ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Continuous Vehicles Capture

Team #21

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1 Introduction

1.1 Objective and Background

In the context of expanding urban areas and mounting traffic congestion, conventional traffic monitoring methodologies (e.g., manual observation, fixed detectors, etc.) frequently encounter challenges in achieving a balance between real-time data and accuracy. Consequently, the traffic department is confronted with an urgent need for a portable monitoring system capable of acquiring real-time information regarding road traffic density, vehicle count, and congestion levels. The implementation of such a system would serve to enhance traffic management and optimise traffic flow.

1.1.1 Goals

The aim of this project is to build a Raspberry Pi based traffic monitoring system that utilizes cameras for uninterrupted video capture and image processing algorithms to identify and count vehicles in real time.

1.1.2 Functions

The system should have the following functions:

- Real-time video capture and uninterrupted monitoring of road conditions using cameras.
- Vehicle identification and counting in live video streams using image processing algorithms.
- Analysis of traffic density and congestion levels based on vehicle counts and traffic flow.
- Real-time data aggregation and visualization through a user-friendly graphical interface.
- Configuration of congestion alerts for relevant departments or personnel.

1.1.3 Features

The system has the following features:

- Portable and easy to deploy, suitable for various road environments.
- Cost-effective and low-power consumption, reducing operational costs.
- High stability and reliability, ensuring continuous operation in outdoor environments.
- Real-time and accurate, providing timely data support for traffic management decisions.

- Scalable and customizable, allowing for future upgrades and integration with other traffic management systems.

1.2 High-Level Requirements List

The system needs to meet the following requirements:

1. Accuracy: Vehicle detection and counting accuracy should be $\geq 90\%$.
2. Real-time performance: The system should be capable of near real-time video analysis and rapid data visualization.
3. Robustness: The system should operate reliably under different weather, light, and traffic flow conditions.
4. Early warning effectiveness: The system should effectively identify and warn of congestion status, assisting traffic management decisions.
5. User-friendly interface: The visualization dashboard should be intuitive and easy to use for relevant personnel.
6. Compatibility: The system should be compatible with common traffic management software and hardware.

2 Design

A general section looks like this. There is usually a blurb introducing the top-level section here.

2.1 Block Diagram

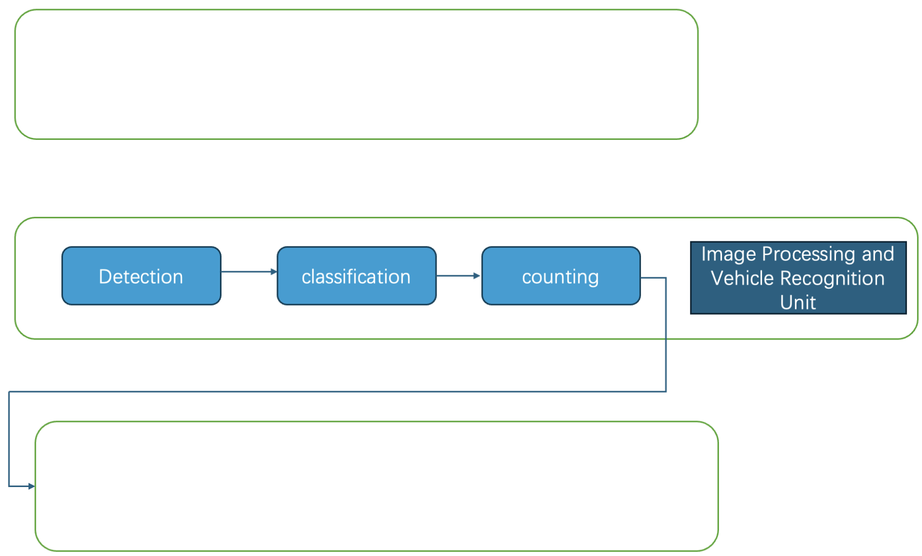

Figure 1: Continuous Vehicles Capture Flowchart

2.2 Mechanical Unit

The mechanical unit comprises an enclosure for deployment in outdoor environments, in addition to a mounting system for the camera and other essential components. This ensures the durability and stability of the monitoring system in a variety of environmental conditions.

2.2.1 Microcontroller

The microcontroller, chosen to be a Raspberry Pi, handles:

- **Image processing**: Capturing and processing real-time traffic images.
- **Vehicle detection and counting**: Running recognition algorithms to determine vehicle density.
- **Data transmission**: Sending processed data to the cloud or a local dashboard for real-time monitoring.

2.2.2 Enclosure and Mounting

The system includes a weatherproof enclosure to protect the Raspberry Pi and other electronic components from dust, rain, and extreme temperatures. The enclosure is:

- IP-rated for outdoor use ensuring resistance against harsh weather conditions.
- Ventilated and thermally managed to prevent overheating of the components.
- Compact and lightweight, making it easy to deploy in various locations.

The camera mounting system is designed to:

- Ensure stability to avoid image distortion due to vibrations or wind.
- Provide adjustable angles for optimal field of view based on the monitoring location.
- Support various camera modules, including high-resolution cameras for better vehicle detection accuracy.

2.2.3 Power Supply and Connectivity

The system is powered by:

- Rechargeable battery or solar panel, ensuring continuous operation in outdoor environments.
- A backup power system, preventing data loss during power interruptions.

For connectivity, the unit supports:

- Wi-Fi and 4G modules, enabling real-time data transmission.
- Local storage (SD card or external SSD) for temporary data backup in case of network failure.

2.3 Image Processing and Vehicle Recognition Unit

The subsystem is dedicated to real-time traffic monitoring and analysis through advanced vehicle detection, classification and counting. It processes video streams to accurately determine vehicle location, type, and movement patterns, generating structured traffic metrics to support local congestion analysis and broader reporting. At the same time, a balance between computational efficiency and robust performance is achieved under different environmental conditions. The subsystem is designed to interact seamlessly with other components, receive incoming video stream information, and feed the data to a centralized traffic management system for final visualization.

2.3.1 Detection Performance

- *Requirement 1: Image Preprocessing*

Implement automatic contrast adjustment and noise reduction with maintaining edge clarity loss $\leq$5%.

- *Requirement 2: Frame Processing Rate*

  Process 720p video at 12 $\pm$ 2 FPS under stable conditions (15–35°C, 50–100k lux).

  Minimum 10 FPS during transient light changes.

- *Requirement 3: Detection Accuracy*

  In different cases:

  Daylight: 100–100k lux ($\pm$5% error) Low Light: 1–50 lux ($\pm$15% error)

- *Requirement 4: Environmental Robustness*

  Regain $\geq$ 90% detection accuracy in 2 seconds under sudden illumination changes with $\pm$ 5% tolerance.

  Maintain $\geq$70% vehicle recall with $\leq$15% false positives in light rain.

2.3.2 Classification

- *Requirement 1: Category Differentiation Requirement*

  Accurately distinguish different vehicle types, such as non–motor vehicle, car, bus, and track.

- *Requirement 2: Classification Persistence*

  Maintain classification consistency $\geq$ 98% in consecutive frames for the same vehicle.

- *Requirement 3: Occlusion Handling*

  Recover tracking after $\leq$2 sec full occlusion with:

  - *Position error $\leq$10% of vehicle size.*
  - *ID mismatch rate $\leq$5%.*

- *Requirement 4: Environmental Robustness*

  Maintain $\geq$85% classification accuracy when vehicles are partially occluded ($\leq$30% area).

  Classification accuracy degradation $\leq$10 percentage points under low light conditions (1-50 lux).

2.3.3 Counting

- *Requirement 1: Virtual Line Counting*

  Count vehicles crossing lines with $\leq$3% error under moderate traffic.

- *Requirement 2: ID Persistence*

  Maintain tracking for ≥90% of vehicles visible for >3 sec.

  Allow ≤1 ID switch per vehicle for short-term tracking.

- *Requirement 3: Occlusion Handling*

  Recover tracking after ≤1.5 sec full occlusion with:

  - *Position error ≤10% of vehicle size.*
  - *ID mismatch rate ≤5%.*

- *Requirement 4: Environmental Robustness:*

  Continue tracking after transient vehicle disappearance (≤1.5s) with ≥95% ID matching accuracy.

2.4 XXX unit

In this section, we will present a comprehensive snapshot of the traffic flow metrics collected by the Raspberry Pi. Graphical representations, such as line charts, bar charts, or dashboards will display key indicators (e.g., total vehicles counted, average traffic volume per day). These high-level summaries will allow stakeholders to quickly assess traffic flow trends and identify potential areas of concern.

2.4.1 Component Module

- *Requirement 1: Transient module*

  The Transient Module focuses on aggregating traffic data over varying time intervals such as 10 min,1 hour and 6 hours.

- *Requirement 2: Traffic flow alerts*

  By comparing traffic volume across different lanes of the same road section, we can identify imbalances or potential bottlenecks in real-time. Visual alerts,such as colored indicators, which will highlight segments exceeding predefined threshold values.

  - Offer automated alerts when a specific lane experiences abnormal congestion relative to neighboring lanes.
  - Provide optimization recommendations, such as lane reconfiguration or signal timing adjustments, aimed at mitigating congestion.

2.4.2 Technical Approach

- *Step 1: Data Collection*

- Raspberry Pi devices will gather vehicle counts through attached sensors or cameras.
- Data will be regularly transferred to a local or cloud-based server for processing and storage.

- *Step 2: Data Processing*
  - A streaming or batch pipeline (e.g., Python or a similar data processing framework) will clean and aggregate traffic data at 10-minute, hourly, and 6-hour intervals.
  - Algorithms will compare real-time lane usage and historical norms to detect anomalies and trigger alerts.

- *Step 3: Visualization Tools*
  - A dashboard platform (e.g., Grafana or a custom web application) will be employed to display charts and alerts.
  - Interactive features (zooming, filtering, drill-down) will facilitate in-depth data exploration and analysis.

- *Step 4 Alert Mechanism*
  - Threshold-based or machine learning-based anomaly detection will notify operators whenever traffic conditions deviate significantly from expected patterns.
  - Visual signals (flashing icons, colored highlights) can be incorporated for timely responses.

2.4.3 Expected Outcomes

- *I*mproved Decision-Making: Clear visualization of short-term and long-term traffic flows supports more efficient traffic signal planning and scheduling.
- *T*imely Interventions: Real-time alerts enable swift corrective actions to address abnormal congestion or imbalance between lanes.
- *L*ong-Term Planning: Aggregated historical data drives data-informed road expansion and infrastructure development decisions.

3 Ethics and Safety

3.1 Ethics

3.1.1 Data Privacy and Security

This project collects traffic data that may include license plates and driver information. To address privacy concerns, we follow the IEEE/ACM Code of Ethics by obtaining informed consent from the public through clear signage near cameras and anonymizing data during processing. Data storage adheres to strict encryption protocols on secure servers with limited access to authorized personnel only.

3.1.2 Algorithm Fairness and Transparency

The vehicle recognition algorithm is designed to avoid discrimination based on vehicle type, color, or brand. If we use deep learning to train model, we must use diverse training datasets and regularly audit the algorithm for bias. In line with ethical guidelines, the system provides transparent decision-making processes, allowing traffic authorities to understand how congestion alerts and vehicle counts are generated.

3.1.3 Environmental and Social Impact

Outdoor camera installations are designed with minimal environmental disruption in mind. We use weatherproof, dustproof enclosures and temperature control systems to ensure longevity without harming local ecosystems. The project aims to benefit society by reducing urban congestion and improving traffic flow efficiency.

3.2 Safety

The system employs robust hardware safety measures, including secure camera mounting and protective enclosures to prevent tampering or damage. Software safety is maintained through regular updates, secure coding practices, and vulnerability testing. The Raspberry Pi platform is chosen for its reliability and low power consumption, ensuring stable operation in various conditions. We follow relevant electrical safety standards for outdoor electronic equipment and ensure compliance with local traffic monitoring regulations.

references

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[3] M. Anandhalli and V. P. Baligar, “A novel approach in real-time vehicle detection and tracking using raspberry pi,” *Alexandria Engineering Journal*, vol. 57, no. 3, pp. 1597–1607, 2018, ISSN: 1110-0168. DOI: 10.1016/j.aej.2017.06.008. [Online]. Available: https://doi.org/10.1016/j.aej.2017.06.008.