Safe Tracker - Combines Road Safety and Tracking Capabilities using Computer Vision

C.Pabitha[1], A. Prathija[2], V. Shamritha[3], R. Vignesh[4]
[1,2,3,4]*UG, SRM Valliammai Engineering College, Kattankulathur Chengalpattu, India*

***Abstract*—In urban areas, traffic management and road safety are crucial issues. The objective of this project is to create a system that leverages AI and computer vision (specifically YOLO) alongside IoT-based sensors to identify road hazards and uphold traffic regulations. The system identifies and classifies potholes by estimating their depth, detects waterlogging, and evaluates the risk of electric current leakage through electrode-based sensing. Moreover, it tracks the use of high beam lights in areas that are already illuminated, employing an LDR sensor for this purpose. In cases of infringement, it produces challans and sends them via email. In order to assess road damage, the system categorizes potholes by severity and adjusts traffic routes accordingly, utilizing the Google Maps API. The system improves road safety by detecting vehicles that violate red signals and ensuring compliance, through the integration of traffic signal analysis. A Raspberry Pi equipped with a camera module is used for real-time video analysis, while an Arduino Nano is employed for sensor-based detections. With this solution, authorities can efficiently and economically keep an eye on road conditions and traffic offenses, thereby lowering the incidence of accidents and damage to infrastructure. By combining AI-based visual methods with IoT sensors, a dependable and scalable method for managing urban traffic is guaranteed. The suggested system aids in enhancing road safety, optimizing traffic flow, and facilitating efficient law enforcement**.

***Index Terms*—Pothole detection, Waterlogging detection, Depth estimation, Traffic rerouting, High beam light detection, YOLO**

I. INTRODUCTION

This project concept was devised by us to tackle serious traffic management and road safety issues through the use of sophisticated technologies. Our proficiency in computer vision, IoT, and machine learning made us aware of the possibilities for real-time detection of potholes, waterlogging, and traffic violations by combining these technologies. The occurrence of frequent accidents due to potholes, serious waterlogging that disrupts traffic flow, and the use of high beams that creates visibility hazards inspired us to take on this project. We noticed that manual road inspections are not effective, and the absence of automated traffic enforcement contributes to bad road conditions and frequent violations. Our goal is to enhance road safety and traffic management by utilizing detection systems powered by AI.

In our past experience with IoT-based safety systems, such as detecting electric current with electrodes in waterlogged areas, shaped our choice to expand the project. We used depth estimation methods to evaluate the severity of road damage and created an automated rerouting system to direct vehicles toward safer paths. Furthermore, we implemented a system for automated enforcement of traffic rules that generates and sends email challans for infringements. We developed a holistic solution for upgrading urban infrastructure and boosting road safety via smart traffic management by integrating AI, IoT, and real-time data analysis.

The goal of this project is to improve road safety and traffic management through the integration of cutting-edge computer vision techniques and IoT-based monitoring. The system is centered on identifying potholes, classifying them according to their severity, and redirecting traffic to safer paths. It also recognizes dangerous waterlogging situations by sensing electric current in stagnant water, thereby averting possible electrocution hazards.

In addition to detecting road damage, the project encompasses traffic rule enforcement and improving visibility. It uses high beam light detection to minimize glare-related accidents in brightly illuminated zones. In addition, helmet detection guarantees the safety of riders, while automatic email challan generation promotes adherence to regulations. To enhance supervision and guarantee effective compliance with regulations, traffic signal evaluation is incorporated as well. The system offers a scalable and efficient solution for critical road safety issues by utilizing AI-driven automation and real-time data analysis.

II. LITERATURE REVIEW

Road issues that affect both safety and traffic efficiency, such as potholes, waterlogging, high-beam infractions, and helmet non-compliance, are major challenges for urban infrastructure management. This review of the literature examines the methods and drawbacks of the current AI-driven techniques for pothole identification, waterlogging estimation, traffic signal optimization, high-beam detection, helmet recognition, and road damage-based rerouting.

A. Pothole Detection and Classification Using Deep Learning

Advanced deep learning models, such as POT-YOLO (YOLOv8 Variant), have demonstrated 99.10% accuracy in pothole detection by processing video frames and applying edge detection techniques, surpassing Faster RCNN and SSD (Bhavana et al). Machine learning-based approaches, such as YOLOX and DSASNet, have been introduced to enhance detection accuracy, achieving F1-scores up to 93.65% and IoU rates of 0.881, outperforming previous segmentation methods (Ranyal et al).

Limitations:

- Image-based detection methods may struggle with occlusions, shadows, and road debris, affecting accuracy.
- Depth estimation techniques for pothole severity assessment remain challenging in uncontrolled lighting and environmental conditions.

B. Urban Waterlogging Estimation and Depth Prediction

In real-world situations, machine learning models that use reference items (such as wheels, traffic cones, etc.) for depth estimate have attained 97% accuracy, providing an affordable substitute. In Siliguri, India, waterlogging hazards have been evaluated using GIS-based Analytical Hierarchy Process (AHP) models, which have been helpful in identifying high-risk flood zones for planning mitigation (Roy et al). During flood disasters, emergency response teams can benefit from real-time geospatial analytics made possible by cloud-based systems such as Google Earth Engine (GEE) with the Floodwater Depth Estimation Tool (FwDET) (Peter et al).

Limitations:

Camera perspective distortions and differences in item size limit object-based water depth estimation techniques.

Waterlogging estimates based on GIS rely on historical data, which could not accurately represent flood conditions in real time.

C. Traffic Signal Analysis and High-Beam Violation Detection

To improve traffic flow and lessen congestion, reinforcement learning-based deep learning models (DRL with MVN, or Masked Activation Values of Decision Neurons) have been presented (Xu et al). Usually relying on manual enforcement or simple picture thresholding algorithms, high-beam detection systems are not flexible in real-time.

Limitations:

Scalability concerns arise when deep reinforcement learning models are implemented in real-time traffic management systems, and they necessitate extensive datasets for training.

Why In well-lit conditions, existing high-beam violation detection methods produce false positives because they are unable to distinguish between purposeful and inadvertent high-beam usage.

D. Helmet Detection and Automatic Number Plate Recognition (ANPR) for Traffic Rule Enforcement

Although YOLO models for deep learning-based helmet identification have increased detection accuracy, it is still difficult to integrate them with license plate recognition (LPR) for automated enforcement (Cheng et al). YOLOv4-tiny, Paddle OCR, and SVTR-tiny are models used in OCR-based number plate identification, which achieves 97.5% recognition accuracy even in difficult circumstances (Mustafa et al).

Limitations:

- Reliability is impacted by helmet detection models' inability to detect occlusions from passengers or vehicle components.
- Camera resolution, illumination, and angle of capture all have a significant impact on license plate recognition, which can result in incorrect identifications in low-visibility situations.

E. Road Damage-Based Rerouting Using Google Maps API

Road damage concerns like potholes and waterlogging are not taken into account by navigation systems like Google Maps, which continuously monitor traffic congestion (Amores et al). Real-time road hazard rerouting techniques have been presented in recent studies to improve travel safety by recommending the most flexible routes with the least amount of road damage.

Limitations:

- Crowdsourced data, which real-time rerouting systems rely on, isn't always reliable or up to date.
- There are scalability issues and ongoing data upgrades when integrating road damage data with current navigation APIs.

III. METHODOLOGY

A. Project Overview

In order to improve traffic management and road safety, this project combines deep learning, computer vision, and the Internet of Things. Its objectives include detecting potholes, evaluating their severity, rerouting traffic appropriately, detecting electric current in places that are flooded, analyzing traffic signal infractions, and identifying infractions of traffic laws, such as the needless use of high beams and helmets. Additionally, the system automatically generates challans for rule offenders via email.

B. Technology Stack

a. Software Requirements

- Operating System: Windows
- Programming Languages: Python
- Deep Learning Frameworks: TensorFlow, PyTorch
- Computer Vision Libraries: OpenCV, YOLOv8, YOLOv10, YOLOv11, MiDaS (Depth Estimation Model)
- Data Preprocessing and Labelling: Roboflow
- OCR for Number Plate Recognition: Tesseract OCR
- Traffic Management & Mapping API: Google Maps API
- Backend Development: Django
- Code Environment: Arduino IDE and Visual Studio Code

b. Hardware Requirements

- Processing Unit: Raspberry Pi 4 Model B
- Camera Module: Raspberry Pi Camera V2 (for image/video capture)
- Microcontroller: Arduino Nano
- Sensors:
  - Electrodes (for electric current detection in waterlogged areas)
  - Light Dependent Resistor (LDR) (for high-beam light detection)
- Alerting Components:
  - Buzzer (for on-site alerts)
- Power Supply: 5V power source for Raspberry Pi and Arduino

C. Working Pipeline

a. Data Collection and Preprocessing

The main dataset for analysis is made up of real-time photos and videos taken using the Raspberry Pi Camera Module. OpenCV is used to preprocess the images to improve clarity and lower noise, as well as to extract frames from the recorded movies. Relevant areas of interest (ROIs) for additional analysis are found using a variety of image processing techniques, such as edge detection and segmentation. The cloud is subsequently used to store the gathered data, guaranteeing convenient access and enabling in-depth analysis and model training.

b. Identification and Classification of Potholes

YOLOv8 is used to accurately identify potholes in road photos. MiDaS depth estimation is used to determine the depth and severity of potholes. Potholes are classified as mild, moderate, or severe depending on their estimated depth. For mapping and navigational purposes, the GPS coordinates of potholes that are identified are also captured and saved.

c. Message Sharing and Rerouting

To improve navigation, the Google Maps API is combined with the locations of the recognized potholes. A smoother and safer trip is ensured by alternative routes that are calculated to assist users in avoiding severely damaged roads. Users are then given real-time updates and navigation support via web or mobile applications that convey these optimal routes.

d. Electric Current Detection in Waterlogged Areas

To find any electrical leaks, electrodes are positioned strategically in areas that are wet. An Arduino Nano is used to measure voltage differences in order to categorize the existence of current in areas that have been flooded. A buzzer and LED indication are triggered by an alert system in the event of an electrical leak. In order to ensure safety and timely action, notifications are also provided via a web interface to the public and authorities.

e. Traffic Signal Analysis

YOLOv11 and other computer vision algorithms are used to track traffic lights in real time. To maximize traffic flow, traffic lights are dynamically modified based on the degree of vehicle congestion. Instances of signal violations are also noted, together with information about the vehicle, for further processing and enforcement.

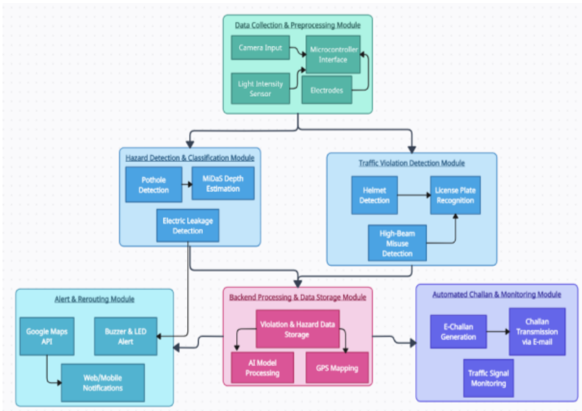

Fig. 1. Block Diagram

f. Identification of Traffic Violations

❖ Identification of High Beam Light Usage

In well-lit situations, excessive light intensity is detected using an LDR (Light Dependent Resistor) sensor. It is possible to identify cars that use needless high beams at traffic lights or in populated areas. Vehicles that violate the law are photographed, and their information is recorded for future use and enforcement.

❖ Identification of Helmets and Number Plates

YOLOv10-based helmet detection is implemented to identify motorcyclists who are not wearing helmets. Simultaneously, OCR (Optical Character Recognition) technology is used to extract license plate details from detected vehicles. The recorded violations are linked to the corresponding vehicle registration details for further legal actions.

g. Automated Challan Generation

Compile information from traffic infractions that have been discovered, such as high beam usage, helmet violations, and signal violations.

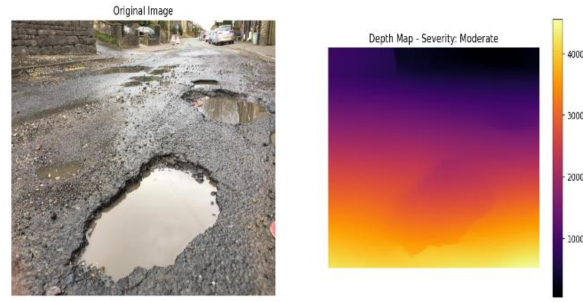

Fig 2. Pothole's Severity Assessment

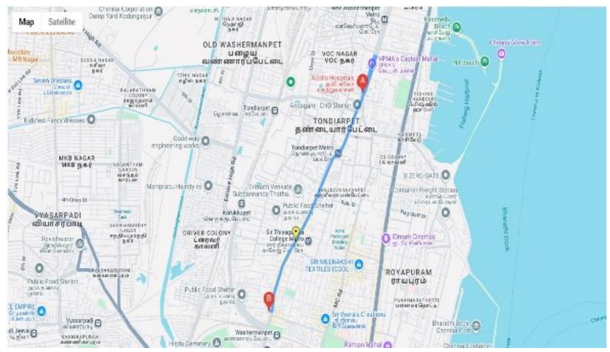

Fig 3. Plotting potholes in maps by using Google Maps API

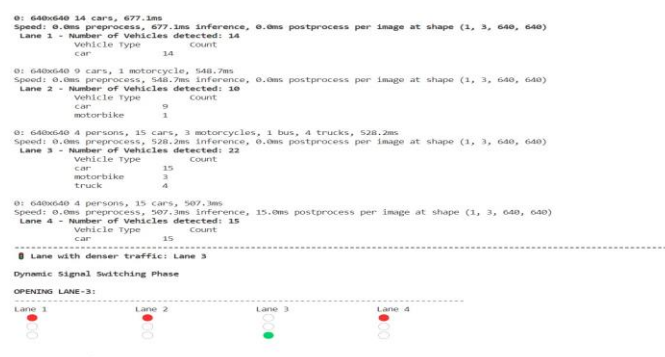

Fig 4. Traffic signal Switching by using YOLOv10 based congestion analysis

Fig 5. Helmet Detection and E-challan Generation via email

IV. FUTURE ENHANCEMENTS

A. Integration with Smart City Systems

The system provides real-time road maintenance notifications and automates the scheduling of pothole repairs by integrating with local authorities. Urban planning may be greatly enhanced and infrastructure management made more effective by sharing real-time traffic and road condition data with smart city dashboards.

B. AI-Powered Predictive Analysis

To forecast the development of potholes and the degradation of roads over time, machine learning techniques are applied to previous data. Predictive models are also used to identify regions that are likely to have waterlogging based on historical occurrences and weather trends, allowing for the early implementation of preventive measures.

C. Enhanced Traffic Violation Detection

The technology being expanded to identify other traffic infractions, like using a cell phone while operating a motor vehicle. By using face recognition technology, helmet detection is significantly improved, enabling rider identification and more stringent helmet compliance enforcement.

D. Automated Fine Payment System

Digital wallets and UPI-based payment channels are connected with the automated challan system to enable smooth fine collection. Additionally, automated reminders about unpaid fines are delivered to violators through communication with government traffic control systems, encouraging on-time payments.

E. Vehicle-to-Infrastructure (V2I) Communication

Real-time notifications about traffic infractions, potholes, and waterlogging are delivered directly to vehicles through in-car displays. Connected vehicle technology is utilized to enhance automatic rerouting and navigation, ensuring a safer and more efficient driving experience.

V. CONCLUSION

This project effectively improves urban road safety and traffic management by fusing cloud computing, IoT, and deep learning. It offers a thorough answer to typical road infrastructure problems by spotting potholes, assessing waterlogging conditions, and identifying traffic infractions. By combining automatic challan creation with real-time rerouting, road safety is approached proactively, resulting in fewer accidents and less traffic. The system's adaptability to smart city frameworks and potential additions, such as AI-powered forecasts and V2I communication, positions it as a scalable and efficient option for intelligent transportation systems. This research advances the long-term goal of safer and more intelligent urban mobility by consistently enhancing detection accuracy and incorporating cutting-edge technologies.

REFERENCES

[1] N. Bhavana, M. M. Kodabagi, B. M. Kumar, P. Ajay, N. Muthukumaran and A. Ahilan, "POT-YOLO: Real-Time Road Potholes Detection Using Edge Segmentation-Based Yolo V8 Network," in *IEEE Sensors Journal*, vol. 24, no. 15, pp. 24802-24809, 1 Aug.1, 2024, doi: 10.1109/JSEN.2024.3399008.

[2] E. Ranyal, A. Sadhu and K. Jain, "AI assisted pothole detection and depth estimation," 2023 International Conference on Machine Intelligence for GeoAnalytics and Remote Sensing (MIGARS), Hyderabad, India, 2023, pp. 1-4, doi: 10.1109/MIGARS57353.2023.10064547

[3] Subham Roy, Arghadeep Bose, Nimai Singha, Debanjan Basak, Indrajit Roy Chowdhury, Urban waterlogging risk as an undervalued environmental challenge: An Integrated MCDA-GIS based modeling approach, Environmental Challenges, Volume 4, 2021, 100194, ISSN 2667-0100, https://doi.org/10.1016/j.envc.2021.100194

[4] B. G. Peter, S. Cohen, R. Lucey, D. Munasinghe, A. Raney and G. R. Brakenridge, "Google Earth Engine Implementation of the Floodwater Depth Estimation Tool (FwDET-GEE) for Rapid and Large-Scale Flood Analysis," in IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022, Art no. 1501005, doi: 10.1109/LGRS.2020.3031190.

[5] D. Xu, C. Li, D. Wang and G. Gao, "Robustness Analysis of Discrete State-Based Reinforcement Learning Models in Traffic Signal Control," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 24, no. 2, pp. 1727-1738, Feb. 2023, doi: 10.1109/TITS.2022.3221107

[6] L. Cheng, "A Highly Robust Helmet Detection Algorithm Based on YOLO V8 and Transformer," in IEEE Access, vol. 12, pp. 130693-130705, 2024, doi: 10.1109/ACCESS.2024.3459591.

[7] T. Mustafa and M. Karabatak, "Real Time Car Model and Plate Detection System by Using Deep Learning Architectures," in *IEEE Access*, vol. 12, pp. 107616-107630, 2024, doi: 10.1109/ACCESS.2024.3430857

[8] D. Amores, E. Tanin and M. Vasardani, "Flexible Paths: A Path Planning Approach to Dynamic Navigation," in IEEE Transactions on Intelligent Transportation Systems, vol. 25, no. 6, pp. 4795-4808, June 2024, doi: 10.1109/TITS.2023.3343490

[9] A. Suraji, G. Subiyakto, D. Irawan, F. Marisa, N. Tjahjono and M. Wahyu Nugroho, "Smart Route Choice Based on Google Maps Application in Urban Road Network," 2022 1st International Conference on Technology Innovation and Its Applications (ICTIIA), Tangerang, Indonesia, 2022, pp. 1-6, doi: 10.1109/ICTIIA54654.2022.9935914.

[10] Wang, H. Lang, Z. Chen, Y. Peng, S. Ding and J. J. Lu, "The Two-Step Method of Pavement Pothole and Raveling Detection and Segmentation Based on Deep Learning," in IEEE Transactions on Intelligent Transportation Systems, vol. 25, no. 6, pp. 5402-5417, June 10.1109/TITS.2023.3340340.

[11] Cheng, Tsung-Hui, Chien-Hao Chen, Chien-Hung Lin, Bor-Horng Sheu, Chia-Hung Lin, and Wen-Ping Chen. 2023. "Leakage Current Detector and Warning System Integrated with Electric Meter" Electronics 12, no. 9: 2123. https://doi.org/10.3390/electronics12092123

[12] H. B. Giri, H. Biradar, N. Gupta, P. V. Jirali and J. N. Hemalatha, "Pothole Detection Using Image Processing and Data Logging," 2023 7th International Conference on Computation System and Information Technology for Sustainable Solutions (CSITSS), Bangalore, India, 2023, pp. 1-5, doi: 10.1109/CSITSS60515.2023.10334176.

[13] J. Bicbic, T. E. Gabriel Macatangay, M. Miranda, M. Ocina and A. Santos, "Automated Pavement Distress Detection and Classification Using Convolutional Neural Network with Mapping," TENCON 2023 - 2023 IEEE Region 10 Conference (TENCON), Chiang Mai, Thailand, 2023, pp. 513-518, doi: 10.1109/TENCON58879.2023.10322464.

[14] Gao, K., Yang, Z., Gao, X., Shao, W., Wei, H., & Xu, T. (2024). Measuring urban waterlogging depths from video images based on reference objects. Journal of Flood Risk Management,17(1), e12948. https://doi.org/10.1111/jfr3.12948

[15] R. Mirajkar, A. Yenkikar, S. Nawalkar, R. Kaul, A. Rokade and K. Rothe, "Enhanced Pothole Detection in Road Condition Assessment Using YOLOv8," 2024 IEEE International Conference for Women in Innovation, Technology & Entrepreneurship (ICWITE), Bangalore, India, 2024, pp. 429-433, doi: 10.1109/ICWITE59797.2024.10502437.

[16] Z. Zhong, G. Kaiser and B. Ray, "Neural Network Guided Evolutionary Fuzzing for Finding Traffic Violations of Autonomous Vehicles," in IEEE Transactions on Software Engineering, vol. 49, no. 4, pp. 1860-1875, 1 April 2023, doi: 10.1109/TSE.2022.3195640

[17] F. Percassi, S. Bhatnagar, R. Guo, K. Mccabe, T. L. Mccluskey and M. Vallati, "An Efficient Heuristic for AI-based Urban Traffic Control," 2023 8th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Nice, France, 2023, pp. 1-6, doi: 10.1109/MT-ITS56129.2023.10241690.

[18] A. Charef, Z. Jarir and M. Quafafou, "Enhancing Road Safety: Automated Traffic Violation Detection and Counting System Using YOLO Algorithm," 2024 Mediterranean Smart Cities Conference (MSCC), Martil - Tetuan, Morocco, 2024, pp. 1-6, doi: 10.1109/MSCC62288.2024.10697076.

[19] C. M. V. Srinivas, S. Jaglan, S. H. S, M. V. Ghamande, P. U. Trivedi and R. Ramakrishnan, "Integrating Smart Technologies for Enhanced Traffic Management and Road Safety: A Data-Driven Approach," 2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS), Trichy, India, 2023, pp. 748-754, doi: 10.1109/ICAISS58487.2023.10250761.

[20] J. R. Fenita, R. Sanchana, G. Sivasree, B. Monica and M. Nithyasri, "Traffic Violation Detection and Control System Using RFID and IOT System," 2024 International Conference on Communication, Computing and Internet of

Things (IC3IoT), Chennai, India, 2024, pp. 1-4, doi: 10.1109/IC3IoT60841.2024.10550318