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Adaptive Traffic Control System for Smart Cities Using Computer Vision and Deep Learning

Shyam Shankaran R [1*], Logesh Rajendran[2]

Senior Engineer, L&T Smart World, Chennai, India[1*]

Principal Architect, L&T Smart World, Chennai, India[2]

Abstract: In country like India, billions of people start and end each working day stuck in traffic or commuting on congested trains and buses. By 2025, cities that implement smart mobility systems on average, reduce commuting cycles by 15-20 percent, with some individuals experiencing even greater reductions. Depending on each city's density, current transit facilities, and commuting habits, the capacity associated with each application is highly variable. Slowed synchronization of traffic signals leads to traffic congestion and delays. The pre-programmed, regular signal timing patterns are employed in traditional signal systems. To overcome the problems of traditional traffic control systems, there is a shift in adaption to an Adaptive traffic control system. The ATCS (Adaptive Traffic Control System) is a traffic management technique that modifies or adapts the timing of traffic signals based on the real demand for traffic and achieved using a control system that includes both hardware and software, where hardware is the sensor used for real-time traffic density estimation and software is designed using captured data analysis of the city's current traffic flow. This paper depicts a model of camera-based traffic monitoring and processing system which reduces the cycle time and possesses special provisions for emergency vehicles.

Keywords: Traffic monitoring, Traffic congestion detection, Adaptive traffic control system, Intelligent Transportation System, OpenCV, Image Processing, Traffic Management System.

I. INTRODUCTION

Traffic congestion has been a matter of problem in any developed urban area with a large population but inadequate infrastructure. Traffic Congestion is a critical problem with dire causes and consequences on the road [1]. Radical population growth and low public quality transportation have caused vehicles to expand massively. Poorly controlled traffic, apart from infrastructure, creates congestion that could survive for hours. A fixed timing system for traffic management will only ease the challenge to a certain degree. Many traffic control systems manage signals on a fixed-time basis, where a series of signal timing protocols is determined by the day of the week and the time of the day. Based on traffic patterns previously studied at various junctions, the time correlation is pre-calculated between the signals. In these fixed time models, it is not possible to expect systems to cope with traffic conditions that vary periodically from those that existed at the instant when the junction was evaluated. In addition, as the flow of traffic vary dynamically, fixed-time techniques for traffic signals often become redundant. This includes resurveying the region and fresh new signal timing plans must be determined. Perspective has shown that this technique is extensive and that resources that are not always readily available are necessary. The challenges of most fixed time traffic signals states clearly that a more adaptive solution to the dynamic traffic conditions are required [2]. The ATCS is one such efficient solution in terms of traffic management. Compared to fixed time systems, this is a positive improvement as it ensures improved decision-making capability.

The fundamental concept of having an adaptive traffic control system is to construct an efficient traffic control and management system in such a way that it functions in response to real-time traffic patterns. We also come across existing traffic light system situations where, if there is no vehicle on a specific lane and heavy traffic on another lane, for a specified time, the traffic signal on the latter lane is green while the other remains red at the very same time. The remedy to these issues is to implement an adaptive system that operates in accordance with the number of vehicle lanes. This traffic system counts the number of vehicles in the lane, compares the data from other lanes, and, based on the number of vehicles, determines whether to offer priority to reducing the average waiting time or reducing congestion/pollution in the lane. The use of a camera-based ATCS system not only offers the solution for traffic congestion, but it also provides additional features for intelligent transport systems like violation detections, prioritizing emergency vehicles, road surveillances, and better civic management. The adaptive traffic control system has become part of intra-urban transportation systems in several cities in developing countries.

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II. INTELLIGENT TRANSPORT SYSTEM

Intelligent Transport System (ITS) Architecture offers a framework for any form of technology-related initiative in the transport sector. The system architecture is a broad description of the facilities, ITS modules, interconnections, and information flow mapping for the different systems and subsystems that cover the ITS project. With a properly designed infrastructure, owners and stakeholders may define both the services provided by end-users, the data for these services, and the interconnection between the various sub-systems.

The preparation and implementation of ITS are in their infancy in India. There are several noteworthy achievements in ITS applications in India mainly in transport technology, traffic control, fare collection, and toll collection systems. However, there is currently no National ITS Plan or ITS Architecture that has been established. The lack of a national ITS architecture does not mean that this move is not necessary. In fact, the World Bank recommends that for those countries and regions that have not yet developed a national or regional ITS Architecture, the ITS Architecture Project Level is a suggested initial step towards starting the process of developing a national ITS Architecture.

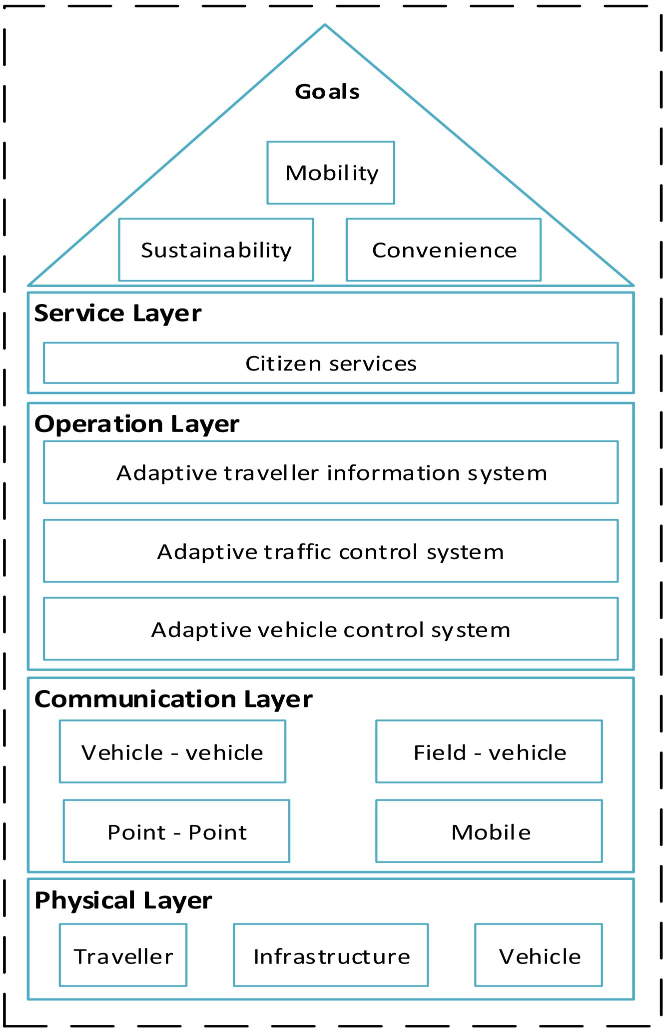

Fig. 1. Layers of Intelligent Transport System

The ITS architecture as a whole involves many user services like Vehicle safety and control system, Traveler information services, Public transport services, Electronic payment services for Toll, Traffic management services, Commercial vehicle operations, Emergency management services and Information warehousing services. In the metro cities of India, the existing traffic control system is inefficient because of randomness in the pattern of traffic density during the day. Because of this, even though the traffic level is much smaller, vehicles must wait for a long time. Hence, the traffic congestion problem can be reduced if the traffic signal timer configured to be manipulated with a constant varying traffic density.

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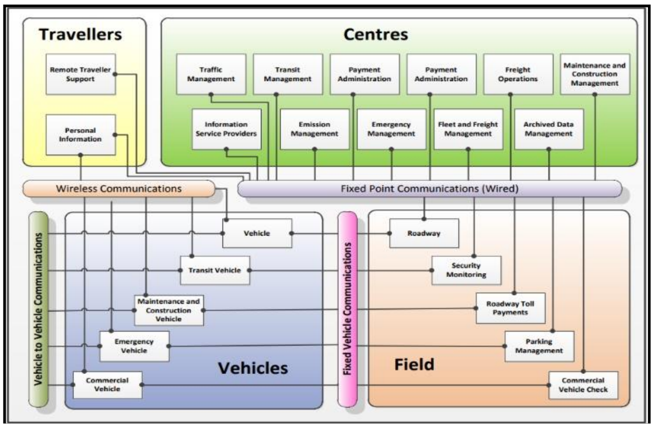

Fig. 2. Architecture of Intelligent Transport System [3]

III. ADAPTIVE TRAFFIC CONTROL SYSTEM FRAMEWORK

The ATCS algorithm continuously changes traffic signal timings based on the demand for traffic at the intersections and projected arrivals from neighboring intersections [4]. It greatly enhances travel time by pushing vehicles steadily through green lights and reduces congestion by creating smoother flow. Using image analysis and signal processing, the proposed method alters the traffic light timer based on random traffic congestion. This framework employs enhanced high-resolution cameras feeds and a closed loop control system to identify dynamic traffic patterns across the junction and to govern the traffic appropriately by transmitting signals to the timer control module [5]. Traffic congestion depends directly on the regulation of the traffic flow and thus on the timer of the traffic signal. As a result of this phenomenon, vehicles have to face an irregular pause during travel in metropolitan areas. At currently, traffic signals as an open-loop control system with no feedback loops [5].

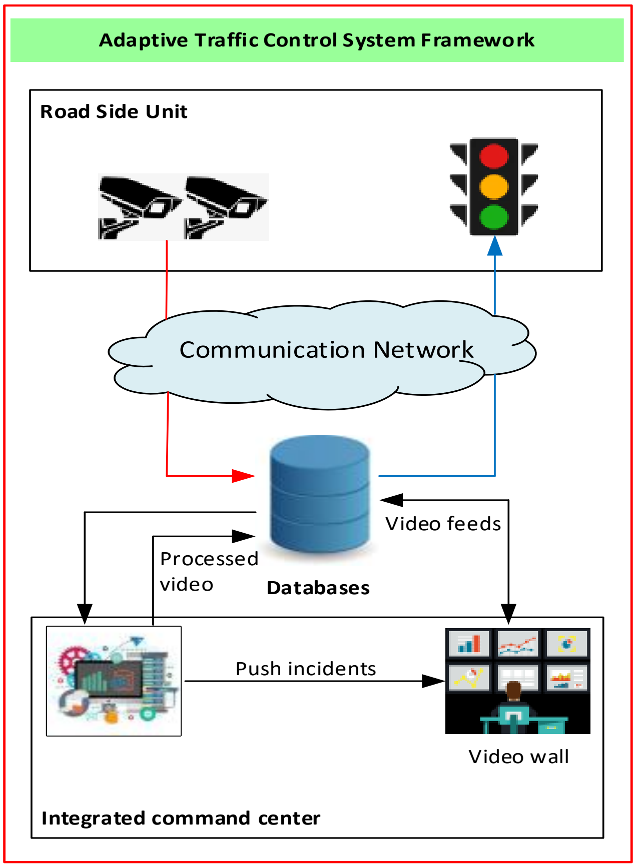

Fig. 3. Overview of ATCS framework

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The goal of this work is to enhance the traffic control system by adding a sensor that directs input to the pre-existing system so that it can respond to evolving patterns of traffic flow and provide the control system with the required signals in real-time. Our key aim is to optimize vehicle transit delays in irregular hours of the day.

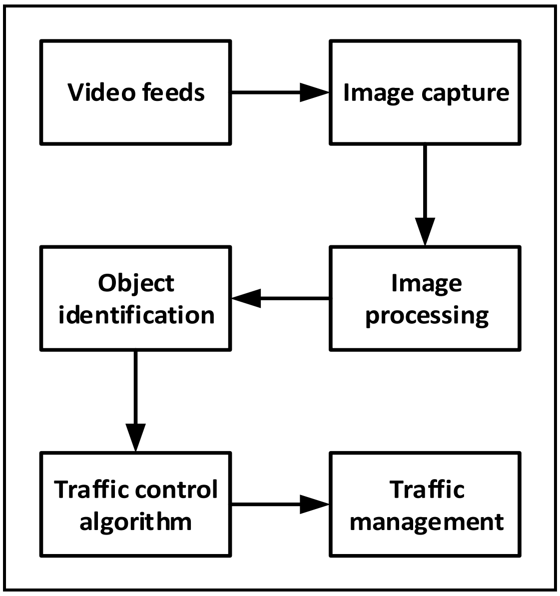

Fig. 4. Sequence of steps for ATCS implementation [7]

The approach suggested in the paper consists of bifurcating the problem into two sub-sections, first of which is to calculate traffic volume using classifiers under the Viola Jones Object Detection System [6]. Encompassing OpenCV libraries, real-time traffic volume estimation was obtained. In contrast to other libraries, OpenCV was selected for effective and consistent operation in real-time projects [6]. The second sub-issue included the development of a control algorithm to overcome traffic congestion.

IV. Implementation of ATCS Using OPENCV

To optimally overcome traffic congestion, call to trigger traffic signals needs to be based on concurrent results. As part of adaptive traffic management, the following steps are followed.

A. *Acquisition of video feed:*

The traffic algorithm is intended to control 4-lane and 2-lane road junctions. This includes acquiring video feeds from various ANPR cameras and manipulating the feeds by suitable algorithms and filters. The video is obtained via the automated processes supported by Direct Display (DShow) techniques from OpenCV. The employment of Dshow helps us to process range of feeds at comparatively higher processing speeds than other methods. The camera feeds are processed in the Integrated Control Center with the aid of big data as a backend technology.

B. *Processing of video:*

Preprocessing of video is achieved by the recurrent trials of the techniques of image processing to the frames. Video inputs from various cameras are collected and analyzed frame by frame in real-time, and the loop is iterated before the user wishes to interrupt it. Video preprocessing methods are essential to enhance efficiency and precision for the calculation of traffic flow. Initially, the video frames are transformed to the Gray scale from the RGB color mode. The channel colors are translated to matching gray intensities. Previous process decreases the volume of data to be processed and thus improves the speed of process. The Histogram is equalized for all video frames in the second level of pre-processing [8]. The equalization of the histogram results in an image of considerably greater contrast and does so by extending the image scale distribution [9]. The histogram represents the pixel intensities of the image with the corresponding values [10].The expected outcome is reached when the picture is first transformed to a gray scale and the histogram is equalized so as to increase the probability of an object being recognized.

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Fig. 5. Processing of digital image by OpenCV

C. Recognition of specific object:

The classification algorithm for recognizing objects, in this context vehicles, was built and trained using the Open CV development kit. In order to detect elements, the cascaded classification algorithm, consisting of several phases of other simple classifiers, uses Haar-like features [11]. With 500 positive samples and 1000 negative vehicle image samples, the classification model was trained. The classifier has been checked on the research samples and the outcome are seen in below table.

TABLE I Performance of system for object detection

Vehicle type	**Detected**	**Not detected**	**Accuracy**
Cars	40	3	93%
Bikes	52	3	94.5%
Trucks & Buses	48	2	96
Ambulances	15	1	93.7%

The output of the system in real-time is presented in the video wall of the ICCC platform for traffic monitoring and to extract beneficial information for decision making by authorities.

Fig. 6. Recognition of vehicles in OpenCV

D. Extraction of data:

Extraction of data from images refers to the acquisition of information which is essential to our specifications from video feeds. It is possible to extract different variables using different techniques. Direction, Shape, Height, centre of object, Orientation, Overall Count, etc. can be the relevant variables in the case of object recognition. We would require the number of items identified for analysis, which could relate to the count of vehicles at the path of traffic intersection. It will take into account the total number of vehicles recognized. For the decision of the appropriate action, count of the vehicles at the junction shall be fed to the system.

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Fig. 7. Extraction of data (Vehicle count) in OpenCV

E. Algorithm for traffic control:

When supplied with data, the control algorithm is responsible for regulating traffic at the junction. The control algorithm includes simple principles for the management of traffic signals used in conjunction to minimize traffic congestion at the intersection.

The control algorithm is based on what area the vehicles are occupied frame. If traffic is greater than 80% of the total area, then maximum time tmax is allotted to the lane. If the traffic of the lane is less than 25% then minimum time tmin is allotted to the lane. Time limits shall be maintained to prevent the arrest of the system in one situation.

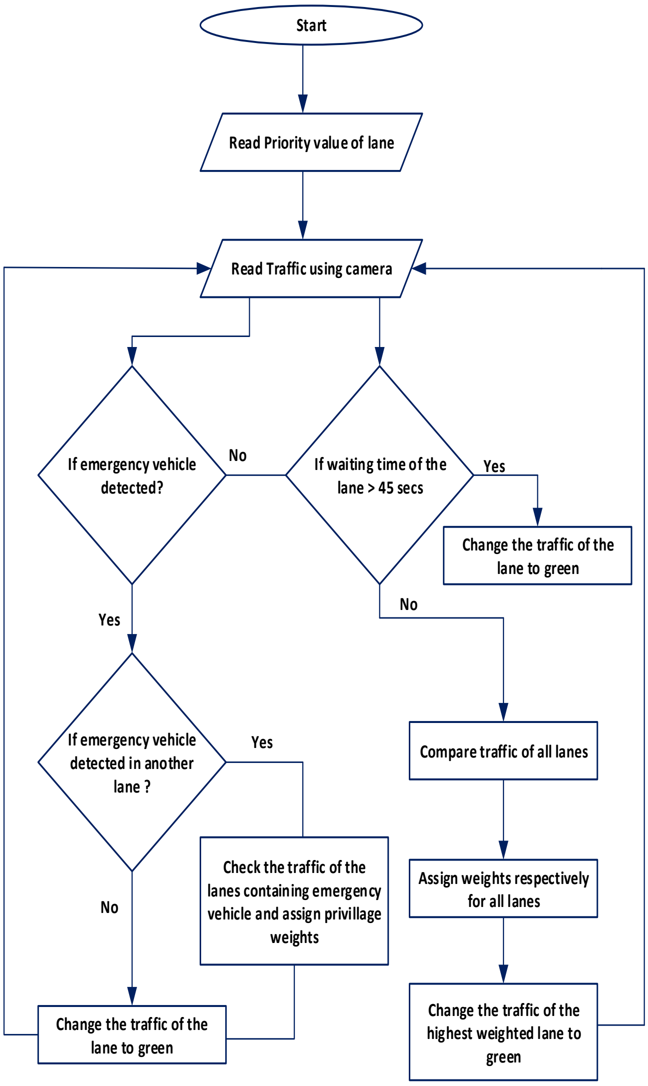

Fig. 9. Flowchart of control algorithm for resolving traffic congestion

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The final base rule aims to guarantee that all methods are granted an equal amount of opportunities for optimal use. The emergency vehicles are given a priority access, so that when the vehicles are detected, the system is overridden by special request from the subroutine and the lane which contains the emergency vehicle such as ambulance, police cars and fire trucks are given priority. Then, the flow switches back to the main routine. The dynamic timing control along with traditional way of queue-based priority method eliminates the shortcomings of the previous methods and enhances the efficiency by reducing the cycle time.

V. RESULTS AND DISCUSSION

Traffic simulation is achieved by using a framed algorithm in a 4-way path with 100 vehicles which spawn in random lanes. The size of the road is taken as 7 metres per lane and the size of the vehicles are taken as 3.5 metres x 1.5 metres. The speed of the vehicles crossing the junction is taken as 20 kmph. The Python 2.7 programs were backed by the OpenCV image processing software and its associated libraries. The picture is read from the video and translated to the colour saturation and value (HSV) form. The background is subtracted from the picture to get the image of the object of interest. The picture is transformed to binary and the subject area is measured. Sufficient traffic at each terminal of the junction was introduced over several cycles.

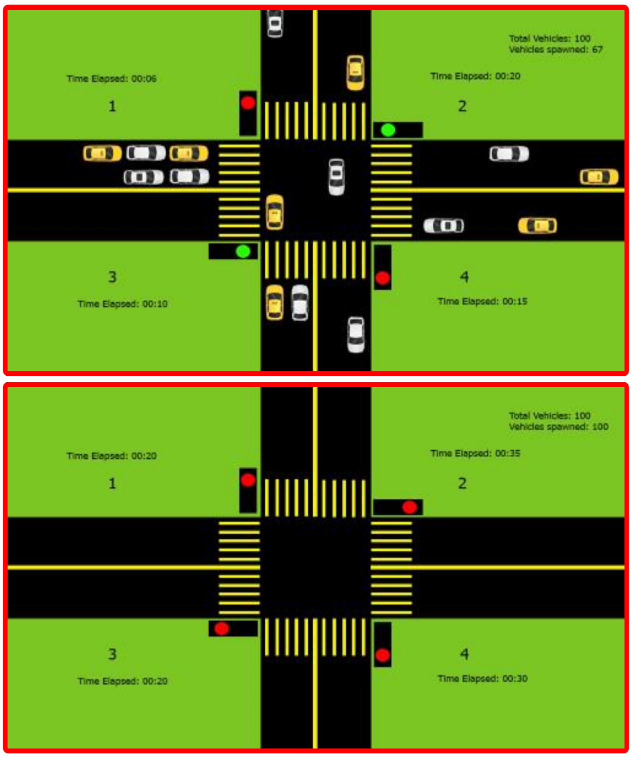

Fig. 10. Simulation of ATCS to calculate cycle time

The table shown reflects the four-way intersection timing cycle. The first two sets are the traditional methods that is programmed in fixed time traffic control systems. The last two cycles have been programmed for the ATCS system.

TABLE II Timing diagram of the simulation of 100 vehicles

Cycle	Lane 1	Lane 2	Lane 3	Lane 4	Time period
Simulation Set A Conventional	60sec	60sec	60sec	60sec	240sec
Simulation Set B Conventional	40sec	60sec	20sec	40sec	160sec
Simulation Set A ATCS	30sec	50sec	10sec	15sec	105sec
Simulation Set B ATCS	20sec	35sec	20sec	30sec	105sec

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In set A – conventional approach, the 100 vehicles are spawned in random lane and the traffic lights operate in fixed timing mode. So, the overall time to resolve 100 vehicles in for set A simulation is around 240 seconds.

In Set B, the overall time is 160 seconds in which the control algorithm employs pre-surveyed data of each lane. In set A & set B simulation when ATCS is programmed the total time of resolving the congestion for 100 vehicles is 105 seconds, which is very much less than the traditional approaches. It can be observed that within a shorter time period, the proposed algorithm resolves congestion.

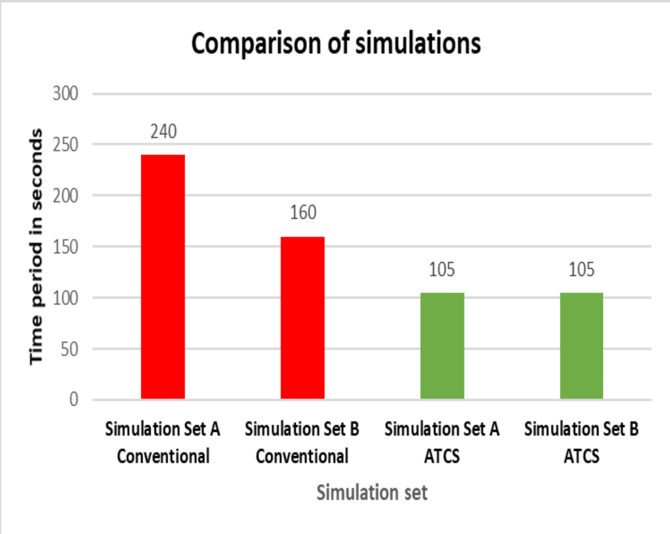

Fig. 11. Comparison of various simulation sets

VI. CONCLUSION

The key benefit of the ATCS framework for traffic management is that it is efficient and is easy to integrate. Using image processing technique, the calculation of the length of the queue across junctions can prove to be more accurate than conventional inferential sensing devices and infrared sensors. The ATCS system also help to reduce the level of noise and air pollution, resulting in low fuel consumption as well. This system shows that it can stabilize traffic in 4-way intersection squares in far less cycles than in traditional fixed time timers with less energy and maintenance. There is an immense number of developments in the modern form of an adaptive traffic control system which might include AI based image processing. The system can be significantly enhanced with the introduction of techniques such as solar operated devices and sensors, LED display boards at junctions, synchronization of all traffic signals in the city and high-resolution cameras with enhanced night vision capabilities

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