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Design of a Traffic Lane Congestion Monitoring and Control System using YOLO Neural Network Approach

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ABSTRACT
Considering the most essential component of the traffic system, the traffic signal; this study presents a traffic lane congestion monitoring and control system with the assistance of image processing. The research uses YOLO (You Only Look Once) algorithm to detect the presence of different classes of vehicles, and then determine the response of the different classes of vehicles to a defined traffic condition. The algorithm achieves this by using a dedicated signal switching algorithm to have a considerable high accuracy even at varying resolutions. The trained model had an entire system accuracy of 86%. The algorithm also has a system sensitivity of 93% and precision value of 84%. The trained YOLO model had an accuracy of up to 99% for close up high-definition images. The result acquired help in regulating green signal time in traffic intersection by providing a more efficient and accurate signal with response to density.

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INTRODUCTION

During the reign of the Roman Empire, roads became an important mode of transportation. The Roman kingdom modernized and used the road more extensively than prior usages, in which donkeys, man, oxen, camel, and horses were the primary carriers in road transportation. Roads, however, were no longer designed for pedestrians, chariots, or horses until the motor car [1]. Throughout the last few years, progression in innovation has prompted the development and production of automobiles, because the general population worldwide takes an exponential increment [2]. An ever-increasing number of endeavors are being made to guarantee less expensive accessibility of vehicles for basic man to manage the cost of it. Additionally, where the accessibility of vehicles is being encouraged, the infrastructure in many metropolitan cities in Nigeria and other developed nations is not significantly improved. Traffic clog is a significant issue, and it has become a developing concern that has led to many issues in different urban communities. Wasteful administration of traffic causes wastage of price-less time, contamination, wastage of fuel, cost of transportation and worry of drivers [3] [4].

Traffic congestion is a condition that arises on road systems, while the number of road vehicles is greater than the quantity of the vehicles that the road can handle [5]. Congestion is characterized by slower vehicle speeds, traffic time delay and lengthy wait vehicles. Traffic gridlock can be borne out from varying cause which varies from a failed traffic signal and auto which affect the constant flow of auto-mobiles The prominent reason for vehicle disruption is dysfunctional traffic signal management, which affects moving traffic hence, the need to introduce an intelligence-based traffic monitoring and control system is helpful to calculate the green signal time of various intersection. The Traffic Lane congestion monitoring and control framework considers the utilization of a high-resolution camera to gather and break down data (images) on each traffic path with the perspective of enhancing the control of traffic light. The system encourages the implementation of prioritized traffic lane congestion monitoring and control systems to provide descriptive data for traffic control and maximize traffic output by tracking and deciding based on the number of vehicles at each traffic intersection, increasing the overall traffic system performance.

This paper is sorted out as follows: Section two depicts the Literature review. Area three talk about the methodology to be utilized and four the results acquired. Finally, area five finishes up the paper.

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LITERATURE REVIEW

Traffic Signal Scheduling as a Problem of the Traffic Light System

Traffic lights play an important role in solving complex and serious urban traffic problems today. How to optimize the scheduling of hundreds of traffic lights has become a challenging and exciting problem, especially in urban development. In large cities, the possibility of construction and expansion of urban roads will be increasingly restricted by urban space. Even the traditional government idea of rebuilding existing urban infrastructure under reasonable planning can be difficult to implement in practice. The optimal distribution of traffic lights at urban intersections provides an efficient and economical way to solve the problem of traffic congestion, which has been widely recognized [6]. The key to the problem is to achieve the overall optimal planning of traffic lights, thereby comprehensively improving urban traffic conditions and accelerating urban traffic flow. Another important point to note is that many cities have hundreds of intersections under the control of traffic lights. The behavior of traffic lights at different intersections must be coordinated to achieve the common goal of optimizing traffic flow. However, programming hundreds of traffic lights is very complex and challenging which makes researchers continue to find new ways to optimize the traffic control process.

Manual Traffic Management Technique

Manual traffic management is a traffic management method that requires manpower to control traffic. It is also a method in which traffic officials are assigned to a conflicting right of-way position and use their intuition to dispatch in real-time based on traffic conditions [7]. Real-time scheduling is the advantage of manual time management [8]. Depending on the country and state, the traffic police might carry signs, traffic lights or whistles to control traffic. They will be instructed to wear specific uniforms to control traffic. However, human-related inefficiencies such as inattention, unfair scheduling, and a high probability of crashes, often render this method ineffective. The effectiveness of the system depends on the experience and skill of the individual [9].

Automatic Traffic Management Technique

To eliminate the biggest weakness of manual traffic control systems, automatic traffic management methods are recommended. This technology is based on static programming, which replaces manual labor in manual traffic management technology. The system includes traditional three-color traffic lights: red, green, and yellow. Under normal circumstances, each lane has a green light of about 60 seconds, but in some areas of the city with less traffic; at that intersection, the green light takes less than about 30 seconds. It all depends on the traffic density in that area of the city. Before the green light, the yellow light is on for about 10 seconds; it indicates that your vehicle is started and ready to move. During the whole process, the red light is on, which means that every car has stopped. The system cannot recognize emergency vehicles such as ambulances. All vehicles and emergency vehicles are treated equally. The disadvantage of the static phase scheduling of the semaphore system is its inefficiency because it uses a fixed time phase du-ration for scheduling [10]. This can lead to unnecessarily long wait times, which can cause impatient drivers to drive past even if they are not organized, which can lead to dead-locks, roadblocks and other related challenges.

Adaptive Traffic Management Technique

To improve the automatic traffic management technology to achieve effective traffic management, the duration of the dynamic phase is introduced. Longer phase durations are as-signed to lanes with the most traffic congestion (with high priority) and shorter phase durations are assigned to lanes with less traffic (with low priority). This is called dynamic phase scheduling of the traffic light system or adaptive traffic management system [8]. This applies to real-time traffic data, just like the manual traffic management method of traffic management, but manual traffic management has little or no limitations. Researchers have tested a variety of methods to optimize adaptive traffic management technology. Most methods can be divided into three parts: reducing congestion, emergencies and pedestrians. Latest and influential work is reviewed subsequently.

Traffic Management for Congestion Reduction

The design of adaptive traffic management to reduce congestion is an active research topic. Researchers around the world are inventing newer methods and innovative

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systems to solve this stressful problem. Apply mathematical equation-based models and sensor-based methods to estimate the waiting time of cars at intersections, the number of cars in the queue, the range of cars waiting along the lane, green, yellow, and the most suitable red light and efficient routing combination for the actual situation [11]. Researchers from different disciplines are collaborating to explore feasible solutions to reduce traffic congestion. Therefore, various methodologies are continuously proposed in the literature, and as many techniques as possible are implemented using the technological advancement of microcomputers, the recently manufactured equipment and sensors, and the modelling of innovative algorithms to cope with the complicated traffic lights.

[12] Proposed, an ideal place for putting smart sensors in traffic congestion. Three types of operatives are constructed in this study to accomplish the shortest possible journey time: a traffic signal control agent, a traffic detecting agent, and a traffic control operator at a junction.

Wireless sensor network (WSN) was employed by [13] carried out at a junction, and these sensors make decisions on traffic developments to minimize holding up times and standard line lengths. So that street clients are not confused, the computation provided in this framework improves traffic signal planning without modifying the requirement for the present light cycles.

In [14], an ideal system was proposed for developing a system capable of recognizing traffic signals on a smartphone platform. The suggested technology can also detect the traffic signal cycle.

[15] Presents a framework comprised of three professionals, namely traffic signal administration professionals, gridlock location professionals, and traffic signal control specialists at crossing locations. To oversee the changes in the light signals, a traffic signal administration professional is stationed at each traffic signal. Gridlock locating specialists are placed in automobiles, and sensors are installed at a few locations to collect traffic data. A crossing point's specialist is a traffic signal correspondence framework at a given convergence that receives data from the nearest gridlock location experts and determines the traffic signal cycle based on that data.

Gridlocks using RFID innovation was recognized in [16]. With the help of the internet of things (IoT) sensor, the traffic signal cycle is strongly handled based on traffic thickness to limit clog. Every car has an inactive RFID tag installed, and the sensor tracks the number of cars passing through to the next sensor.

A pheromone-based traffic control system that combines dynamic automobile rerouting tactics and traffic signal control to decrease congestion was presented in [17]. During a voyage, each vehicle's pheromone traffic deposit and pheromone intention (indicating current and prospective traffic volumes) are recorded. If there is traffic congestion, the framework employs a proactive vehicle rerouting technique. Vehicles that must be diverted are identified and offered an alternate route before accessing a congested road.

Traffic Management for Emergency Vehicles

Gridlock around the world has resulted in a loss of lives as a result of failure to deliver transportation mishap casualties, basic patients, clinical, gear, and meds on time. With the constant growth of vehicular traffic worldwide the combination of the Internet of Things (IoT) and Vehicular Ad Hoc Network (VANET) has left a promising stage for an Intelligent Traffic Management System (ITMS). Analysts proposed various arrangements in their proposals without putting into consideration how to focus on crisis vehicles when the trafficking framework is compromised due to hacking [18]. As a result, various strategies are constantly proposed and numerous procedures are carried out utilizing the mechanical advances of microcomputers, continuously produced gadgets and sensors, and creative calculations displaying, as much as possible, in the complexity of traffic signals.

RFIDs are used by [19] to identify stolen vehicles. When a stolen vehicle passes through an intersection, a text message is sent from the police station. RFID labels are used to identify emergency vehicles, and the concept of green waves (constantly receiving a green light) is used. Because of weather concerns, this instrument does not have a camera (if the climate is terrible, the picture quality disintegrates, and the picture preparation is confounded), creates an integrated framework so that every

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vehicle can communicate. Every vehicle provides data (speed) for other vehicles. The green light term is determined by the vehicle's distance from the crossing point and the season of appearance. A camera is used to count the number of vehicles, and sensors are used to identify emergency vehicles. PLCs based traffic light plan was created in [21]. RFID labels are used to identify crisis vehicles and activate crisis proto-cols. The normal sign succession is maintained under nor-mal working conditions; when the crisis convention is triggered, the condition of the gadget is changed before a crisis vehicle arrives at the convergence. When the crisis is over, the machine returns to its normal state. A control framework based on software-defined networking (SDN) and the Internet of Things (IoT) to adjust the traffic signal cycle when there is a crisis using traffic cameras as guidance was proposed in [22]. The SDN regulator communicates with the cloud to gather traffic data and organize the traffic signal cycle based on that data. [23] Employs RFID to track the appearance of ambulances at a predetermined distance. A microcontroller prepares the RFID data and changes the light sign to green when the emergency vehicle passes through the traffic signal. GPS, which is installed in the cell phones of rescue vehicle drivers, is used to send data from the phones to the cloud. Cell phones are used to confirm the emergency vehicle's crisis and non-emergency states.

TRAFFIC MANAGEMENT FOR PEDESTRIANS

The majority of pedestrian deaths in street collisions occur alongside travels in urban areas, particularly while crossing streets, where persons on foot collaborate with mechanized transportation. The investigation of persons on foot poses a risk to openness. while street crossing under various conditions along metropolitan outings may contribute to more productive and passerby-arranged execution of street con-figuration, traffic signal and intersection offices, more precise assessment of walkers' street crash hazard in metropolitan regions, and thus to the improvement of people on foot wellbeing [24]. In like manner, diverse methods are persistently proposed within the composition, and different techniques are completed utilizing the mechanical propels of microcomputers, determinedly conveyed gadgets and sensors, and imaginative estimations appearing, be that as it may much as could reasonably be anticipated, within the complexity of activity lights. In [25], an ideal system uses a fuzzy-based strategy, employing three class labels (low, medium, and high) for the flow of traffic (input) and the timing of the traffic lights (output). A rule determines the crucial time (passing time again is tight) and low priority time.

The pedestrian crossing is precedence, therefore as the number of crossers grows, so does the allotment of red-light time for automobiles. [26] Establishes a model for signal-controlled convergence reproduction that can be used to verify the adequacy of flexible control in various rush hour jam scenarios, including the presence or absence of varied pedestrian traffic, using the Monte Carlo technique. The vehicle delay, line length, and traffic signal cycles determine the pace of the incoming traffic stream and the presence or absence of passerby traffic. This investigation develops a mathematical model that handles the presentation of a crossing point with flexible control to get the average value of the traffic signal cycles that may be used, the length of the queue and the vehicle delay. A street crossing framework that uses sensors, CCTV, and illuminators to track and illuminate pedestrians to enable drivers more efficiently avoid hazardous situations was used in [27]. This framework is made up of six major com-ponents: a CCTV analyzer, which works in tandem with CCTV to track people on foot and record intersections; limit locators, which identify walkers and vehicles entering specific areas; illuminators, which illuminate intersections and allow walkers to be seen from a distance and provide light to CCTV; control units and control focus, which allow for the most accurate tracking possible and crisis reaction communities for detailing frameworks to the control place in case of a mishap. [28] Advances traffic signals so that slow pedestrians (incapable old people) may cross safely and congestion is reduced. Extra green light time is given to walkers only when a tardy passerby is identified (from the IoT gadget introduced on the lethargic person on foot).

PROPOSED METHODOLOGY

A technique for implementing a working project that is based on traffic lane congestion monitoring and control system using

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YOLO neural network consists of three modules: Vehicle detection module, Signal switching Algorithm, and Simulation module.

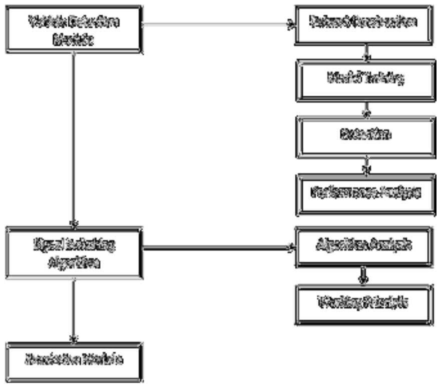

Fig. 1. Block Diagram of Methodology

Vehicle Detection Module

The Vehicle Detection Module uses YOLO (You only look once) for vehicle detection, which provides the desired accuracy and processing time. A custom YOLO model was trained using the google colab, which can detect different classes of vehicles like cars, bikes, heavy vehicles and rick-saws. The dataset training model was prepared by scraping images from the google image dataset and capturing some using a high-definition camera and labelling of the images using the roboflow framework, a graphical image annotation tool. Then the model was trained using the pre-trained weight downloaded from the YOLO website. The configuration of the .cfg file used for training was changed in accordance with the specifications of our model. The number of output neurons in the last layer was set equal to the number of classes the model is supposed to detect by changing the 'classes' variable. After making these configuration changes, the model was trained until the loss was significantly less and no longer seemed to reduce. This marked the end of the training, and the weights were now updated according to the specified requirements. These weights were then import-ed in code and used for vehicle detection with the help of OpenCV library. A threshold is set as the minimum confidence required for successful detection. After the model is loaded and an image is fed to the model, it gives the result in a JSON format i.e., in the form of key value pairs, in which labels are keys, and their confidence and coordinates are values. Again, OpenCV can be used to draw the bounding boxes on the images from the labels and coordinates received.

Signal Switching Algorithm

The Signal Switching Algorithm adjusts the stop sign timers of other lights based on the traffic volume given by the vehicle detecting module and updates the green signal timer accordingly. It also cyclically alternates between the signals based on the timers. The information about the vehicles observed by the detection module is fed into the algorithm as input. This is in JSON configuration file, with the key being the identified vehicle's label, and the values being the confidence and coordinates. The total number of vehicles in each class is then calculated using this data. Following that, the signal's green signal time is calculated and assigned, and the red signal intervals of other signals are altered as necessary. Any number of signals at an intersection can be scaled up or down using this approach.

$$GST = \sum_{vehicle\ class} \frac{(No\ of\ Vehicles_{vehicle\ class} + Average\ Time_{vehicle\ class})}{(No\ of\ Lanes\ + 1)} \qquad (1)$$

The default time for the first signal of the first cycle is established when the algorithm runs for the first time, and the algorithm sets the times for all other signals of the first cycle and all signals of subsequent cycles. The detection of vehicles for each direction is handled by a different thread, while the current signal's timer is handled by the main thread. When the current signal's green light timer (or the subsequent green signal's red-light timer) reaches zero seconds, the detecting modules take a picture of the next direction. The result is then parsed, and the timer for the next green signal is set using equation 1. While the main thread counts down the current green signal's timeout, all of this occurs in the background, while the task scheduler counts down the current green signal's timeout. This enables for a seamless timer assignment and hence eliminates any latency. The following signal be-comes green for the period of time defined by the algorithm whenever the current signal's green timer reaches zero. If the time of the next green signal is zero seconds, the image is captured. This provides the algorithm a total of 5 seconds (equal to the Yellow Signal Timer value) for

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image processing, for detection, for green signal time and for setting the time of this signal, as well as for the red signal times of subsequent signals and also the number of vehicles of each class present. The average speed of vehicles during start-up and their acceleration times were used to find the optimum green signal times based on the number of vehicles in each class at a time of signal, which showed an estimation of how long each class of vehicle takes to pass through.

EXPERIMENTAL RESULTS

A 416 x 416-pixel picture is used to train the model, and the batch size is set to one to match the image's resolution. When testing the YOLOv5 model, it was able to identify distinct types of vehicles in the test data set. There are three curves displayed for the detected cars: precision, recall, and precision-recall and they are illustrated in figs 2, 3, and 4 respectively. Under the default parameters in figs 2, 3, and 4, we discover that due to the usage of tiny data sets, the findings are not as impressive as they may be.

Precision Evaluation

According to fig 2, the accuracy ranges from 0 to 1. As the level of confidence grows, so does the precision. Also, the precision may be arbitrarily enhanced if the degree of confidence is high enough. 96% accuracy was achieved.

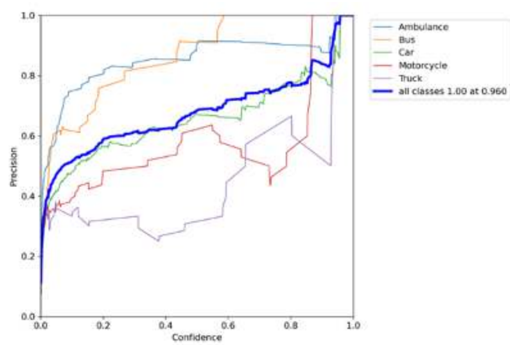

Fig. 2. Precision result of the various classes

Recall Evaluation

On the recall graph (fig 3), it is evident that the recovery ranges from zero to one. As the confidence level grows, it lowers. As well, it has been shown that recall is possible as long as confidence levels are low. In addition, 62% of the recall's outcomes was achieved which is a good one.

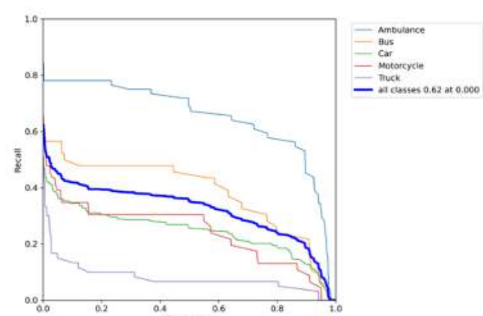

Fig. 3. Recall result of the various classes

Precision-Recall Curve Evaluation

Accuracy recovery curves may be created by graphing confidence values between 0 and 1 together with accuracy values along y-axis. Fig 4 shows the results of the PR curve. This indicates that the accuracy and recovery rate are both extremely high when the confidence level is very high (less than 1.0), but

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the recovery rate is virtually 1.0 when it is very low (0.01 or more). The proportion of positive samples in the data set is the same. The ideal classifier's accuracy recovery curve is attained.

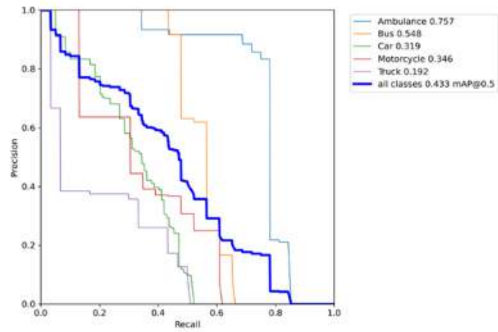

Fig. 4. PR curve of the various classes

YOLO- Automobile visualization

The YOLO- Automobile visualization results in fig 5 and 6 were carried out to view the detected vehicles with their confidence score. The improvement in the model performance can be seen as the missed vehicles detections in fig 5 before modification is found in fig 6 with an increased in percent-age detection.

Fig. 5. Result of automobiles with low confidence score

Fig. 6. Result of automobiles with high confidence score

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Signal Switching Algorithm

Following are some images of the output of the Signal Switching Algorithm:

1. Initially, all signals are loaded with default values as shown fig 7, only the red signal time of the second signal is set according to green time and yellow time of first signal.

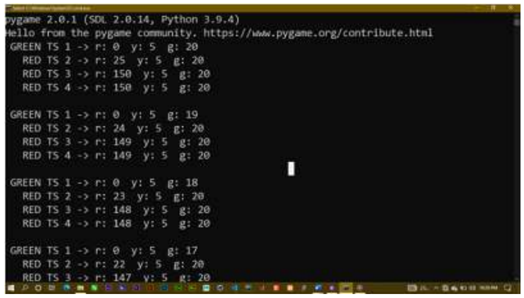

Fig. 7. Default value been set.

2. On the left-hand column, you'll see a signal's current state (red, yellow, green), followed by its number and the red, yellow, green timers that are currently active. This happens when the traffic signal 1 (TS 1) goes from green to yellow (see fig 8). According to the findings of the vehicle detection algorithm, the green light time for TS 2 is 9 seconds. The green light time for TS 2 is set to 10 seconds since this number is less than the lowest green light duration out of 10 possible. At zero, TS 1 goes red, and TS 2 turns green, and the countdown resumes. It is also updated to the second total of the yellow and green signals from TS 2, i.e., 5 + 10 = 15 for TS 3. It is also updated to the second total of the yellow and green signals from TS 2, i.e., 5 + 10 = 15 for TS 3.

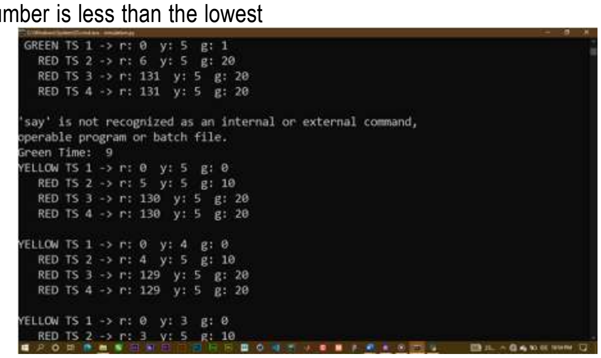

Fig. 8. Switching from signal 1 to signal 2.

Simulation Module

Pygame a simulation software that helps in providing a perfect replica of the system using a GUI (graphical user interface) that mimic the behavior of a real-life system.

Following are some images of the final simulation:

1. Red and green lights are shown in fig 9, together with the green signal at the start of simulation. The default countdown timer is set to 20 seconds, and the next blank signal is shown by a red timer. When there is a signal until the timer hits 10 seconds. Each car, which started off at 0, is now represented by a number next to the sign. In the upper right corner, you can see how long it has been since the simulation began.

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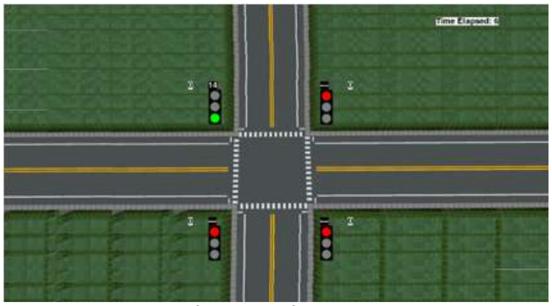

Fig. 9. Default timer for initial process.

2. Simulated yellow light and red time for the following signal are shown in fig 10. So those cars may start up and be ready to drive as the signal turns green, we show the countdown counter when the red signal period is less than 10 seconds long.

Fig. 10. Simulation showing yellow light and red time for next signal.

3. According to the cars traveling in that direction, fig 11 displays a simulation demonstrating the green time of signal for vehicles heading up set to 7 seconds. Compared to the other lanes, we can clearly observe that the number of cars is much lower in this lane. It would have taken 30 seconds to get a green signal on every light if the present static system had been in place That time would have been mostly squandered, however, in this particular scenario A few cars are detected by our adaptive system, which adjusts the green time accordingly, in this example to 7 seconds.

Fig. 11. Simulation showing green time signal for moving vehicles.

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CONCLUSION

The design of traffic lane congestion monitoring and control system was successfully achieved using YOLO (You Only Look Once) algorithm for detection and Google Colab for teaching various kinds of cars and Pygame for Graphical User Interface (GUI) simulation. The system can adaptively set the green signal time according to the traffic density of the signal, assigning a long-time green signal to the direction with high traffic compared to the direction with low traffic. This reduces unnecessary delays, reduces congestion and waiting times, and reduces fuel consumption and pollution. The system was developed according to the system goals. The model was able to identify vehicles of various classes, and did not misclassify surrounding objects such as cars. The overall performance evaluation of the YOLO model indicated a 43% for mAP, 96% for accuracy and 62% for re-call. Finally, the use of images of cars taken from very close distances improves the confidence level of the system, which in turn improves the confidence scores of the vehicle detection algorithms

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