Network for Traffic Monitoring in a Smart City

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Thomas Courtney

3175353

Supervised by Assoc. Prof. Kaushik Mahata

School of Engineering

University of Newcastle

Abstract

Traffic congestion is a growing issue in urban centers that contributes to carbon emissions and wastes time and money. A lightweight traffic data capture system could be used to reduce data collection costs and increase the amount of data available to traffic network stakeholders. A system that utilizes computer vision to produce real-time traffic data running on an embedded system serves this purpose. This thesis explores the design, testing and implementation of a network of cameras that capture video of sections of a traffic network and use a computer vision algorithm based on background subtraction to determine the volume and approximate speed of traffic at that location. An exploration of existing traffic data collection methods was performed and an investigation into computer vision techniques appropriate for object detection and tracking was undertaken to arrive at this system. In 8 different traffic settings the system achieved an average accuracy of 95% for vehicle volume counts. For camera perspectives perpendicular to the direction of vehicle movement a speed measuring accuracy of 95% was achieved. These results demonstrate that an effective lightweight system for traffic monitoring can be developed.

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Contributions

The following list outlines the key features I have contributed to my project:

- Designed, implemented and tested an algorithm to count and measure vehicle speed.
- Designed and tested a set of object tracking criteria to increase system accuracy.
- Derived a set a calibration guidelines for different traffic scenarios.
- Developed a GUI to present the traffic data collected by the system to a user.
- Designed and implemented a database to house data collected by the system.
- Undertook an extensive review of the fundamentals of image processing and computer vision.

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Supervisor Signature ____________________

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Chapter 1

Introduction

Economies of the world have been industrializing for over two centuries [1] and the consequent advent of machines and factories has seen a great migration of humanity from farmlands to cities. Such a shift in population density has posed a plethora of infrastructural challenges and led to many iconic solutions to high density living, like the skyscraper, subway train and traffic light. One unfortunate metropolitan trait, however, continues unabated and is in fact growing in size [2] - it is traffic congestion.

Road transport contributes 16.5% of global CO2 emissions [3] and costs the US $305 billion of productivity per year alone [4][5] thus even a small improvement in traffic efficiency will yield great benefit to society and the future of the planet. Unfortunately its persistence is only an indicator of its difficulty to solve.

There is no single solution to the problem of traffic congestion, whether it be the building of tunnels, the conversion of traffic lights to roundabouts or the widening of roads though a number of studies [6][7][8][9] have found that the integration of several lightweight and inexpensive techniques is a far more efficient approach than the aforementioned heavy-handed methods. A 'Smart City' is such an approach, and part of its design is to deploy many devices in an urban area that collect data [10] which is then transmitted and processed to make useful conclusions about a system. This technology could be applied to collect traffic data more completely and inexpensively than is currently the case. Data of interest includes traffic volume and vehicle speed.

Current widely employed methods of traffic data collection [11] have inherit weaknesses that justify a movement to new techniques that exploit advantages provided by the latest technology. For example, manual counting requires that a person be visually counting traffic and is very expensive, hence, it is used only for short surveys necessitating data extrapolation at a cost to accuracy. Automatic methods of data collection such as inductive loops and piezo-electric sensors are able to measure speed and mass of vehicles due to the change in electric field that they generate as they pass a sensor however these systems are embedded in roadways and thus have high installation and maintenance costs. Less invasive automatic methods of data collection include pneumatic road tubes that sense change in air pressure as a tire passes over them. These systems are often temporary and accuracy is subject to temperature and traffic conditions. Infra-red sensors are inexpensive but cannot provide coverage across multi-lane roads and magnetic sensors embdedded in roadways often cannot differentiate between closely placed traffic.

A single *modular* lightweight system capable of performing all the functions of the aforementioned devices would be advantaged by significantly lower maintenance fees, dynamic installation capabilities and efficiency borne of the simplicity of relying on a single system set. Further, if many system modules were employed at key locations and data was transmitted in real-time to a central database for processing a complete picture of the state of the traffic system at anytime could be developed. A module running a computer vision algorithm with a small camera module would be able to complete these functions and facilitate such data analysis.

Computer vision is a versatile method by which image classification and object tracking may be achieved. An algorithm can be tailored to produce high accuracy real-time results requiring only images as input. Computer vision attempts to mimic human vision's ability to rapidly identify objects like separating a vehicle from its surroundings and tracking its movement. An increasingly effective method of image classification utilizes machine learning and trains a neural network to recognise objects in an image, however, this method is hindered by the large amounts of computational power required to train the network and the many thousands of data samples needed to train the network on. In a specific use-case like traffic monitoring a specialized algorithm that does not depend on a neural network but image processing techniques alone can yield high quality results. The implementation of a robust computer vision algorithm for traffic monitoring is not trivial however, and many techniques have to be choreographed for the algorithm to perform well.

It is the objective of this report to explain the design and operation of a lightweight and discrete traffic data collection module whose capabilities to estimate traffic speed and volume depend on an underlying computer vision algorithm. Further the module will transmit real-time results to a central database. It's basic structure is comprised of a microcontroller controlled camera mounted above a road that processes images to produce and transmit data to a central database. The overall system can be scaled to include many microcontroller nodes transmitting information. The collected data can queried and downloaded from a web-based GUI connected to the database.

Chapter 2 explores the relevant theoretical background underpinning the computer vision and image processing techniques implemented by the algorithm. This begins with the fundamental qualities of a digital image and ends with an explanation of the probabilistic model that is used to determine which image pixels belong to foreground objects and which do not.

Chapter 3 details the system's overall design and how its subsystems interface with each other to produce a functional data collection product. The design's subsystems are the Computer Vision Algorithm, Networking, Hardware, Data Storage and Organization and The User Interface. The Computer Vision section in particular explains how the theoretical principles discussed in Chapter 2 are employed.

Chapter 4 outlines the capabilities of the system and the results it is able to produce and gives an analysis that identifies and explains the strengths and weaknesses of the system.

Chapter 5 summarizes how well the system satisfied the requirements it was designed to meet and also suggests augmentations that could be made to the system to improve its performance and applicability.

Chapter 2

Conclusion

2.1 System Outcomes

The objective of the system, to create lightweight traffic data collection system, was satisfied. The system achieved accuracies of 95% and 95% for volume and speed measurements respectively, satisfying the primary objective of collecting traffic data. The best results were obtained for camera setups looking down at a road scene as this angle provided the least vehicle occlusion. The system was implemented on versatile and inexpensive hardware showing that a lightweight and modular data collection system is plausible and appropriate for a Smart City. The system's detection algorithm was shown to suffer accuracy reductions due to edge cases caused by camera movement and partial or complete vehicle occlusion. Handling these cases requires additional complexity in the computer vision subsystem that may comprise the system's simplicity and reduce its execution speed. That the system produced real-time statistics extends its usability to applications that require real-time data such as live traffic rerouting.

2.2 System Extensions

There are a number of additions and improvements that could be made to the system to improve its overall performance and the experience of those using the system. These additions were omitted from the system's present implementation due to time restrictions.

The most beneficial extension would be to test and implement node networking on a wide area network such as 4G as this iteration of the system was implemented only on a local area network. Communication with nodes over long distances would enable technicians to calibrate them without having to go to the installation site reducing costs. Node calibration could be added to the user interface and show in real-time the effect of modifying detection algorithm parameters.

To address the edges cases such as vehicle occlusion new features could be considered in the detection algorithm such as object luminance and vehicle shape. This additional information could be used to verify not only that an object was a vehicle but also more accurately develop the object's shape and hence determine the *type* of the vehicle (truck, car, motorbike...) which is valuable traffic data in and of itself.

This iteration of the system was tested very little under nighttime conditions and so this is a natural extension of the project to provide a system that develops a whole picture of a traffic network's usage. This could be implemented with many of the same techniques that are already present in the system but with the addition of a light sensor to determine when it's dark and an infra-red camera to capture images.

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Appendix A

Hardware Specifications

A.0.1 Raspberry Pi 4

A.0.2 Pi Cam

Appendix B

Mathematical Theorems and Proofs