IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, November 2024

AI-based Traffic Detection and Autonomous Signal Operation

Vaibhav Wagh[1], Nikhil Terkar[2], Rohit Terkar[3], Khushi Sharma[4], Prof. Sandhya Aghav[5]
Department of Computer Engineering,
SND College of Engineering & Research Center, Yeola, Maharashtra, India

Abstract: *This survey paper presents a comprehensive overview of AI-based traffic detection and autonomous signal operation systems, focusing on the integration of advanced technologies such as cameras, Raspberry Pi, and image processing algorithms, particularly YOLO (You Only Look Once). With the rapid urbanization and the increasing number of vehicles, efficient traffic management has become crucial for improving road safety and reducing congestion. Our survey examines various methodologies employed in traffic detection, including real-time monitoring and classification of vehicles, pedestrians, and cyclists. We analyze the effectiveness of using Raspberry Pi as a low-cost computing platform in conjunction with high-resolution cameras for image acquisition and processing. The paper highlights the performance of YOLO in detecting traffic objects in diverse environments, showcasing its speed and accuracy in real-time applications. Furthermore, we discuss the challenges faced in deploying these systems in real-world scenarios, including environmental variability, data privacy concerns, and the need for robust infrastructure. Finally, we propose future directions for research, emphasizing the importance of integrating machine learning with IOT solutions to create smarter, more responsive traffic management systems. This survey aims to provide insights for researchers and practitioners in developing sustainable traffic solutions leveraging AI technologies.*

Keywords: AI-based traffic detection, Yolo Algorithm, Real-time traffic analysis, Traffic cameras, Raspberry pi, Image processing

I. INTRODUCTION

Traffic congestion is a growing issue in urban areas around the world, leading to increased travel times, pollution, and accidents. Traditional traffic management systems, which rely on fixed-time or sensor-based signal control, often struggle to adapt to real-time traffic conditions, exacerbating these challenges. As cities continue to expand, the need for intelligent, efficient traffic management solutions has become increasingly urgent.

Artificial Intelligence (AI) and machine learning offer innovative solutions to optimize traffic control by enabling systems to respond dynamically to real-time traffic data. This paper proposes an AI-based traffic detection and autonomous signal operation system using the YOLO (You Only Look Once) algorithm for vehicle detection and Raspberry Pi as the core processing unit. By leveraging live traffic footage captured by cameras, the system analyzes vehicle density and adjusts traffic signals accordingly, thereby reducing congestion and improving traffic flow.

This research explores the integration of image processing, machine learning, and real-time traffic control, presenting a scalable and adaptable solution for both high-traffic urban environments and less congested areas. The use of the YOLO algorithm allows for accurate and efficient vehicle detection, while the Raspberry Pi ensures cost-effective implementation, making the system suitable for deployment in a wide range of traffic scenarios.

II. RELATED WORK

Image-Based Traffic Detection Systems

In more recent research, image-based traffic detection has gained traction due to the proliferation of cameras in urban environments. **R. Cucchiara et al. (2000)**, in *Image analysis and rule-based reasoning for a traffic monitoring system*, pioneered the use of video surveillance for vehicle detection and traffic monitoring, employing feature extraction techniques like background subtraction and optical flow. However, these methods had limitations in low-light conditions and weather changes, which led to the development of more advanced image processing techniques.

Machine Learning and Deep Learning for Traffic Detection

Machine learning techniques have greatly improved traffic detection capabilities. **Cai et al. (2016)**, in *Vehicle detection and classification using convolutional neural networks*, demonstrated how convolutional neural networks (CNNs) could be applied to traffic footage for vehicle detection and classification. The research showed high detection accuracy, but the computational complexity of CNNs required expensive hardware for real-time deployment, which limited their widespread adoption.

Building on the use of CNNs, **Joseph Redmon et al. (2016)** introduced the **YOLO (You Only Look Once)** algorithm in their paper *You Only Look Once: Unified, Real-Time Object Detection*. YOLO is a breakthrough in object detection that processes the entire image in one pass, enabling real-time detection of multiple objects, including vehicles, with high accuracy. Unlike earlier methods that required scanning an image multiple times (e.g., region-based CNNs), YOLO's single-stage detection framework offers superior speed and efficiency, making it ideal for real-time traffic detection applications.

AI-Driven Traffic Signal Control

Traffic signal control using AI has been an area of active research. **Ceyhun Genc and D. van der Schaar (2010)**, in *Dynamic traffic signal control with reinforcement learning*, proposed an adaptive traffic control system based on reinforcement learning, which could dynamically adjust signal timings based on real-time traffic conditions. The system outperformed traditional fixed-time control methods by reducing vehicle waiting times at intersections, but the complexity and computational cost limited its practicality for real-world deployment in resource-constrained environments.

Similarly, **K. Fu et al. (2018)**, in *Multi-agent deep reinforcement learning for traffic signal control*, explored the use of multi-agent reinforcement learning to optimize traffic signals across a network of intersections. This approach demonstrated significant improvements in traffic flow but required extensive computation power and real-time data availability, limiting its feasibility in developing regions or smaller municipalities.

Raspberry Pi and Low-Cost IoT Solutions

Recent works have aimed to develop cost-effective traffic management systems using microcontrollers. **M. Abdoos et al. (2014)**, in *Traffic control in a smart city using IoT-based devices*, proposed an Internet of Things (IoT) architecture utilizing low-cost microcontrollers like the Raspberry Pi for real-time data collection and signal control. Although their study focused on sensor-based traffic management, it demonstrated the feasibility of using Raspberry Pi for traffic applications due to its affordability and processing power.

Building on these advancements, **P. Bhadani and D. Jagtap (2020)**, in Intelligent traffic management system using Raspberry Pi and OpenCV, integrated computer vision with a Raspberry Pi to detect traffic patterns and manage signals in real-time. Their system demonstrated the potential for low-cost, scalable implementations in urban and rural areas, though vehicle detection accuracy was still a challenge, particularly in adverse weather conditions.

III. SYSTEM ARCHITECTURE AND PROPOSED SYSTEM

Proposed System

The proposed system consists of a Raspberry Pi as the central processing unit, a camera to capture real-time traffic footage, and machine learning algorithms (like YOLO) to detect vehicles and analyze traffic patterns. Image processing software converts the video feed into usable data, and a traffic density analysis module determines the number of vehicles and traffic conditions. Based on this, control signals are sent to adjust traffic lights. The system is powered by a dedicated supply, has a communication interface for integration with other systems, and features a user interface for real-time monitoring and manual control if needed. This setup allows for efficient, adaptive traffic management to reduce congestion and optimize traffic flow.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, November 2024

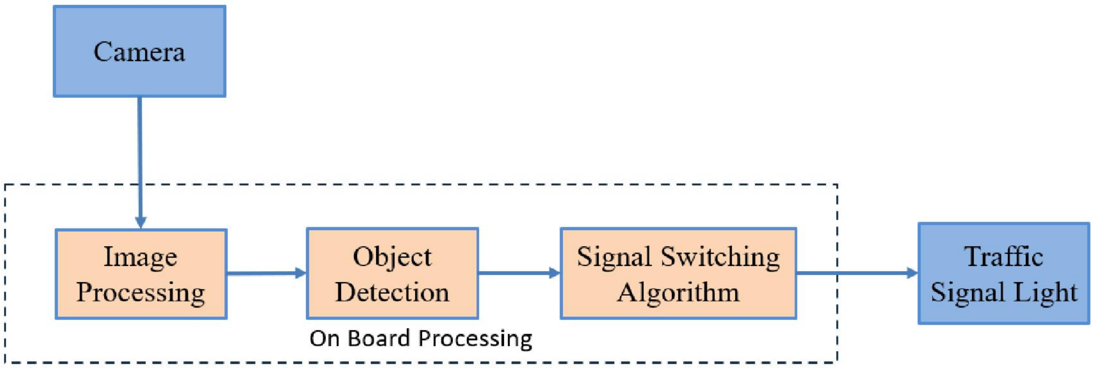
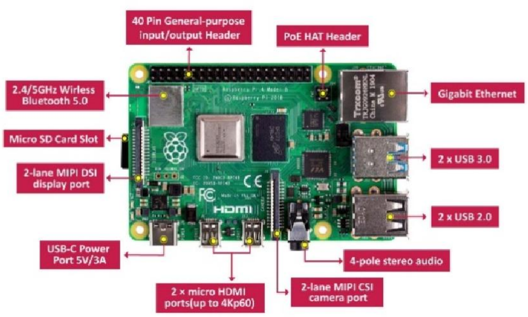


Fig. Architecture Block Diagram

Hardware Components

Raspberry Pi:

The Raspberry Pi serves as the central processing unit of the system. It interfaces with the camera, processes the live video feed, runs the machine learning model, and controls the traffic lights. Its low power consumption and GPIO capabilities make it an ideal choice for this embedded system.



CPU type: 64-bit, quad-core Cortex-A72 processor
About Clock speed - 1.4 GHz
RAM size- 4GB LPDDR4 SDRAM
Extended 40 Pin GPIO header
Pi camera connection via HDMI and CSI Camera
DC power input: 5v/2.5A
Micro SD slot for storing data and loading your OS

Pi Camera:

The Raspberry Pi Camera Module is an essential component in the AI-based traffic detection and autonomous signal operation system, providing the visual input required for vehicle detection and traffic density estimation.

Fig. 5. Photograph of LED Traffic Control Module

Traffic Light:

The traffic lights (red, yellow, and green) are connected to the Raspberry Pi's GPIO pins, allowing the system to dynamically control their status based on the traffic density.

Power Supply:

The system is powered by a stable power source connected to the Raspberry Pi, ensuring continuous operation even during peak traffic hours.

Software Components

- YOLO (You Only Look Once) Algorithm: The YOLO object detection algorithm is employed to detect vehicles in real-time from the live camera feed. YOLO processes each video frame to identify objects (e.g., cars, trucks, buses) and classify them. This provides a fast and efficient solution for traffic detection.
- Open CV: OpenCV (Open Source Computer Vision Library) is used for image processing tasks such as reading video frames, preprocessing images, and displaying output. It assists in preparing the data before sending it to the YOLO algorithm.
- Python Scripts: Python is used to integrate all the system components. Custom scripts are developed to process the camera input, apply the YOLO model for vehicle detection, and control the traffic lights based on traffic conditions

Traffic Density Estimation

Once the vehicles are detected using the YOLO model, the system counts the number of vehicles in each frame. Traffic density is estimated based on the number of vehicles present in each frame. The system classifies the traffic into categories such as "Low," "Medium," or "High" traffic density. This information is used to dynamically adjust the traffic signal timings.

Signal Control Logic

Based on the estimated traffic density, the system adjusts the traffic light timings:

- Green Signal Duration: When traffic density is high, the system increases the green signal duration to allow more vehicles to pass through. When the density is low, the duration is reduced to minimize waiting time.
- Red Signal Timing: Correspondingly, the red light duration for other lanes is adjusted to maintain traffic flow balance at the intersection.
- Real-Time Adaptation: The system recalculates the traffic density every few seconds and updates the signal timings dynamically, ensuring optimal traffic flow at all times.

Communication Flow

- Video Input: The camera captures the live video feed, which is streamed to the Raspberry Pi.
- Image Processing: The video feed is processed frame-by-frame using OpenCV, and then passed to the YOLO algorithm for vehicle detection.
- Vehicle Detection and Counting: The YOLO model identifies and counts vehicles in real-time.
- Decision Making: Based on vehicle count and traffic density, the Raspberry Pi uses a decision-making algorithm to adjust the signal timings.
- Signal Output: The Raspberry Pi sends control signals to the traffic lights to update their status (red, yellow, green) as per the current traffic conditions.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 1, November 2024

Data Flow Diagram

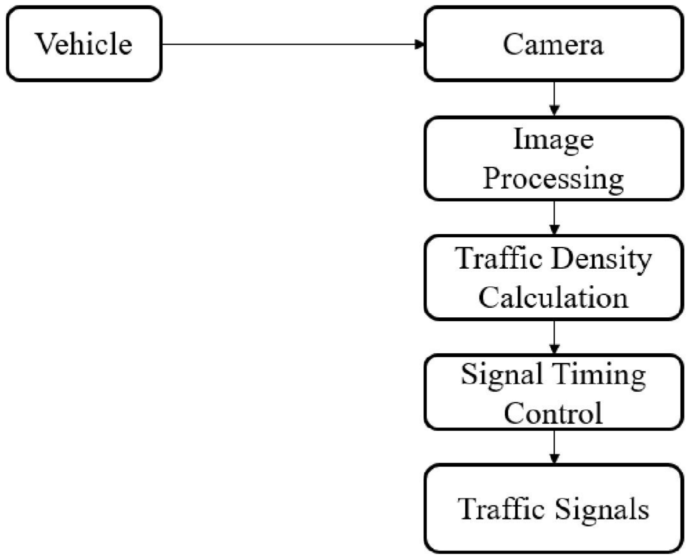
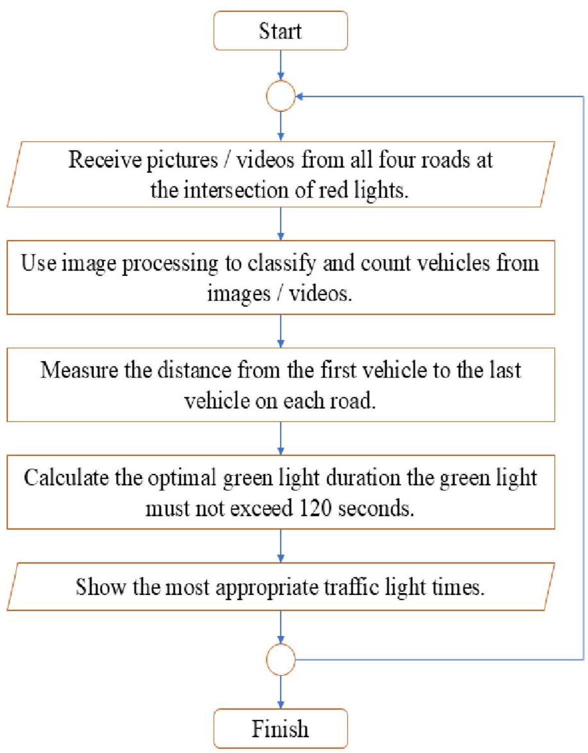


Fig. Data Flow Diagram

Algorithm



IV. ADVANTAGES AND DISADVANTAGES

Advantages

- Reduced congestion and less emission.
- Improved road traffic discipline and safety.
- In addition to the need for increased convenience and safety, the deployment of this system and connected car technology is necessitated by the world's rapidly urbanizing cities.
- Better planning and decision making.
- Time saving and operation efficiency.
- Improved customer service and reduced frustration.
- Improved health due to less environmental pollution.
- Reduce road accidents and enhanced productivity.
- Based on the detection, the system takes self-decisions and performs the operation. Hence human work is not required.
- YOLO algorithm has self-learning capabilities from previous experience.
- It leads to diverse transportation which is important for smart cities.

Disadvantages

- Requiring significant funds to adopt
- It's hard to detect an error
- AI needs human assistance

Applications

Artificial intelligence-based systems can be a smart investment for governments looking to get the most out of their restricted funds for streets and roads. The ability to manage more traffic and a growing population while lowering the capital expenses of creating new or rebuilt roadways is made feasible by them. Only 15% of the world's population was residing in metropolitan regions a century ago. More than fifty-five percent of people live in cities today, and sixty-eight percent are projected to do so in 2050. Hence urbanization needs smart traffic system implementation. With all the development comes an equal rise in traffic, necessitating the use of technology to help control the movement of people and commodities. The AI based system can also help the traffic agencies in penalizing the offenders and act as deterrent. The cameras installed can detect and identify the vehicles which disobey traffic rules and fine them electronically. The AI based traffic system can cut-down the waiting time at traffic signals by almost half. Hence there is a scope and need for smart traffic implementation in real world to ease clogged roads and cope up with growing number of cars.

V. CONCLUSION

The integration of AI-based traffic detection and autonomous signal operation utilizing cameras, image processing, and Raspberry Pi represents a significant advancement in smart traffic management systems. By leveraging real-time data captured through cameras and processed using advanced image analysis algorithms, this approach enhances the ability to monitor and manage traffic flow dynamically. The Raspberry Pi platform, known for its affordability and versatility, enables the deployment of sophisticated AI models at the edge, providing real-time processing capabilities without relying on centralized servers. This setup ensures prompt and efficient traffic signal adjustments based on current traffic conditions, thereby reducing congestion and improving overall road safety. The application of image processing techniques facilitates accurate detection of vehicles, pedestrians, and other critical elements, enabling adaptive signal control that responds to varying traf fic scenarios. This not only optimizes traffic flow but also prioritizes emergency vehicles and enhances pedestrian safety.

VI. FUTURE WORK

In the future, the AI-based traffic detection and autonomous signal operation system can be enhanced by integrating cloud platforms for real-time data collection and analysis, allowing the system to make more informed decisions based on long-term traffic patterns. Additionally, expanding the system to manage multiple intersections in coordination would optimize traffic flow across a wider area, improving overall efficiency. Incorporating advanced detection capabilities to identify specific vehicle types, such as emergency vehicles or buses, could help prioritize traffic and further reduce congestion. The system could also be integrated into broader smart city infrastructures, connecting with other IoT systems like public transportation or environmental monitoring. Finally, deploying more advanced AI models on edge devices, like the Raspberry Pi, would enable faster processing and reduce reliance on centralized computing, enhancing the system's real-time performance and scalability for future urban traffic management needs.

REFERENCES

[1] Gong, Suning & Huan, Zhiying & JI, Mingmei & Chen, Xinxin & Bao, Yuanqiu. (2021). "ITLCS Based on OpenCV Image Processing Technology". Journal of Physics: Conference Series. 2143. 012031. 10.1088/1742-6596/2143/1/.

[2] Sharma Moolchand and Bansal, Ananya and Kashyap, Vaibhav & Goyal, Pramod & Sheakh, Dr.Tariq (2020). "Intelligent Traffic Light Control System Based on Traffic Environment Using Deep Learning".

[3] N. Seenouvong, U. Watchareeruetai, C. Nuthong, K. Khongsomboon and N. Ohnishi, "A computer vision based vehicle detection and counting system," 2016 8th International Conference on Knowledge and Smart Technology (KST), 2016, pp. 224-227, doi: 10.1109/KST.2016.7440510.

[4] Tanvi Sable, Nehal Parate, Dharini Nadkar, Swapnil Shinde. "Density and Time-based Traffic Control System using Video Processing". ITM Web of Conferences 32, 03028 (2020).

[5] S. Zhao and F. You, "Vehicle Detection Based on Improved Yolov3 Algorithm," 2020 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS), 2020, pp. 76-79, doi: 10.1109/ICITBS49701.2020.00024.

[6] O.I. Olayode, L.K. Tartibu, M.O. Okwu, Application of Artificial Intelligence in Traffic Control System of Non-autonomous Vehicles at Signalized Road Intersection., Procedia CIRP, Volume 91, 202Pages 194- 200, ISSN 2212-8271

[7] V. Zinchenko, G. Kondratenko, I. Sidenko and Y. Kondratenko, "Computer Vision in Control and Optimization of Road Traffic," 2020 IEEE Third International Conference on Data Stream Mining & Processing (DSMP), 2020, pp. 249-254, doi: 10.1109/DSMP47368.2020.9204329.

[8] B. Ghazal, K. ElKhatib, K. Chahine, and M. Kherfan, "Smart traffic light control system," in Proc. 3rd Int. Conf. (EECEA), Apr. 2016, pp. 140-145.

[9] C. K. Toh, J. A. Sanguesa, J. C. Cano, and F. J. Martinez, "Advances in smart roads for future smart cities," Roy. Soc. Publ. J., vol. 476, no. 20190439, pp. 1-24, Dec. 2019.

[10] S. Singh, "Critical reasons for crashes investigated in the national motor vehicle crash causation survey," Tech. Rep., 2015.

[11] R. Lanctot et al., "Accelerating the future: The economic impact of the emerging passenger economy," Strategy Analytics, vol. 5, 2017