Smart Junction: IoT and Image Processing Based Traffic Monitoring and Managing System

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Abstract - **The number of vehicles on the road at a time is increasing rapidly these days. This generates a heavy traffic queue on the roads hence a proper traffic management system is needed to manage those traffic queues and most of the current traffic queues are handled by manual traffic management systems. That will require more human interaction and can lead to an increase in the stress level of the controllers, low efficiency in responding to emergency situations and will lead to more human errors. Considering the current traffic management scenarios, this research helps to enhance the road safety by developing a smart junction that has the embedded systems of junction coordination and synchronization by controlling traffic lights, emergency vehicle detection and prioritization, rule violation incidents and vehicle accidents identification and a safe pedestrian crossing system controlled based on dynamic factors. This study uses a Convolutional Neural Network (CNN) Network Architecture with Internet of Things (IOT) devices to automate the system. The significance of this research is that this will help to enhance overall road safety.**

Keywords: Convolutional Neural Network, Internet of Things, synchronization, ambulance detection, rule violation, accidents identification, pedestrian crossing.

I. INTRODUCTION

Urban areas face significant challenges in managing traffic congestion and optimizing traffic light control systems. The increasing vehicle density and reliance on manual traffic management systems have led to delays and potential risks, particularly in managing traffic near intersection areas. Over 1.35 million people lose their lives in vehicle accidents every year. Injuries that are not fatal affect between 20 and 50 million people because of these incidents. The difficulty lies in lowering the death rate from accidents[1]. The key components of the study include detecting vehicle crashes and rule violation incidents on the roads, coordinate junctions with synchronizing traffic light control, dynamically coordination of junctions to prioritize the ambulance service and pedestrian crossing system for pedestrians to cross the road effectively which directly affects reducing traffic accidents. The study ensures to develop a smart junction that minimizes traffic congestion and enhances road safety.

Junction Coordination is an important component which is discussed in most traffic control related studies. This component uses image processing technology to create a method that synchronizes interconnected junctions with traffic lights to dynamically allocate time to pass those intersections according to the vehicle count. This component can reduce vehicle traffic congestion and manage the flow of vehicle traffic. It will be measured with dynamically changing variables like the density of vehicles, travel time and waiting time. The other part was developed to give priority to Emergency vehicles such as ambulances. When they are stuck in an urban area which has a higher traffic density with several traffic light intersections, the proposed system will let the ambulances pass those intersections. In this system, there are registered and unregistered ambulance users. Unregistered ambulance users will be identified by the image processing algorithms and control the traffic lights to give priority in the traffic queues. The significance of this research component is that ambulances who registered for the service will get the chance to reach their destination without getting stuck in traffic queues. This will help to save lives in emergency situations and minimize the emergency vehicle accidents.

The system was also developed to enhance the pedestrian crossing in the junctions. Pedestrian crossing timer will dynamically change according to the normal pedestrian and the disabled pedestrian count. By implementing such components, it will help both disabled and normal pedestrians to cross the roads safely. And this system consists of vehicle crash and rule violation detection process. These systems for vehicle crash detection, rule violation detection, and pedestrian crossing detection will capture real-time data from cameras which were located on the roads. It will automatically identify objects and incidents using image processing technology. In accident detection, it will identify accident incidents and get the accurate accident location. In the rule violation detection, it will get the rule violated vehicle number and violated rule policy. This data will display in the central

dashboard which is monitored by the authorities. This process will decrease the death rate of vehicle accidents, automate the traffic monitoring, and enhance the road safety.

Considering the current world scenarios, authorities will use manual traffic management systems to control the traffic. That will reduce the efficiency and effectiveness of traffic management. Hence, a fully automated system such as the one implemented in this study holds significant importance in augmenting road safety.

II. LITERATURE REVIEW

During cases of emergencies, emergency vehicles, especially ambulances, are generally used to provide transportation and medical assistance to people in need. But even during such scenarios, there are high possibilities of the ambulances being blocked up in traffic queues. When the issues related to emergency vehicles being stuck up in the traffic queues are considered, there are a few approaches suggested by the existing literature. One approach involves the use of image processing technology and real-time data analysis to detect emergency vehicles [2][3][4][5] and optimize traffic light timings[6]. Another research uses WSM Radio waves allow emergency vehicles to communicate with traffic light networks to make the lights green so they can pass intersections safely[7], IOT technology is also a widely used method to control traffic light systems to handle emergency vehicles with the use of RFID sensors, but still there is no system which can guide an ambulance until it reaches its destination such as a hospital, without being stuck at the traffic queues or without being delayed due to the traffic congestions and without being involving in accidents at the road. This existing research primarily focuses on individual intersections[8]. This is a problem which must be taken into consideration as human lives are very precious and even delays by fraction of seconds can be the cause of the loss of such valuable lives.

Considering the current manual traffic management and vehicle rule violation detection systems, most of them are controlled by humans and fixed timed. So, it can result in more errors while leading to the increased stress levels of the controllers. Moreover, those systems lack the efficiency to identify rule violations and have a less accuracy to respond immediately to vehicle accidents. There is an existing research outcome to identify rule violation incidents such as jumping on the redlight, not wearing helmet on the road, and not wearing seat belts inside a vehicle by using YOLOV3 and Darknet-53 techniques. Even though that existing system can identify rule violations, that is not upgraded to identify vehicle accidents[9]. Identifying the vehicle accidents are very much important to save the lives whereas the identification of rule violation incidents and to make the relevant authorities aware about the incident are equally important to avoid the possibilities of accidents being caused in future. Enhancements are needed to identify vehicle accidents, minimize casualties, and enhance overall road safety.

When the incidents of rule violations are considered, most of the rule violation incidents occur at the pedestrian crossings. Rule violations and accidents often occur at pedestrian crossings due to delays experienced by both pedestrians and drivers[10]. Existing traffic light systems typically rely on fixed timers, which can contribute to inefficiencies[11]. Previous research suggests the use of dynamic timers and sensor data to improve pedestrian crossings. However, these suggested systems are considered inefficient due to the factor such as the controlling of dynamic timers based on the data collected by sensors are not much accurate due the fact that the sensors are less reliable in data collection and moreover, this method is not much cost efficient and therefore it is not much scalable and requires huge funds to be implemented in large scale. When the total world population is considered, about 1 billion people (almost 15% of the world's population) experience disability but still, there is no inbuilt mechanism to assist the disabled people in the usage of pedestrian crossings just like the normal people[12]. Most of the previously available literature suggests the usage of external hardware devices or mobile applications particularly for differently abled individuals but not all the differently abled people are able to afford them. However, there is still a lack of an all-in-one embedded system that addresses both dynamic traffic control and facilitates the use of pedestrian crossings for differently abled individuals[13].

Further research is necessary to develop comprehensive and scalable traffic management systems. Coordinated control systems that address the challenges of interconnected junctions, scalability, communication, and adaptability are essential with prioritizing emergency vehicles. Additionally, efforts should be made to integrate incident detection and reporting mechanisms into automated traffic management systems, enabling effective rule enforcement and efficient pedestrian crossing management while enhancing road safety. By addressing these vehicles and advancements in traffic management can be achieved to mitigate congestion, prioritize emergency vehicles, and improve overall traffic flow.

III. METHODOLOGY

The overall architecture of the proposed system is indicated in the system diagram provided as follows with its components depicted separately.
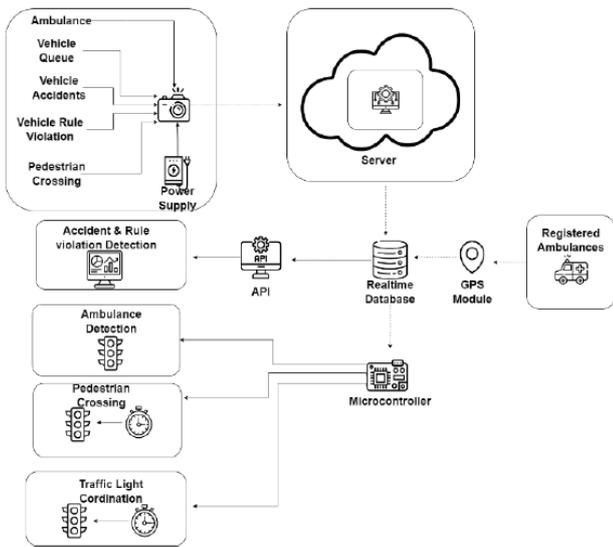
Figure 1: Overall System Diagram

A) The ambulance detection and prioritization system

In the ambulance detection and prioritization feature, it will provide the service for two kinds of ambulances. This prioritization feature can be applied to both registered and non-registered ambulances in the system. In case of registered ambulances, first, an ambulance must register to the system to get this service. After the registration they will receive a GPS Tag for the ambulance. Then whenever they need to go to a hospital in case of an emergency, the destination expected to be reached by the driver must be selected and submitted via the mobile application. After submitting the destination to the system, the ambulance can proceed moving towards its destination. When the ambulance arrives at the first traffic light, it will be identified by the GPS Module on the ambulance and then it will get to the relevant destination from the system. A database of choice on the cloud will be updated with the location of the ambulance instantaneously. The locations of the traffic light intersections are always fixed in practical scenarios. Hence, once both ambulance's location and the traffic intersection's location are same, it will trigger a Firebase Realtime database state and a signal will be sent to the relevant IoT device which is located at the traffic light intersection to control the traffic lights. Then, it will green the traffic light to pass the intersection. Then the interconnected traffic lights will communicate the route that ambulance needs to follow. After that it will turn every traffic light intersection to green in that route to reach the ambulance to its destination.

The other system will work for any kind of ambulance. It does not matter if they are registered or not. They do not have to get registered with the service to use it. When an ambulance comes near to a Traffic light intersection it will be recognized by the camera, which is fitted on the traffic light. It uses image processing technology to recognize the ambulance. After recognizing the vehicle as an ambulance, it will immediately turn the green light on to pass that intersection.

B) Adjacent junction synchronization and coordination

The methodology of Adjacent Junctions' Synchronization and coordination with traffic light control research component aims to address the main objective of coordinating junctions with traffic light control using real-time data and image processing technology. To achieve this, a combination of hardware and software components will be employed. The specific objectives will be followed for the methodology implementation. Firstly, image processing techniques will be utilized to detect vehicle density by analyzing real-time data captured by cameras. This information will be crucial in determining the appropriate green light timer. Secondly, dynamically changing factors such as travel time, congestion, and safety will be analyzed to further refine the green light timer calculation. These components will play a significant role in optimizing traffic flow in urban areas.

The following equations will be used to calculate how much the green light time must be assigned to a particular lane in the main Junction and adjacent junctions. These values will be calculated by using respective variables such as the total vehicle count and the number of lanes. Also, the maximum time that can be assigned to the timer must not exceed the value of 90 seconds.

Equation for the main junction:

$$T = [[(VCL1 + VCL2) * L]/S] + 5$$

T – Green-light timer
VC_{L1} – Vehicle Count in Lane 1
VC_{L2} – Vehicle Count in Lane 2
L – Average length of the vehicle
S – Average speed of a vehicle
(+5) – Extra time

Equation for the adjacent junction 1

$$T = \left[\frac{[(VC_{L1}) * L]}{S}\right] + 5$$

Equation for the adjacent junction 2

$$T = \left[\frac{[(VC_{L2}) * L]}{S}\right] + 5$$

The proposed smart traffic light control system will consist of several hardware components, including microcontrollers for inter hardware communication, traffic light modules for simulating traffic lights, cameras for capturing real-time data and a Wi-Fi module for wireless

communication. Additionally, digital displays will be used to display the calculated timers, while a computer will serve as the central traffic control unit. The hardware setup will be connected using a breadboard and jumper wires, powered by batteries. On the software side, the Arduino IDE will be used for programming the microcontrollers.

Figure 2: Sample structure of the connected junctions

When the vehicles arrive at the main junction the vehicle count will be calculated using image processing technology. The vehicles will be detected in separate lanes and get the separate lane vehicle counts as Lane1count and Lane2count. To decide the main junction green light timer, both counts will be used as mentioned in the equation. Lane1count and Lane2count will be used to calculate the Junction1 and Junction2 green light timers even before the vehicles approached the sub junctions.

Image processing techniques that are implemented using programming languages such as Python and OpenCV, will be employed to detect vehicle density. These algorithms will analyze the captured images and provide valuable insights for traffic light control. Additionally, simulation software will be utilized for testing and evaluating the proposed system's performance. The efficiency of the proposed approach can be assessed by implementing and evaluating the traffic control system in practical and simulated environments.

C) Vehicle accident detection

For the sake of the research, the authors assume that CCTV cameras are placed right in front of vehicle lanes in a junction. Those real time data will be uploaded to a cloud system. In the cloud virtual environment, the image processing technique is used to detect vehicle accident incidents according to real time data. Vehicle accident data sets were gathered from Kaggle and RoboFlow. Those vehicle accident data were labelled, annotated, and pre-processed using the RoboFlow platform. In the preprocessing stage we augmented the images by flip, exposure, rotating 90 degree and 180 degrees in RoboFlow. Nearly 5000 images were used to train the model. 80% images for train, 15% images for valid and 5% images were used test in preprocessing the dataset. The YOLOV8 model was trained using the google Collaboratory virtual environment.

The output data such as accident location and the accident took time will update in the firebase real time database. The central dashboard will call an application programming interface (API) and display the updated output. This automated process will help the authorities to identify vehicle accident incidents and get immediate actions to minimize the death rate of the vehicle accidents.

D) Vehicle rule violation detection

In this research component, we used YOLOV8 tracking model to detect the objectives in Rule violation incidents such as jumping on red lights and wrong direction driving. OpenCV, TensorFlow and PyTorch libraries are used to develop python codes. In this system we collected data from allocating cameras in different angles on a junction.

In jumping on red lights, the system will check the traffic light state. This will identify using the OpenCV. On the video footage image, we draw pre-defined virtual lines. If the traffic lights are red, it will check whether the line near the traffic light has passed or not. If the line is passed, the system will identify the rule violation incident and get the line crossed vehicle number. Then the vehicle number will update the firebase database and display in the central dashboard with the violated rule. In the direction violation, the system will check the lanes frequently whether the lane is crossed or not. If a lane crossing incident is detected, the system will get the direction violated vehicle number, violated rule, rule violated time and location will be sent to the firebase database. Finally, those output data will display in a central dashboard. This automated system will reduce the stress level of traffic management authorities and increase the efficiency and effectiveness of traffic management.

E) Pedestrian crossing controlling based on image processing technology

This feature mainly focuses on controlling the pedestrian light timer according to the real time data with the help of image processing technology. When the methodology of this system is taken into consideration, first the images of the people at the pedestrian crossing will be captured using the web camera installed at the pedestrian crossing and these cameras will be fixed at a higher angle to cover a larger distance. This plays an essential role in obtaining real time data with great clarity within the assigned time intervals. Then, the captured real time images will be uploaded to the image processing algorithm using the Node MCU module.

The Yolo V5 algorithm is used to train the datasets to detect the density of people at pedestrian crossings and this would be the major software requirement to develop the system. After the identification of the people's density at the

pedestrian crossing and the identification of differently abled people at the pedestrian crossing, the green light timer of the traffic light will be calculated accordingly based on these dynamic factors such as the density of the people at the pedestrian crossing and identification of any differently abled people at pedestrian crossing.

The traffic light module is programmed to act according to the dynamically calculated time updated in the firebase. When the time to display the green light is considered, according to the previously written literatures, it is evident that the time taken by the people to cross a pedestrian crossing depends on the length of the intersection as well as the mean walking speed of the people. The mean walking speed of the people mainly varies according to the age of people, but still even the age of a general age group varies according to different countries [14].

As per the factors such as the mean walking speed and the length of the intersection, a set of standards is used to calculate the time given to cross the road for normal people and an extra amount of time will be allocated if any differently abled people were identified. And then the calculated time will be sent to the micro controller and will be displayed in the timer.

The implementation of this system will probably vary according to the countries where this system is intended to be deployed as the mean walking speed of people, the traffic flow rates, length of intersections and some other factors affect the time to be allocated for the displaying of the green light, which enables the pedestrians to cross the pedestrian crossing. The time will be calculated as ten seconds for five or less people irrespective of normal or disabled, and one second extra for each normal person as well as two seconds extra for each differently abled person.

IV. TESTING

The functionality and efficiency of the proposed Smart Junction system were thoroughly assessed during the testing phase of the proposed research. Each element was properly evaluated using controlled trials and simulated scenarios.

Various ambulance routes and traffic scenarios were used to evaluate the Ambulance Detection and Prioritization System, assessing response times and ambulance passage success rates. The Adjacent Junction Synchronization and Coordination was assessed, demonstrating its capacity to improve traffic flow and reduce congestion in various traffic scenarios. The Vehicle Accident and Rule Violation Detection system's accuracy in incident detection and reporting was confirmed using scenarios involving accidents and rule violations. Real-time video footage is used to test the rule

violation detection system. It successfully identified the red-light jumping rule violation incident with a higher accuracy. Shown in figure 3.
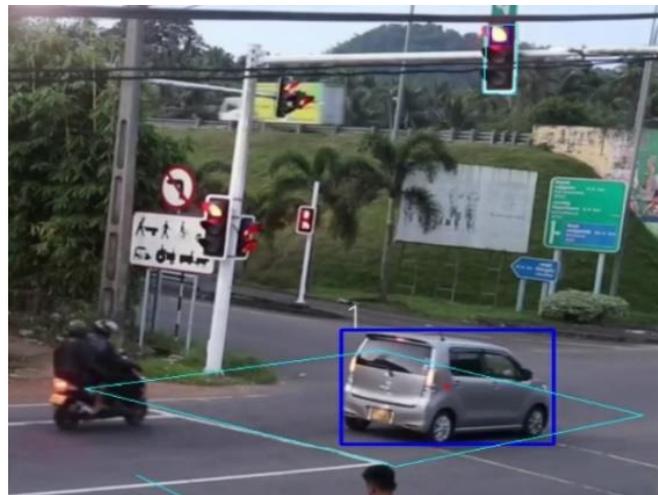

Figure 3: Red Light Violation Detection

Direction rule violation incident identified successful for the input video footage. The rule violated vehicle number, location and time will be updated in the firebase database without any delay. Central dashboard will display updated data in the firebase database. Cordiantes of the virtual lines can be changed according to the location of the real time video footage. Show in figure 4.
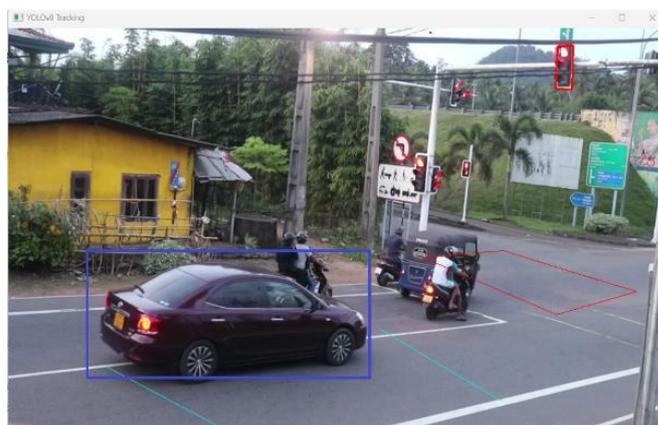

Figure 4: Direction Violation Detection

The ability of the Pedestrian Crossing Control system to change crossing timer based on current pedestrian density was demonstrated during testing with pedestrians who were both normal and differently abled. The diagram shown in figure 5 indicates the test case of how the time allocation happens when there are five normal pedestrians and one differently abled pedestrian in the pedestrian crossing.

Figure 5: Test case

To ensure smooth coordination between the system's numerous components, the interactions of the entire system were analyzed through an integrated test. These tests collaboratively proved the system's capability to improve traffic management, increase emergency response, and improve road safety, validating the contributions and importance of this research project.

Figure 6: Emergency vehicle detection

This is a sample image of an ambulance which is put to the image processing model. It was detected successfully with the accuracy rate of 95%.

Figure 7: Separate lane vehicle detection

The developed system of junction synchronization was evaluated using sample images captured from video feeds in a junction. The YOLOv5 object detection model accurately detects vehicles in both lanes the images, with over 90% average accuracy. Shown in Fig.7. This model is used to get the vehicle counts for the synchronization of the connected junctions. A prototype was developed to simulate the traffic lights and to display timer values in main junction and connected sub junctions.

Figure 8: Prototype of junction synchronization system

V. CONCLUSION AND FUTURE WORK

This research study proposes a comprehensive and innovative strategy to reduce traffic congestion and improve road safety in urban settings. The study provides a comprehensive framework with a major component and associated subcomponents by integrating image processing technology, machine learning, and advanced coordination systems. The goal of this research on "Smart Junction: IoT and Image Processing based Traffic Monitoring and Managing System" is to enhance pedestrian safety, optimize traffic flow, and improve emergency response through ambulance prioritizing. The research makes a substantial contribution to reducing traffic, lowering dangers, and improving road safety in urban settings through these novel approaches. Innovative future developments for the system include integrating synchronized mobile applications for real-time traffic updates, enhancing public awareness and decision-making. Expanding the ambulance detection and prioritization system via a cloud-based network could broaden connectivity with various devices. The vehicle crash and rule violation detection component could evolve to identify more violations like mobile phone use while driving, functioning efficiently even in low light. Merging pedestrian system control with existing technologies like pedestrian flashing red systems, as seen in Japan, would bolster safety. These forward-looking ideas signify the potential for broader impact on traffic management, safety, and urban mobility.
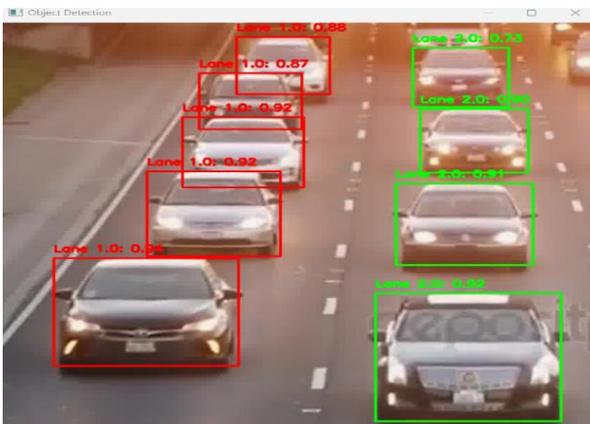
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