Density-Based Real-Time Traffic Controlling System Using Image Processing

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Abstract

The vehicle population is growing rapidly with the growth of the population. Therefore, traffic congestion is increasing in urban areas. Associated problems such as accidents, stress, and pollution also increase in proportion to traffic problems. In most cities, traffic light systems are used to reduce traffic congestion. Most traffic lights work with a pre-programmed method, or Traffic Police control traffic congestion manually. In Sri Lanka, there is usually heavy traffic congestion during peak hours. During peak hours, Traffic Police control traffic congestion manually. Since this manual procedure is inadequate to control heavy traffic congestion, a real-time traffic controlling system is needed to solve this problem. Our proposed system is implemented to control this traffic congestion problem using real-time traffic density. Further, it is expected to avoid or minimize traffic congestion using image processing techniques.

Keywords: Traffic light systems, Traffic congestion, Image processing, YOLO, Queuing Theory

I. INTRODUCTION

Traffic light systems are used to control and reduce traffic congestion at intersections. In addition, they are one of the best ways to guarantee safe traffic flow everywhere. There is a universal code for traffic lights to follow with a sequence of illuminating lamps or LEDs (Light Emitting Diodes) of three standard colors which are red, green, and yellow. In most cases, traffic light systems are programmed according to the time allocation for each directional traffic flow during the cyclic process. It is the mainly used timer model. They operate according to preset times stored in memory, which is processed by a processor and powered by electricity. Most developed modern counties use sensor-based traffic control methods to detect the number or the density of vehicles and produce the appropriate signals (Nafeel, 2015). The traffic control system, based on vehicle density with image and video processing techniques, is a better alternative to time-based systems (Sable et al., 2020). This system is based on the actual traffic density of the road and real-time traffic monitoring. Python Open CV can be used as an image processing tool to detect and count the number of vehicles in each lane. This system is mainly implemented for four-lane junctions and considered when pedestrians cross the road.

An implementation of a video-based real-time traffic controlling system and respective methodologies are presented in this study. The rest of the paper is structured as follows. Section II describes related work. Section III discusses the methodologies used, Section IV Discussion and section V presents the conclusion of this paper.

II. RELATED WORK

This section discusses the related work used to develop traffic light control systems, and it briefs the variety of methods that can be used in traffic control. There are two main traffic light controlling methods. One is the Fixed Time Technique (Siddamma and Pashupatimah, 2018). Here, the system is programmed based on the time allocation provided to each directional traffic flow during the cycle. This is a fixed-time technique, i.e. for a specific time interval, say 15 seconds, the cyclic pattern of time distribution will remain the same (Subramaniam, Esro and Aw, 2012). The second one is Vehicle Activated Time Technique. This is a pre-defined mode, and adjustments can be made based on the approaching traffic flow detected by the sensors. These observations made by the sensors are then processed and appropriately timed by the traffic controller. However, this method has not been introduced in Sri Lanka. The comparison between the fixed time technique and the vehicle's activated time technique is shown in Table 01.

Table 01: Comparison between the fixed time technique and vehicle activated time technique

Fixed time technique	Vehicle activated time technique
Based on a pre-programmed sequence	Based on sensors
Operates without any consideration of real-time behavior	Operates in real-time
A time-allocated cyclic process	Commonly used sensors are inductive loops, cameras, radars, infrared sensors

Some of the traffic control methods which can be used as alternatives for traffic problems are described in the following.

A. Density-based Traffic Controlling

With the rapid development of road infrastructure, the density of vehicles on the road network has increased. This is mainly due to the rapid increase in vehicles in a certain area in a short period. The density-based traffic control system is a better solution to overcome those kinds of problems. Using real-time video and image processing techniques, this can be achieved. In most cases, electronic sensors embedded in the pavements are used to detect vehicles in a lane. Magnetic loop sensors are the most used sensors in vehicle detection, but the maintenance and installation costs are inconvenient (Guerrero-Ibáñez, Zeadally and Contreras-Castillo, 2018). Therefore, cameras can be used as image sensors to capture images. They can be analyzed using digital image processing for vehicle detection, and according to the density of traffic, traffic lights can be controlled (Raj A.M. *et al.,* 2020).

B. Traffic Controlling Using Image Processing

Traffic parameters can be estimated using real-time traffic monitoring. Vision-based cameras are more versatile for traffic parameter estimation. The captured images provide quantitative and qualitative parameters (Guerrero-Ibáñez, Zeadally and Contreras-Castillo, 2018). Speeds of vehicles and vehicle count are some quantitative traffic parameters. It can give complete traffic flow information to meet traffic management requirements (Prakash *et al.*, 2018). An example of vehicle tracking is shown in Figure 01(a). The real-time traffic density on the road can be measured using image processing. The images are continuously captured and stored in a server and compared with live images captured by the camera to determine density. This process can be used to determine the traffic density on both sides of the roads and enable traffic signal control options for drivers or users by using a software application. Some image processing techniques which can be used in vehicle detection are described below.

(a) (b) (c) (d)

Figure 01: (a) Vehicle tracking using image processing (George, George, and George, 2018) (b) Image computed by GMMs input (Bhaskar, 2014), (c) output (Bhaskar, 2014) (d) Detected image using background subtraction(Sobral, 2015)

1) YOLO (You Only Look Once) Algorithm:

Traffic sign detection is a challenging task due to obstacles such as occlusions in natural scenes, changing lighting conditions, and camera perspective. Deep convolutional networks are used for image recognition and object detection as they provide the desired performance in terms of speed and accuracy (Vikram, 2018). Test time latency is one of the important factors in real-time traffic detection. Due to the complex computation, Convolution Neural Networks (CNNs) are considered unsuitable for real-time traffic detection. You Only Look Once (YOLO) architecture can be explored to detect and classify the signs in real-time. It can be used to exhibit object detection in real-time and classification at a rate of around 45 frames per second (Redmon *et al.*, 2016).

2) Background Subtraction:

This is a common method used to detect moving objects in a series of frames from cameras. It is based on detecting moving objects from the difference between the current frame and reference frame which is called the 'background image' of the 'background model'. This is usually done through detection; foreground detection is the main task. All current detection techniques are based on modelling the image background, i.e. setting the background and detecting changes that occur. Defining a proper background can be difficult when the background contains shadows, shapes moving objects, etc. When defining the background, all techniques assume that the color and intensity of stationary objects will change over time. Figure 01(d) shows an example image detected by the Background subtraction technique.

3) Gaussian Mixture Model:

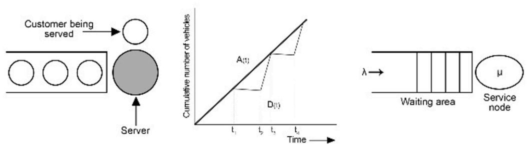
Gaussian Mixture Models (GMM) are used to measure parametric probability densities, expressed as a weighted sum of Gaussian component densities (Dahiya, 2021). GMM is used for various applications in different fields such as astronomy, machine learning, computational biochemistry, and other applications (Reynolds, 2009). GMM sorts the foreground and background from image frames by learning the background of a certain scene. In vehicle detection and tracking, GMM uses the common observable attribute change factor between the current image and the reference image to deal with the changes in the image frames and automatic gain by the camera. Then, the Mahalanobis distance of the Gaussian is calculated based on the common observable property change factor, the current color intensity, and the Gaussian component means estimate. The threshold is calculated to determine the similarity of an objective norm of color quality, regardless of its brightness between the background and the pixels in the foreground where the currently observed image is learned by obtaining GMM. Figure 01(b) and (c) show an example image computed by GMM and the output (Bhaskar, 2014).

C. Fuzzy Rule-Based Control

Adaptive Neuro-Fuzzy based modules are used for the analysis of traffic data. A set of 40 fuzzy decision rules are used to adjust the signal timing parameters (Wannige and Sonnadara, 2009). The rules for adjusting cycle time, phase splitting, and offset are decoupled so that these parameters can be adjusted independently (Mohanaselvi and Shanpriya, 2019). Adjusting the cycle time is used to maintain good saturation when the top is close to the saturation (George, George, and George, 2018). Saturation is defined for a given method as the actual amount. The vehicles passing through the intersection during the green light time are divided by the maximum number of vehicles that can pass through the intersection during that time (Mohanaselvi and Shanpriya, 2019). Adjust the offset to coordinate adjacent signals to minimize the direction of dominant traffic flow. The controller first determines the number of dominant directions of the vehicle according to each method. The arrival time of the convoy leaving the upstream intersection can be calculated based on the time of the next green light at the upstream intersection.

D. Queueing Theory

Queuing theory is a mathematical study of the movement of people, objects, or information through lines to identify and correct points of congestion in processes (Gosvi, 2020). Queue theory is used to break in down the line into six elements such as the arriving processes, the serving and departing processes, the number of serving and departing processes, the number of servers available, the queue capacity, and the number being held (The Investopedia Team, 2022). When creating a model of the whole process from beginning to end, it is necessary to identify and resolve the cause of congestion.



(a) (b) (c)

Figure 02: (a) Queuing System (Gosvi, 2020) (b) Analyzing the traffic flow using queue theory (Papacostas and Prevedouros, 1993) (c) M/M/1 Queuing system (Anokye, Annin and Oduro, 2013).

1) Traffic Flow Analysis Using Queue Theory:

Vehicle traffic provides the basis for measuring operational performance on the road. Various dimensions of traffic, such as the number of vehicles per unit of time, vehicle type, vehicle speed, the variation of traffic flow over time, and highway operations can affect the performance of highways (Chandra, Mehar and Velmurugan, 2016). It is important to use theoretically consistent quantitative techniques to analyze traffic conditions. These techniques can be used to simulate traffic flow, speed, and temporal fluctuations (Srinivas *et al.*, 2013). Queuing theory can be used to analyze the traffic flow approaching and passing through intersections controlled by traffic lights. This is used to analyze the cumulative transit time of vehicles as a function of time. The above queuing diagram (Figure 02(b)) for interrupting flow shows the flow on one intersection approach. t_1 to t_2 time of Figure 02 (b) is the red signal interval, then the traffic is stopped. Traffic starts to leave the intersection at the start of the green interval (t_2) at the saturation traffic flowing rate (qG) and continues until the queue runs out. The departing rate $D(t)$ equals the arriving rate $A(t)$ until t_3, which is the beginning of the next red signal. This process is started over at this point (Papacostas , C.S. and Prevedouros, 1993).

2) *M/M/1 Queuing Theory:*

M/M/1 refers to negative exponential arrival and service times with a single server. This is the widely used queuing system for analysis purposes. M/M/1 is a good approximation for large queuing systems (Anokye, Annin, and Oduro, 2013). The conditions of the M/M/1 queuing system are, (1) The number of objects (vehicles) in the system is very large, (2) A single object consumes a small percentage of system resources, and (3) All vehicles are independent, i.e. their decision to use the system is independent of other users (Schwarz *et al.*, 2006).

III. METHODOLOGY

This research presents a solution for traffic light management using cameras. In this system, the cameras are used as image sensors for capturing vehicles. Images will be analyzed, and image processing techniques will be used for detecting and counting vehicles. Vehicle types and their traffic parameters will be measured for implementing an algorithm for traffic light waiting time. It will be mainly based on quantitative traffic parameters such as the speed of a vehicle, arrival time, size of a vehicle, etc. The system will not be dependent on the type of camera and the number of lanes in the road structure. It will depend only on the traffic parameters. There are two main parts included in this proposed methodology. They are (1) Vehicle detection and counting using image processing and (2) Creating an algorithm for traffic light control using Queuing Theory.

1) *Vehicle Detection and Counting Using Image Processing*

This part is done by using Python OpenCV background subtraction. Firstly, the relevant video was cropped using the algorithm and converted into grayscale, and filters such as blur, dilate, and the kernel were used. After that, the number of vehicles in each lane of the four-way intersection was counted.

2) *Creating an Algorithm for Traffic Light Controlling*

The traffic controlling algorithm is based on queuing theory. We have considered the traffic flows which follow the M/M/1 Queuing Theory. This algorithm mainly finds the green light time of the traffic light, and according to Traffic Engineering, it is equal to the waiting time of a vehicle.

(a) (b)

Figure 03: (a) Sample frame for detection and counting vehicle (b) Grayscale image of the sample frame

The main assumptions we have made in this method are that the arrival pattern follows the positioning process, the arrival of vehicles is from one direction, there is no turning lane at the intersection, and the queue process follows the FIFO discipline.

The commonly used equation for traffic light waiting time calculation is given below. In this equation, λ refers to the arrival rate, and μ refers to the departure rate of vehicles. W is referred to as the waiting time.

$$W = \frac{1}{\mu - \lambda} \quad (1)$$

The waiting time of each lane can be calculated by using equation (1) and then can control the traffic light according to the number of vehicles at the relevant time.

IV. DISCUSSION

Throughout this project, we have tested several image processing techniques and we have chosen

Python OpenCV as our image processing algorithm among them because the highest accuracy has been achieved by using that. We have achieved more than 90% accuracy using vehicle detection algorithm. It has been tested using several video sets. Most of them have more than 90% accuracy.

Real-time traffic control can be done using sensors and this paper is based on image sensors and image processing techniques. This project is mainly focused on four-lane junctions and these algorithms are independent of types of cameras and number of lanes. This can be developed into any number of lanes. We have used the Python-OpenCV background subtraction method and it can be changed for certain image processing methods and also can be developed to connect several traffic nodes and it can be easy to use a IoT platform for node-to-node communication.

V. CONCLUSION

This paper is based on developing a density-based traffic-controlling system. The proposed method consists of two main parts for detecting and calculating the vehicle density and the waiting time according to the vehicle density. Python OpenCV background subtraction method was used in vehicle detection and counting, and creating a waiting time algorithm was done based on M/M/1 Queuing Theory. This system would be a real-time traffic-detecting system. With the help of this system, we can manage and control traffic congestion and minimize the number of road accidents.

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