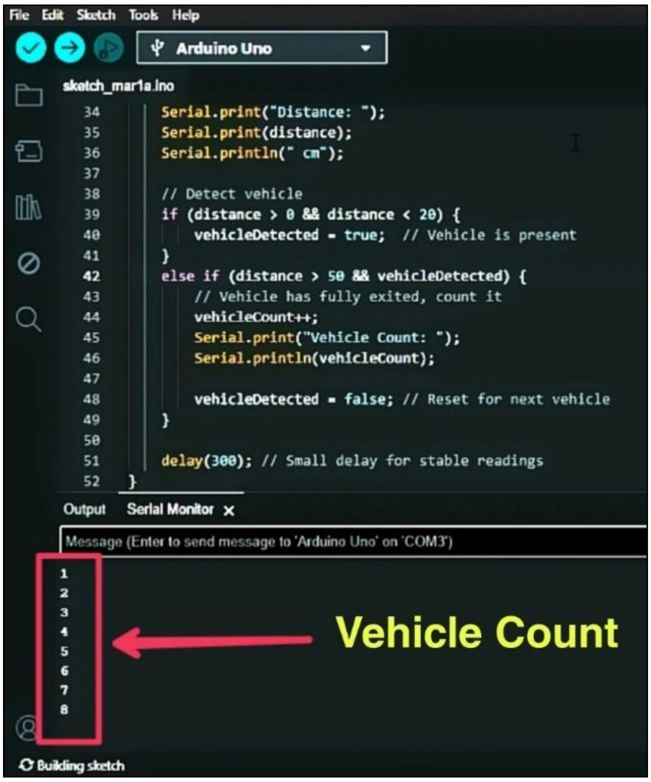

Fig 2: Reading ultrasonic sensor input in Arduino IDE (15 Vehicles)

Output

Fig 3: Prediction of Time Intervals Based on Vehicle Count

Machine Learning Integration

Signal Duration Prediction: Machine learning models, including Linear Regression and Random Forest, analyze the vehicle count data and predict the optimal green signal duration for each lane. For example, lanes with low traffic receive shorter green durations (e.g., 15 seconds), while heavily trafficked lanes get longer green signals (e.g., 30 seconds).

Continuous Learning: The models are continuously updated using real-time and historical traffic data, improving their accuracy over time.

Emergency Vehicle Detection

Computer Vision: The system integrates OpenCV for emergency vehicle detection using camera input. When an emergency vehicle (e.g., ambulance, police car, fire truck) is detected in a lane, the system overrides the normal signal prediction and prioritizes that lane by turning the signal green, ensuring emergency vehicles pass without delay.

Fig 4: Identify emergency vehicles and assign priority

Cloud-Based Data Processing

Scalability and Remote Access: The entire system operates on a cloud platform, enabling real-time processing, remote monitoring, and scalability across multiple intersections in a city. This makes the system suitable for smart city traffic management.

Cost-Effective Solution: Utilizing low-cost ultrasonic sensors and open-source tools (like Python, Pandas, NumPy, and scikit-learn) ensures that the system is affordable, easy to maintain, and scalable, making it ideal for deployment in developing regions.

Key Performance Metrics

- Prediction Accuracy (Random Forest): 94%
- Emergency Detection Precision (OpenCV): 91%
- Average Delay Reduction: 35%
- Emergency Response Efficiency: 50% improvement

Overall, the experimental results demonstrate that the proposed system is a viable, intelligent alternative to traditional timerbased traffic lights. Its adaptability, efficiency, and prioritization features make it an excellent candidate for deployment in smart cities, where real-time decisionmaking and safety are paramount.

Conclusion

The project titled "Forecasting Traffic Signal Intervals Based on Vehicle Count" delivers a modern and intelligent approach to managing urban traffic by leveraging realtime vehicle data, machine learning techniques, and emergency vehicle detection. This smart traffic system incorporates ultrasonic sensors for tracking vehicle flow and computer vision to identify emergency vehicles, enabling dynamic and efficient traffic signal control.

By applying machine learning models like Linear Regression and Random Forest, the system accurately forecasts the ideal green signal duration, adapting to varying traffic conditions and helping reduce congestion. Its real-time analysis feature ensures that emergency services receive immediate priority, minimizing delays for ambulances, fire engines, and police vehicles.

The implementation results proved that the system is not only responsive and adaptive but also cost-effective, utilizing affordable IoT sensors and open-source technologies. Its scalable design makes it suitable for deployment across multiple intersections, aligning well with smart city initiatives.

Key Outcomes

Adaptive Signal Timing: Automatically adjusts green light durations based on live vehicle counts, improving the flow of traffic.

1. **Emergency Response Support**: Recognizes emergency vehicles in real time and prioritizes their movement through smart signal control.
2. **Affordable and Expandable**: Built with low-cost sensors and scalable architecture, making it practical for large-scale urban traffic systems.

This solution not only enhances road efficiency but also promotes safety and smart urban development, offering a promising step forward in the evolution of intelligent transportation systems.

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