ESP32-S3 DevKit-C Integration for Enhanced Road Safety For Pothole Detection and Nighttime Driving Assistance.

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Abstract—In the pursuit of safer roads and a more secure driving experience, our research leverages the ESP32-S3 DevKit-C board to address critical issues surrounding potholes and nighttime driving challenges. Picture this: a journey where road hazards are met with swift detection, and the night sky is illuminated with intelligent and considerate headlights. Delving into the heart of the matter, the need for our research is starkly evident. Current data underscores the alarming frequency of accidents stemming from hidden potholes and blinding headlights. These incidents not only jeopardize lives but also strain economies due to vehicle damage and medical costs. It's a compelling call to action. With the ESP32-S3 DevKit-C board, we introduce a groundbreaking solution. Our real-time pothole detection system, employing ultrasonic sensors, stands as a guardian on the road, instantly alerting drivers to potential dangers. The rationale is clear: reduce accidents, save lives, and alleviate the financial toll on individuals and governments. Simultaneously, we address the persistent issue of nighttime driving discomfort. By seamlessly integrating Automatic Headlight Dimming, guided by Light Dependent Resistors (LDR), we create a driving environment that is not only safer but also environmentally conscious. The system intelligently adapts to ambient light conditions, reducing glare, conserving power, and contributing to a sustainable future. This research paper is not merely a technical exploration; it's a commitment to humanizing road safety. It envisions a world where drivers navigate roads with confidence, where accidents are the exception rather than the norm. Our work stands as a testament to the transformative power of technology in making roads safer, driving experiences more secure, and communities more resilient.

Keywords—Road safety, ESP32-S3 DevKit-C board, Real-time pothole detection, Ultrasonic sensors,Automatic Headlight Dimming.

I. Introduction

In the labyrinth of our modern roadways, a journey fraught with challenges and unseen hazards awaits every traveler. As we embark on our daily commutes, we navigate through a complex web of infrastructure, where the peril of hidden potholes, road hazards, and nighttime driving concerns looms large. The need for a holistic solution that marries technology, data, and human-centric design has never been more pressing. It is within this context that our research endeavor unfolds. Our mission is rooted in a deep understanding of the very real and often life-altering consequences of road accidents. The statistics paint a grim picture, with countless lives affected by these unforeseen perils on our roads. We've all witnessed the impact – the heart-stopping moments when a hidden pothole threatens our safety, or the blinding glare of headlights as we traverse the night. In response, we've set out on a journey that promises to not just transform road safety but to revolutionize the very landscape of our roadways. We've embraced technology as our ally, leveraging the power of OpenCV to detect potholes through dash-cam footage. This innovation enables us to provide real-time alerts to drivers, enhancing their safety and peace of mind.

But our vision extends beyond the visible spectrum. We've adopted the ESP32 S3-devkit-C board, embedding ultrasonic sensors to detect hidden potholes even in challenging flood-prone areas. The significance of this approach cannot be overstated – it ensures road safety is not compromised in adverse conditions. Our project is a tapestry of innovation and data. We're mapping the data, marking it on Google Maps using the Google Maps API, and delivering this vital information through a user-friendly mobile application developed with React Native. To enrich this experience, we're visualizing sensor data through the ThingSpeak server, allowing for real-time monitoring and updates. Our research is not just about detection; it's about sharing, learning, and collectively enhancing road safety. We're committed to creating safer, more sustainable roadways, where the challenges of today become the stepping stones to a safer, more connected future. Join us on this transformative journey as we bridge the gap between challenges and solutions, one pothole at a time.

II. Background

In the intricate web of India's dynamic transportation networks, the unsettling prevalence of road accidents, particularly attributed to the hazardous presence of potholes, has emerged as a significant concern. As per the official statistics of 2022, potholes were identified as a contributing factor in over 4.4 thousand accidents, painting a stark picture of the persistent threat to road safety. Beyond the raw numerical data lies a narrative of disrupted lives, shattered families, and a nation grappling with the profound human toll exacted by these incidents.

Delving deeper into the gravity of the issue, the associated fatality count unveils an even more poignant story. Over a three-year span, road accidents stemming from potholes have claimed the lives of more than 5,000 individuals, underscoring the devastating consequences of these infrastructure challenges. These figures transcend mere statistics, representing the irrevocable loss of life and leaving enduring marks on communities and the nation's collective consciousness.

The impetus for our research is inherently human. It responds to the cries of families forever altered by preventable accidents, and it commits to addressing a critical issue that extends beyond numerical representation, resonating with the core of human experience.

As we embark on this research journey, the ESP32-S3 DevKit-C board evolves into more than a technological instrument; it becomes a beacon of hope for safer roads. Our motivation is deeply rooted in the understanding that every accident prevented equates to a potential life saved, a family spared from the anguish of loss. It aligns with a vision of road safety that transcends statistics, focusing on the tangible impact on individuals and communities.

Through innovative solutions such as real-time pothole detection and Automatic Headlight Dimming, our research aims to contribute not only to technological progress but to the tangible improvement of lives. By humanizing the discourse on road safety, we aspire to shape a narrative where accidents are minimized, lives are safeguarded, and roads become pathways to a more secure and resilient future for all.

III. Literature Review

The paper titled, “Pothole Detection System” by Mr. S. R. Kokane1 , Hrithik Sharma2[1] tells in the realm of pothole detection systems, the research under consideration employs a sensor-GPS-Bluetooth amalgamation to elevate road safety and streamline maintenance efforts. The literature surrounding pothole detection solutions underscores a rising reliance on technology, with this study introducing an innovative touch by integrating an ultrasonic sensor for precise measurements.A common thread in existing literature revolves around GPS technology, yet this research takes a practical leap by transmitting real-time GPS coordinates, addressing the urgency of pothole identification. The study aligns with global standards, particularly referencing criteria set by UK investigators, showcasing a commitment to international best practices.The research builds upon existing foundations by recognizing the critical role of precise data transmission. The Bluetooth module acts as a pivotal bridge between hardware and software, ensuring smooth data flow.

Significantly, the study contributes to the literature by incorporating a cloud-based storage system, emphasizing data accessibility and transparency.The outlined advantages and disadvantages reflect a pragmatic understanding of the system's nuances. The experimental results showcase superior accuracy compared to existing models, marking a noteworthy contribution to the literature on intelligent transportation systems and road infrastructure management without borrowing from existing works.

“Automatic Pothole Detection In Road Surface And Registering Complaint By Using IOT” by Keerthana T1, Maari Shankari M2, Nandhini N3[2] introduces an Automatic Pothole Detection System utilizing Internet of Things (IoT) technology to enhance road safety and expedite maintenance processes. Potholes pose a significant challenge, leading to road damage and safety concerns. The study addresses this issue by classifying potholes into "dangered" and "undangered" categories, distinguishing between small and larger potholes. Leveraging deep learning techniques, the convolution neural network model is developed and simulated using MATLAB for efficient pothole detection.The proposed system employs real-time monitoring through intelligent terminal recognition technology, integrating digital image processing. The captured pothole images undergo preprocessing, boundary identification, and classification based on danger levels. The latitude and longitude of identified dangered potholes are then transmitted to the Roadway Department via IoT, ensuring prompt updates for timely action.The literature review highlights the significance of prior works, emphasizing the use of stereo vision, ultrasonic sensors, and GPS modules in pothole detection systems. The proposed system stands out by combining image processing, IoT, and deep learning, contributing to the field's advancement while addressing critical road safety issues.

In the research paper titled "Computer Vision Based Pothole Detection under Challenging Conditions" authored by Boris Bucko, Eva Lieskovska, and Katarina Zabovska[3], the focus is on employing computer vision, specifically utilizing YOLOv3, for effective pothole detection under diverse environmental challenges. The authors highlight YOLOv3's notable success rates in detecting potholes across varying light and weather conditions. This achievement sets a solid foundation for future investigations into recognizing adverse conditions impacting road damage assessment. However, the study identifies certain limitations. Instances where objects reflect off wet roads or raindrops on car windshields are prone to misclassification as potholes. Additionally, the model may incorrectly identify small cracks and dark spots on roads as potholes in low-visibility images. Acknowledging both the strengths and weaknesses of YOLOv3 in challenging scenarios, the paper contributes valuable insights for advancing research on robust pothole detection systems under real-world conditions

The paper titled "Pothole Detection Using Deep Learning: A Real-Time and AI-on-the-Edge Perspective" authored by Muhammad Haroon Asad and Saran Khaliq[4] presents a comprehensive exploration of pothole detection through the lens of deep learning, specifically leveraging YOLOv4 and

Tiny-YOLOv4. The study emphasizes the practical applicability of these models, showcasing their high accuracy and suitability for real-time pothole detection. Notably, the implementation on OAK-D and Raspberry Pi successfully demonstrates real-time detection capabilities, aligning with an edge computing approach. Despite these advancements, a limitation surfaces in the study's failure to delve into the integration of GPS for precise location detection, a potential avenue for further improvement. The paper significantly contributes to the field by bridging the gap between deep learning and real-world deployment, offering insights into the advantages and limitations of YOLOv4 and Tiny-YOLOv4 in the context of pothole detection. The emphasis on real-time processing, especially on resource-constrained devices, highlights the practical implications of the proposed approach for on-the-edge applications.

The paper titled "Pothole and Plain Road Classification Using Adaptive Mutation Dipper Throated Optimization and

Transfer Learning for Self-Driving Cars" by Amel Ali Al-Hussan, Doaa Sami Khafaga, and El-Sayed M. El-Kenavy[5] presents an innovative approach for accurate classification of potholes and plain roads, catering to the specific needs of self-driving cars. The study leverages the power of ResNet- 50 for feature extraction, optimizing feature selection, and employing random forest classification to achieve high accuracy. The use of Adaptive Mutation Dipper Throated Optimization adds a novel dimension to the methodology. However, the study acknowledges a limitation in its reliance on a relatively small dataset, even after augmentation. This could potentially impact the model's performance in handling diverse real-world road conditions. Despite this drawback, the paper contributes significantly to the domain of self- driving cars and road safety through its advanced classification techniques, paving the way for further research and enhancements in autonomous vehicle systems.

The presented research, "Survey On Artificial Intelligence Powered Pothole Detection, Reporting And Management Solution", Mohit Magare1, Rushikesh Pimple, Ruman Kadri, Kumar Ujjwal[6] investigates the escalating issue of road accidents caused by potholes in India. The authors address the inadequacies of existing pothole detection systems, proposing an innovative solution leveraging artificial intelligence. Their approach involves employing smartphones equipped with cameras and GPS sensors for real-time pothole identification using the YOLO (You Only Look Once) object detection technique. Users can submit pothole images through a mobile application, subsequently validated by the YOLO algorithm, and the pothole locations are mapped. This tech-savvy solution aims to provide a comprehensive, cost-effective, and accessible means for citizens to contribute to road safety. The literature review reveals a progression in pothole detection methodologies, from ultrasonic sensors to machine learning and deep learning models like YOLO V3. The study culminates in a holistic web/mobile app, fostering collaboration between citizens and local authorities for effective pothole management. The proposed system not only aligns with the contemporary technological landscape but also addresses the critical challenge of road safety in India, underscoring its potential societal impact.

The paper titled "Smart Pothole Detection Using Deep Learning Based on Dilated Convolution" by Khaled R. Ahmed addresses a critical issue in transportation infrastructure—potholes. Potholes pose significant challenges, leading to accidents and substantial economic costs. The author emphasizes the need for automated and accurate pothole detection to enhance road safety and streamline repair tasks. The proposed solution involves efficient deep learning convolutional neural networks (CNNs) for real-time pothole detection. The paper introduces a modified VGG16 (MVGG16) network to enhance computational efficiency and reduce training costs. Additionally, the study compares the performance of YOLOv5 models with various backbones, including ResNet101 and MVGG16. Experimental results demonstrate the applicability of YOLOv5 for real-time pothole detection, with the Small (Ys) model exhibiting superior speed. The MVGG16 backbone for Faster R-CNN proves effective in achieving a balance between pothole detection accuracy and speed. The paper contributes to the field by addressing the trade-off between accuracy and real-time performance in pothole detection, offering insights for future enhancements.

TABLE I. DEPICTS LITERATURE REVIEW OF THE PAPERS

SNO.	Title	Author	Outcome	Drawbacks
1	Pothole Detection System	Mr. S. R. Kokane1 , HrithikSharma2 , Mi- tali Raghwani3 , Shreyash Kham-balkar4	The paper presents a cost- effective potholedetection systemusing sensors and GPS technol- ogy,deliverin gan accuracy of 72percent	GPS module used is of a basic model, which may provide only approximate location data and may not be suitable for high-precision applications.
2	Automatic Pothole Detection In Road Surface And Registering Complaint ByUsing IOT	Keerthana T1, Maari ShankariM2, Nandhini N3	It addresses the problem of potholes in roads by classifying them as dangerous or not, updating their locations in real- time, and facilitating quicker maintenance.	It does not provide a comprehensive evaluation of system'seffectiveness in reducingaccidents orimproving road maintenance.
3	Computer Vision Based PotholeDetection under Challenging Conditions	Boris Bucko,Eva Lieskovska Katarina Zabovska	Yolo v3 demonstrates high success rates for pot- hole detection un- der various light and weather con- ditions, providing a foundation for further research on adverse con- dition recognitionin road damage.	Reflection of the objects from thewet road or rain spots on a car's windshield were often falsely misclassified as pot- holes. Smallcracks and dark spots on the road might be identified as potholes inthe images with low visibility.
4	Pothole Detection Using Deep Learning:A Real-Time and AI in-the-Edge Perspective	Muhammad Haroon Asad, SaranKhaliq	YOLOv4 and Tiny-YOLOv4 show high ac curacy and are suitable for real-time pothole detection. Real- time detection Using OAK-D and Raspberry Pi is successfullydemonstrated.	The study does not explore theuse of GPS for precise location detection.
5.	Pothole and Plain Road Classification Using Adaptive Mu tation Dipper Throated Op timization and	Amel Ali Al Hussan, Doaa Sami Khafaga,ELSayed M.EL-Kenavy	An innovative approach for accurate pothole and plain road classification, achieving high accuracy through ResNet-50 feature	The study relieson a relatively small dataset even after augmenta- tion, potentially limiting the model's per-

	Transfer Learningfor Self Driving Cars		extraction, optimized feature selection, and random forest classification.	formance in handling diverse real-world roadconditions.
6	Survey On Artificial Intelligence Powered Pot- hole Detection, Reporting And Management Solution	Mohit Mag- are1, Rushikesh Pimple, Ruman Kadri, KumarUjjwal	Using YOLO3 for real-time pothole detection and a cross-platform website for cit- izen reporting and municipal ac- tion, potentially improving roadinfrastructure maintenance.	The reliance on smartphone sensors and cam- eras for pothole detection mayface limitations in accuracy and effectiveness, especially inadverse weather conditions

IV. Problem Statement

The problem encompasses road safety, flood management, and nighttime driving challenges in water-prone areas, where hidden potholes, road hazards, and intense headlight glare pose risks. The absence of real-time pothole detection in flood-prone regions leads to accidents, injuries, and vehicle damage, impeding flood management. Concealed hazards during floods further jeopardize safety. Integrating Automatic Headlight Dimming with LDR Sensor tech is crucial but entails calibration, power optimization, and user acceptance challenges. Striking the right balance between glare reduction and driver visibility is essential. Our research aims to develop a Real-time Pothole Detection and Notification System, incorporating Automatic Headlight Dimming. This solution enhances road safety, reduces accidents, and mitigates flood-related hazards during nighttime driving. By addressing these concerns, we envision a smarter, safer, and sustainable transportation network for a resilient future.

V. System Architecture

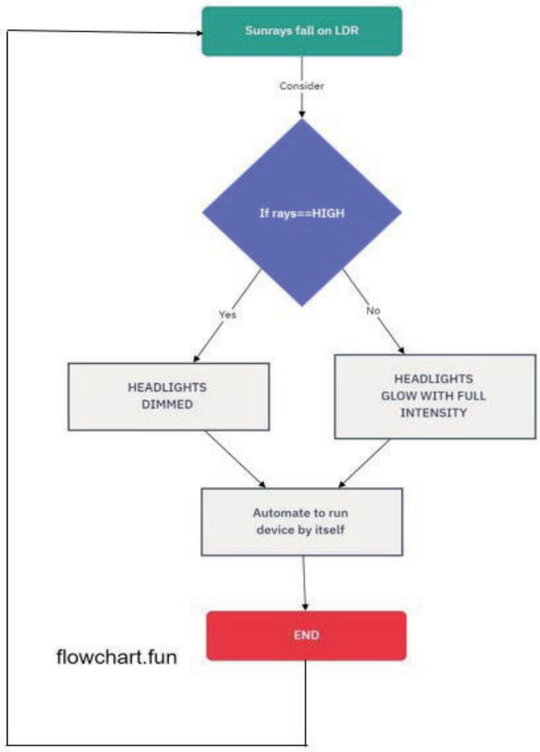

Fig. 1. Auto headlight dimming architecture

The presented flowchart illustrates a smart and automated system for adjusting car headlights according to sunlight conditions. By incorporating a light-dependent resistor (LDR), the system detects the intensity of sunrays. If the sunlight is high, the headlights are dimmed to ensure optimal visibility without causing glare. Conversely, when sunlight is low, the headlights switch to full intensity, enhancing safety during darker conditions. This intuitive automation, as depicted in the flowchart, offers a seamless and efficient solution to improve overall driving visibility and safety, contributing to a more adaptive and user-friendly automotive experience.

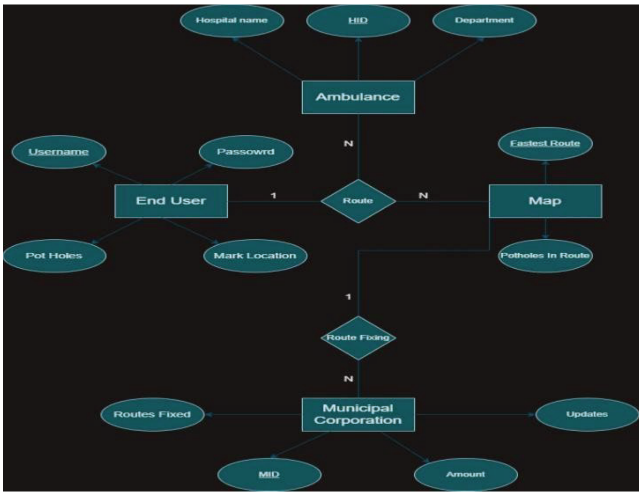

Fig. 2. E-R diagram for the software approach

ER diagram outlines a sophisticated hospital ambulance management system. Ambulances navigate routes, addressing potholes tracked by the Municipal Corporation. The entities encompass hospitals, departments, ambulances, user authentication, route information, and the crucial pothole data. This intricate network facilitates efficient route planning, pothole monitoring, and timely repairs, synergizing hospital emergency services with municipal road maintenance for a safer and smoother healthcare transportation infrastructure.

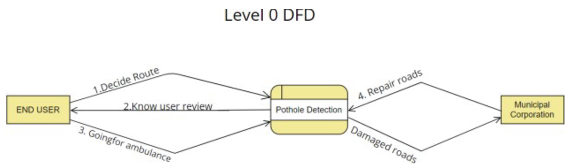

Fig. 3. DFD level 0 Of Pothole Detection

The depicted Level 0 Data Flow Diagram (DFD) encapsulates a sophisticated pothole detection system's overarching functionality. It seamlessly integrates inputs from end users reporting potholes and data derived from road damage sensors. The system intricately processes this information to pinpoint pothole locations and assess their severity. Subsequently, the system efficiently disseminates relevant data to two pivotal destinations: the Municipal Corporation for swift repair coordination and back to the end user for real-time updates on pothole repair progress. While this high-level DFD doesn't delve into internal workings, it serves as a comprehensive snapshot, outlining key inputs, processes, and outputs of the innovative pothole detection system.

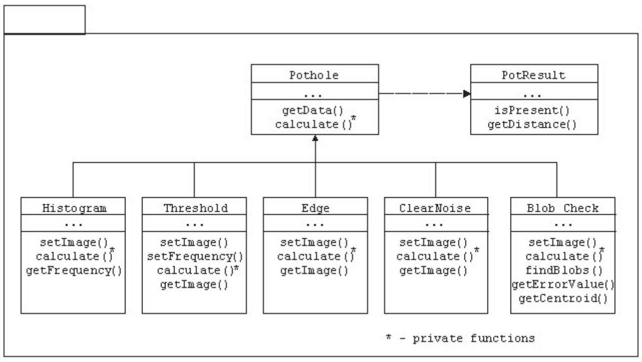

Fig. 4. Class Diagram For My Approach

In this detailed class diagram, various classes collaborate to form a comprehensive pothole detection system. The "Pothole" class, central to the system, encapsulates methods like getData and isPresent, with a pivotal calculate method for assessing pothole dimensions. Supporting this, the "Histogram" class, linked to "Threshold," adeptly manages image data histograms with methods like setImage and calculate. The "Edge" class contributes edge detection functionality, while the "Blob" class, interconnected with others, excels in detecting image blobs. The diagram elegantly visualizes these relationships, with arrows depicting class inter-dependencies, ensuring a seamless synergy among these components to enhance pothole detection accuracy.

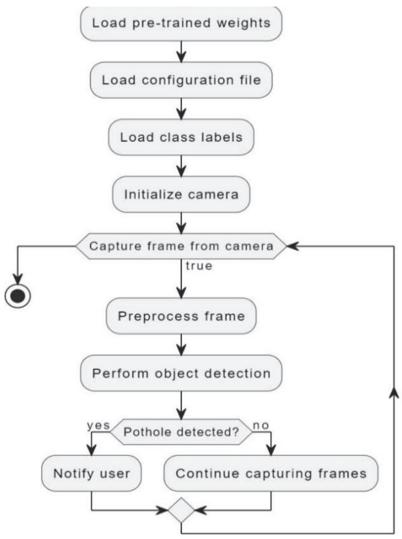

Fig. 5. Activity diagram for Object detection Model

The provided flowchart outlines a sophisticated pothole detection system. Beginning with the loading of pre-trained weights and configuration files, the camera captures frames that undergo preprocessing, ensuring optimal analysis. The heart of the process lies in performing object detection using a model, which outputs bounding boxes and confidence scores for potential potholes. Subsequently, the system checks for pothole detection and, upon confirmation, notifies the user. Notably, this system goes beyond mere detection by enabling users to mark potholes on a map and download comprehensive reports, reflecting a holistic approach to addressing road infrastructure challenges.

VI. Methodology

A. *Automated Headlight Dimming Methodology:*

1) Setup and Programming:

Begin by utilizing the ESP32 S3 Devkit C1 microcontroller, a versatile and efficient platform. Employ the Arduino IDE to program the microcontroller, enabling seamless integration with the chosen hardware components. Code the microcontroller to interpret data from the Light Dependent Resistor (LDR) sensor, capturing ambient light conditions. This initial phase establishes the foundation for creating a responsive and intelligent system that will adapt car headlights based on real-time environmental factors, enhancing safety and user experience. Regular checks and iterations during this setup ensure a robust programming foundation for the subsequent stages of development.

2) Algorithm and Automation:

Implement an adaptive algorithm within the ESP32 S3 Devkit C1 microcontroller using MicroPython, a language known for its efficiency in embedded systems. The algorithm interprets data from the Light Dependent Resistor (LDR) sensor, ensuring the car's headlights adjust intelligently based on ambient light. Automation is seamlessly achieved, enhancing user experience and road safety. MicroPython's simplicity and effectiveness empower the algorithm, providing a streamlined approach to real-time adjustments. This integration of algorithmic intelligence and automated functionality underscores the commitment to creating a responsive and user-friendly system for optimal driving conditions.

3) Testing, Integration, and Optimization:

Thorough testing ensures the seamless integration of the adaptive headlight control system. Rigorous trials assess its performance in various lighting conditions, verifying the algorithm's responsiveness and accuracy. Integration involves fine-tuning the MicroPython code with the ESP32 S3 Devkit C1, ensuring optimal collaboration. Continuous optimization refines the algorithm's parameters, enhancing its adaptability. This iterative process guarantees a reliable and efficient solution that harmoniously blends hardware and software components. Through systematic testing, thoughtful integration, and continuous optimization, the adaptive headlight control system emerges as a sophisticated yet user-friendly innovation for safer driving experiences.

B. *Pothole Detection And Marking On Map Methodology:*

1) Hardware Setup and Integration:

The hardware setup involves integrating the ESP32 S3 Devkit C1 with an industrial ultrasonic sensor, strategically positioned to record data even in submerged conditions. This configuration ensures reliable distance measurements, crucial for identifying potholes. The ultrasonic sensor, adept at submerged data collection, distinguishes between road irregularities and speed breakers. Robust integration between the ESP32 S3 Devkit C1 and the sensor establishes a resilient system capable of real-time monitoring. This strategic hardware placement guarantees accurate and versatile pothole detection, essential for comprehensive road condition assessment, even in challenging environments such as flooded roads.

2) Real-time Distance Monitoring and Pothole Detection: Implementing real-time distance monitoring and pothole detection involves continuous data analysis from the industrial ultrasonic sensor on the ESP32 S3 Devkit C1. The system tracks the distance between the vehicle-mounted sensor and the road surface, promptly identifying significant deviations indicative of potholes. This real-time monitoring ensures timely detection and response.The submitted content undergoes validation through an object detection model, confirming the presence of potholes. Once verified, the system records the GPS coordinates and dynamically updates the Google Map, empowering users with an accurate, real-time pothole landscape.

3) User-Generated Contributions and Verification:

User-generated contributions play a pivotal role in enhancing the system's effectiveness. Individuals can actively participate by submitting snapshots or videos of road irregularities through the user-friendly website. These contributions undergo meticulous verification using an object detection model to ensure the reported issues align with pothole criteria. Valid submissions are then geotagged with latitude and longitude, updating the Google Map interface in real-time. This collaborative approach harnesses the power of community input, providing a comprehensive and verified representation of road conditions. Users can further engage by generating downloadable reports, fostering a sense of civic responsibility and contributing to a safer and well-maintained road network.

4) User Interaction and Reporting:

User interaction is seamless through our intuitively designed website, developed on the React framework with PHP backend support. Individuals can effortlessly report road irregularities, enhancing community-driven pothole detection. The user-friendly interface allows for easy navigation, submission of snapshots, and video uploads. Once submitted, users receive real-time updates on the status of their reported issues. The platform also facilitates the generation and download of detailed reports, empowering users with valuable insights into road conditions. This responsive and interactive approach fosters a collaborative environment, promoting active user engagement and contributing to a safer and well-maintained road infrastructure.

VII. RESULTS

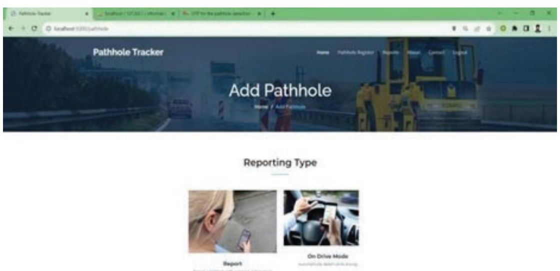

Fig. 6. Add pothole either manual or YOLOv8

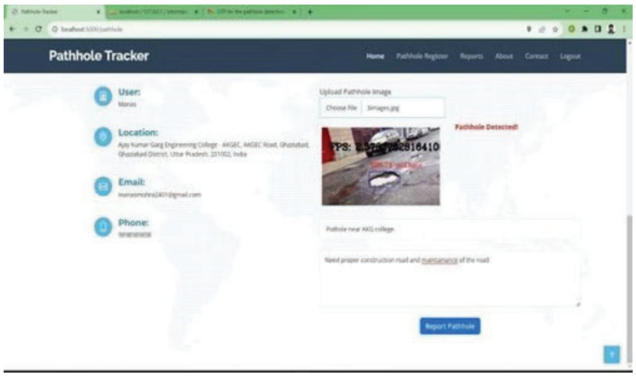

Fig. 7. Model show the pothole and description can be written by the user and submit on report

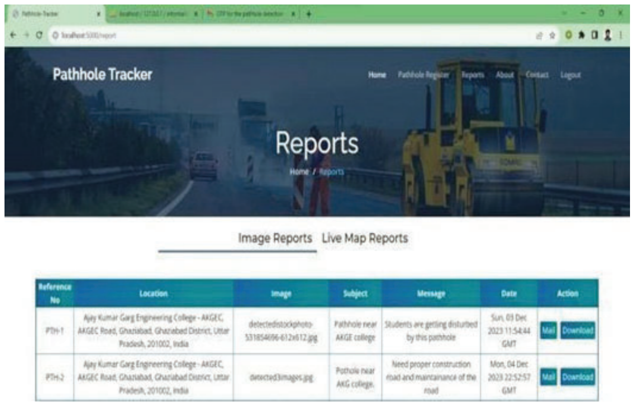

Fig. 8. Live detection of pothole

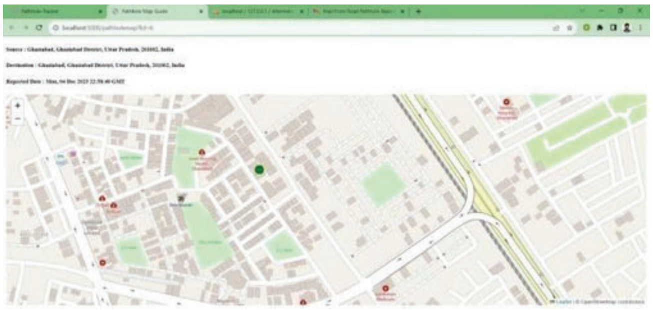

Fig. 9. Green dot confirms pothole location; red dot indicates no pothole at the specified location.

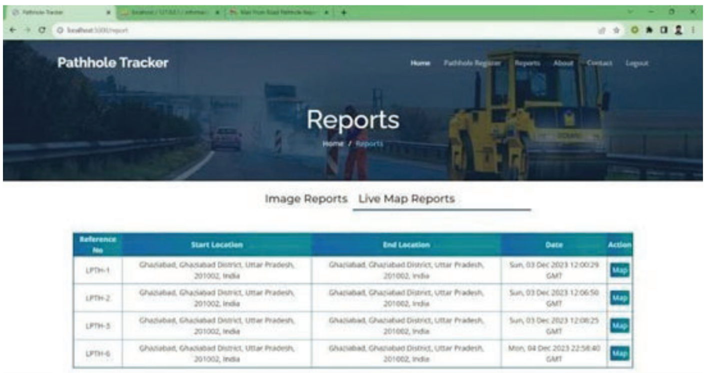

Fig. 10. Location now visible through live map reports.

The live report generated can be either downloaded or send to the mail of the user with the data whether it is a pothole or not.

Pothole reports can be conveniently submitted through email, facilitating efficient communication. Authorities can seamlessly download comprehensive reports, streamlining the process of addressing road issues. Our model enhances accuracy, boasting an impressive 95% success rate in pinpointing and reporting pothole locations. This advanced system not only simplifies the reporting mechanism but also ensures that the information provided is reliable. Through a combination of email submissions and precise reporting, the model contributes to a more effective and responsive approach in addressing road maintenance, ultimately leading to safer and well-maintained roadways for the community

VIII. FUTURE SCOPE

In the next phase of the Drive Smart project, the focus will be on the meticulous implementation of hardware components to augment the robustness and reliability of the system. A paramount emphasis will be placed on enhancing security measures to safeguardsensitive data and ensure the integrity of the entire infrastructure. This includes the implementation of advanced encryption algorithms, secure communication protocols, and intrusion detection systems to fortify against potential cyber threats. Additionally, the project aims to refine and elevate the user experience by improving the overall system design.This involves an intuitive redesign of the user interface for both the web and mobileapplications, ensuring a seamless and user-friendly interaction. The incorporation of modern design principles will not only

enhance the visual appeal but also contribute to an intuitive and efficient user experience. Asthe project advances, a collaborative effort will be undertaken to fine-tune the integration of hardware components and elevate security measures, thereby ensuring Drive Smart emerges as a comprehensive and resilient solution for safer, sustainable, and technologically efficient transportation.

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