Project 2306 | July 2024

SJSU SAN JOSÉ STATE UNIVERSITY

MTI MINETA TRANSPORTATION INSTITUTE

Development of the Roadway Pothole Management Program

DingXin Cheng, PhD, PE

CSUTC California State University Transportation Consortium

CP² Center

CALIFORNIA STATE UNIVERSITY Chico

CSU TRANSPORTATION CONSORTIUM

transweb.sjsu.edu/csutc

MINETA TRANSPORTATION INSTITUTE

Founded in 1991, the Mineta Transportation Institute (MTI), an organized research and training unit in partnership with the Lucas College and Graduate School of Business at San José State University (SJSU), increases mobility for all by improving the safety, efficiency, accessibility, and convenience of our nation's transportation system. Through research, education, workforce development, and technology transfer, we help create a connected world. MTI leads the Mineta Consortium for Transportation Mobility (MCTM) and the Mineta Consortium for Equitable, Efficient, and Sustainable Transportation (MCEEST) funded by the U.S. Department of Transportation, the California State University Transportation Consortium (CSUTC) funded by the State of California through Senate Bill 1 and the Climate Change and Extreme Events Training and Research (CCEETR) Program funded by the Federal Railroad Administration. MTI focuses on three primary responsibilities:

Research

MTI conducts multi-disciplinary research focused on surface transportation that contributes to effective decision making. Research areas include: active transportation; planning and policy; security and counterterrorism; sustainable transportation and land use; transit and passenger rail; transportation engineering; transportation finance; transportation technology; and workforce and labor. MTI research publications undergo expert peer review to ensure the quality of the research.

Education and Workforce Development

To ensure the efficient movement of people and products, we must prepare a new cohort of transportation professionals who are ready to lead a more diverse, inclusive, and equitable transportation industry. To help achieve this, MTI sponsors a suite of workforce development and education opportunities. The Institute supports educational programs offered by the Lucas Graduate School of Business: a Master of Science in Transportation Management, plus graduate certificates that include High-Speed and Intercity Rail Management and Transportation Security Management. These flexible programs offer live online classes so that working transportation professionals can pursue an advanced degree regardless of their location.

Information and Technology Transfer

MTI utilizes a diverse array of dissemination methods and media to ensure research results reach those responsible for managing change. These methods include publication, seminars, workshops, websites, social media, webinars, and other technology transfer mechanisms. Additionally, MTI promotes the availability of completed research to professional organizations and works to integrate the research findings into the graduate education program. MTI's extensive collection of transportation-related publications is integrated into San José State University's world-class Martin Luther King, Jr. Library.

Report 24-22

Development of the Roadway Pothole Management Program

DingXin Cheng, PhD, PE

July 2024

California Pavement Preservation Center
California State University, Chico

A publication of the
Mineta Transportation Institute
Created by Congress in 1991

College of Business
San José State University
San José, CA 95192-0219

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
24-22		

4. Title and Subtitle	5. Report Date
Development of the Roadway Pothole Management Program	July 2024
	6. Performing Organization Code
7. Authors	**8. Performing Organization Report**
DingXin Cheng, PhD, PE	CA-MTI-2306
9. Performing Organization Name and Address	**10. Work Unit No.**
Mineta Transportation Institute College of Business San José State University San José, CA 95192-0219	**11. Contract or Grant No.** ZSB12017-SJAUX
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
State of California SB1 2017/2018 Trustees of the California State University Sponsored Programs Administration 401 Golden Shore, 5th Floor Long Beach, CA 90802	**14. Sponsoring Agency Code**

15. Supplemental Notes

10.31979/mti.2024.2306

16. Abstract

Addressing the issue of potholes is a primary concern for maintaining urban infrastructure. The research team has developed a prototype pothole management program. The program includes a mobile application and two machine learning models. The mobile app enables users to upload images of potholes, report relevant information, and provide driving directions to the pothole location. With the help of this application, the user can seamlessly capture images of the potholes, record pertinent information, and submit the data for necessary action. The mobile application is an essential tool in the Pothole Management Program (PMP), as it enhances the program's efficiency, effectiveness, and user experience. The program utilizes two machine learning models. The first model, Visual Geometry Group (VGG16), uses deep learning neural network technology to classify potholes with over 90% accuracy. The second machine learning model, You Only Look Once (YOLO), has been designed to detect and accurately mark potholes on submitted photos. Overall, this innovative pothole management program offers a comprehensive solution to help address the critical issue of potholes in urban areas.

17. Key Words	18. Distribution Statement
Pavement condition, Pothole reporting, Tracking, Management	No restrictions. This document is available to the public through The National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37	

Form DOT F 1700.7 (8-72)

DOI: 10.31979/mti.2024.2306

Mineta Transportation Institute
College of Business
San José State University
San José, CA 95192-0219

Tel: (408) 924-7560
Fax: (408) 924-7565
Email: mineta-institute@sjsu.edu

transweb.sjsu.edu/research/2306

Acknowledgments

The author would like to acknowledge the support from the Mineta Transportation Institute at San Jose State University, especially to Dr. Karen Philbrick and Dr. Hilary Nixon for their leadership and support of the project. This study used funds provided by Senate Bill 1 to the CSU Transportation Consortium, which includes four universities: SJSU, CSU Chico, CSU Fresno, and CSU Long Beach. The author appreciates the work from the student research assistants, Eulises Lepoz, Pablo Raigoza, and Devin Cheng for their help to develop the pothole management app and machine learning models. The author also appreciates the reviewers and editors who provided feedback on this report.

CONTENTS

List of Figures

List of Tables

Executive Summary

The road infrastructure in California has been a source of concern as highlighted by the 2021 Report Card for America's Infrastructure. The report assigned a grade of “D” to the roads, indicating a pressing need for improvement and investment. This assessment aligns with the findings of the San Francisco Bay Area’s Metropolitan Transportation Commission’s Pothole Report from 2018, which underscored the risks facing Bay Area roads and emphasized the urgency for maintenance and upgrades to ensure safety and efficiency. The condition of the roads not only affects daily commutes but also has broader economic implications. Poor infrastructure with many potholes can lead to increased vehicle operating costs and hinder economic growth. Addressing these issues is critical for the well-being of California’s residents and the overall functionality of its transportation systems.

Maintaining transportation pavement conditions presents a significant challenge, with potholes being a primary concern for comfort, safety, and vehicle damage. To address this issue, the research team has developed a prototype pothole management program consisting of a mobile application and two machine learning models.

The mobile application serves as a crucial element of the program, allowing users to upload images of potholes, report relevant information, and provide driving directions to pothole locations. This application streamlines the process of capturing images, recording pertinent data, and submitting information, enhancing the program’s efficiency, effectiveness, and user experience.

The first machine learning model, Visual Geometry Group (VGG16), utilizes deep learning neural network technology to classify potholes photos with an accuracy rate of over 90%. The second machine learning model, You Only Look Once (YOLO), is designed to detect and accurately mark potholes on submitted photos.

Overall, this innovative pothole management program presents a potentially comprehensive solution to address the critical issue of potholes in urban areas. It incorporates advanced machine learning techniques and a user-friendly mobile application to provide an efficient and effective approach to pothole management.

1. Introduction

The state of California's road infrastructure has been a point of concern, as highlighted by the 2021 Report Card for American's Infrastructure, which assigned a grade of "D" to the roads, indicating a pressing need for improvement and investment (ASCE, 2021). This assessment aligns with the findings of the Metropolitan Transportation Commission's Pothole Report from 2018, which underscored the risks facing Bay Area roads, emphasizing the urgency for maintenance and upgrades to ensure safety and efficiency (MTC, 2018). The condition of the roads not only affects daily commutes but also has broader economic implications, as poor infrastructure can lead to increased vehicle operating costs and hinder economic growth. Addressing these issues is critical for the wellbeing of California's residents and the overall functionality of its transportation systems. The discussions and report of California's poor road conditions serve as a call to action for policymakers and the public to prioritize infrastructure development and allocate the necessary resources to bring California's roads up to a standard that supports its vibrant economy and population.

Potholes are a significant issue for urban infrastructure. For example, big cities such as Los Angeles have struggled to respond to the record number of pothole reports (Carino, 2017). The correlation between poor pavement conditions and the emergence of potholes is well documented, with the latter posing risks not only to vehicular safety but also contributing to increased maintenance costs and environmental emissions. The statistics provided by AAA underscore the economic impact of potholes on American drivers, highlighting a substantial annual expense. AAA found that two-thirds of American drivers are concerned about potholes, and a study from AAA revealed that potholes cost U.S. drivers approximately $3 billion annually (AAA, 2016). Without proper repair, potholes can further damage other parts of the roadway at an accelerated rate (Caltrans, 2008).

The challenges faced by local agencies, especially in financially constrained communities, further exacerbate the issue, as limited resources hinder timely and effective road repairs. This cyclical problem is particularly pronounced during seasons with adverse weather conditions, which can accelerate roadway deterioration. Addressing the root causes of pavement degradation and investing in resilient infrastructure are critical steps towards mitigating the formation of potholes and ensuring safer, smoother travel for all road users. Moreover, adopting innovative materials and technologies for road construction and maintenance could offer long-term solutions to this pervasive issue. It is clear that a multifaceted approach, involving both immediate repairs and strategic planning, is essential to overcome the challenges posed by potholes and to enhance the overall quality of road networks.

Managing roadway infrastructure is a challenging task, particularly in the context of pothole repair. While apps like SeeClickFix (SeeClick/Fix, 2021) have been instrumental in enabling cities like Oakland to track and address roadway issues, there is a clear need for more advanced features that can provide local agencies with accurate locations and sizes of potholes, repair cost estimates, potential vehicle damage assessments, and possible emission modeling capabilities. The absence of these functionalities in current applications represents a gap in the tools available to city planners and maintenance teams. Moreover, the limited availability of these apps to smaller cities and low-income communities exacerbates the issue, leaving many without the means to efficiently report, repair, track, and manage potholes.

1.1 Background

With the rapid development and improvement in Artificial Intelligence (AI), our research team integrated deep learning models for more accurate pothole detection and the deployment of AI capability apps to facilitate real-time reporting. Such advancements not only streamline the process of identifying potholes but also enhances the precision of repair cost estimations and vehicle damage assessments. The development of a comprehensive pothole management program that includes these features is a significant step forward. It not only improves road conditions, but also contributes to the safety and comfort of drivers, reduces vehicle damage, and potentially lowers emissions due to smoother traffic flow. The research and implementation of such a program will be particularly beneficial for smaller cities in California which currently lack access to robust pothole reporting and repairing tools.

Addressing the pothole problem in California requires a multifaceted and multiple step approach that includes technological innovation, increased accessibility of reporting tools by citizens, and strategic planning. By leveraging the latest advancements in technology and making these tools available to all cities, regardless of size, California can make strides in improving its roadway infrastructure and the overall quality of life for its residents. The urgency of this matter cannot be overstated, as effective road maintenance is crucial for ensuring the safety and efficiency of the transportation networks that are vital to the state's economy and public welfare.

1.2 Organization of the Report

This report is organized into the following sections: Section 2 discusses the objectives of the research; Section 3 describes the methodologies used for this research; Section 4 shows the results and analysis; Section 5 presents the conclusions and recommendations.

2. Objective

The objective of this research is to develop a pothole management program that integrates modern technologies like smartphones and machine learning algorithms to support the agencies that report, track, and manage potholes.

The development of a comprehensive pothole management program is a significant step towards enhancing the efficiency and safety of California's roadway network. By integrating modern technologies such as smartphones and machine learning, agencies will have the ability to efficiently report and track the occurrence of potholes, and use the information to predict and model future pavement maintenance needs and associated vehicle costs. This proactive approach allows for timely interventions, reducing the frequency and impact of vehicle damage caused by potholes. Furthermore, the data collected through this program can be instrumental in designing predictive maintenance schedules, optimizing resource allocation, and improving overall pavement conditions. The use of machine learning techniques can facilitate the analysis of vast amounts of data to identify patterns and predict pothole formation, enabling preemptive repairs that can extend the lifespan of road surfaces. Additionally, the incorporation of smartphone technology empowers citizens to participate in the reporting process, fostering a collaborative environment between the public and the agencies responsible for road maintenance. This synergy can lead to more accurate and comprehensive data collection and enhance the effectiveness of the pothole management program. Ultimately, it is expected that the implementation of such a program will lead to safer driving conditions, a reduction in maintenance and vehicle repair costs, and a more resilient infrastructure capable of withstanding the challenges posed by traffic and environmental factors. The success of this initiative could serve as a model for other states and countries facing similar challenges, showcasing the potential of technology-driven solutions in public infrastructure management.

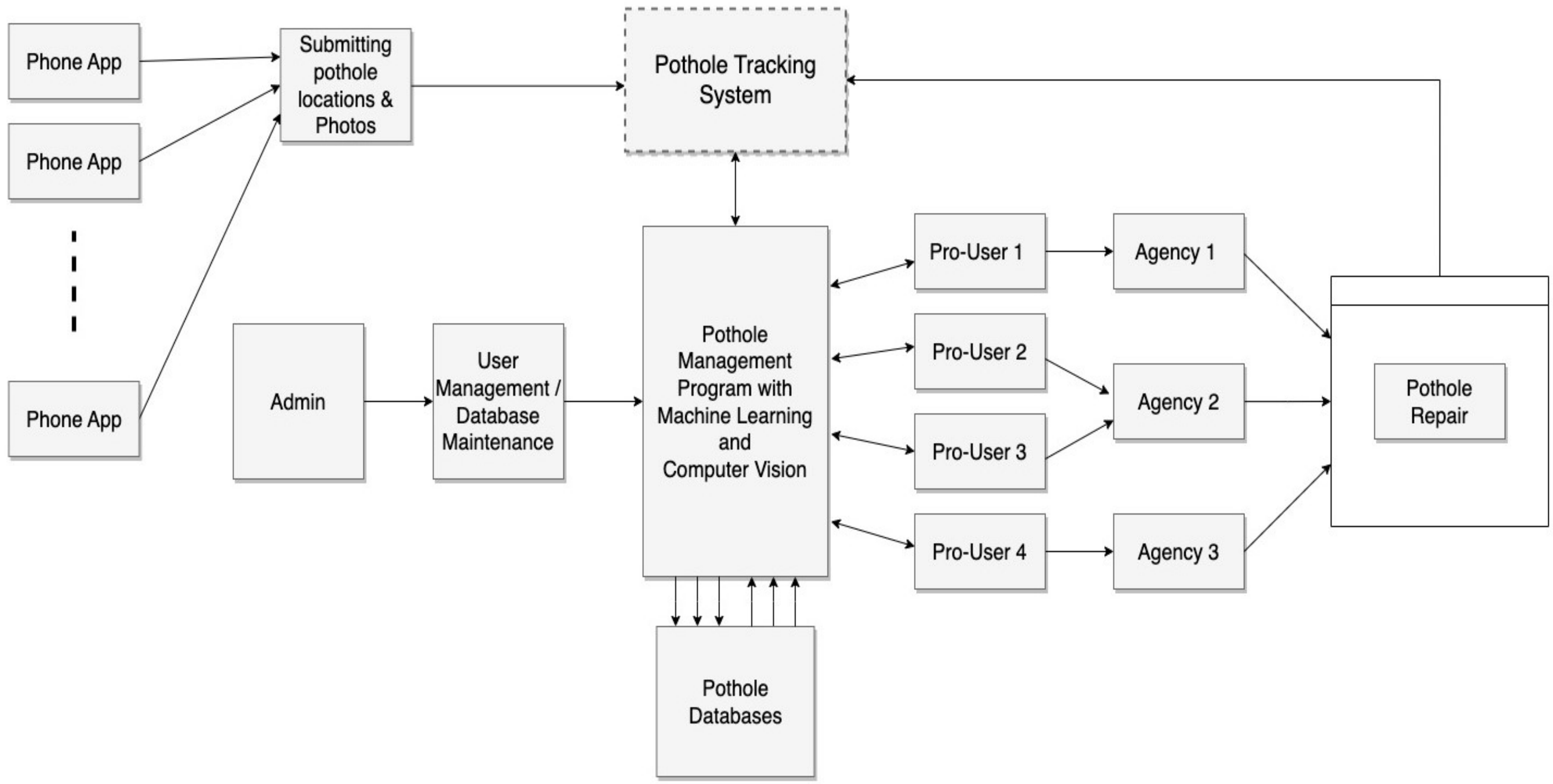
3. Research Approach

The research team has developed a prototype of a pothole management program (PMP) with the aim of establishing an effective reporting process that will contribute to the safety of everyone using the roads and improve maintenance of roadways for agencies. The PMP incorporates various features designed to enable reporting, tracking, and prioritizing of pothole repairs. The program is expected to provide a structured mechanism for managing potholes which can lead to better road safety and reduced repair costs.

3.1 Structure of Pothole Management Program

As shown in Figure 1, the PMP includes a mobile app that citizens can download and use to report potholes. The pothole information is submitted to an online server which functions as a pothole tracking system. Within the PMP, a machine learning algorithm has been developed to classify and detect potholes each submitted photo. The pothole photo along with its GPS location and timestamp can be saved in the pothole database. Based on the location of a pothole, the information can be sent to the agency responsible for the repair and maintenance of the roadway surface. A Pro-User is set up in the system to help manage the potholes submitted. General users can only see the potholes reported by themselves, but a Pro-User can view all pothole photos and their related information. A Pro-User of an agency PMP can send the maintenance crew to repair the pothole. After the pothole is repaired, the information is sent back to the pothole tracking system. The pothole is then marked as repaired, and the record can be saved in the PMP.

Figure 1. Diagram of the Pothole Management Program



3.2 Pothole Reporting

The integration of smartphones into daily life has revolutionized the way we approach community issues such as infrastructure maintenance. With virtually everyone equipped with a camera in their pocket, citizen science initiatives have become a powerful tool for identifying and reporting problems like potholes. By empowering citizens to photograph and report potholes, the team aims to create a collaborative platform for infrastructure reporting. This method not only engages the community in a shared goal of improving road conditions, but also provides authorities with real-time, geotagged data to prioritize repairs. Such a participatory approach can enhance the responsiveness of services, foster civic engagement, and promote a sense of collective responsibility. Moreover, it could potentially streamline the maintenance process, reduce costs, and reduce the response time to such issues. This innovative use of technology and community involvement exemplifies the potential of citizen science to contribute to the betterment of everyday life. The research team's approach to utilize citizen science for pothole reporting is a testament to the innovative ways in which technology can be harnessed to improve quality of life and civic engagement.

3.3 Use Machine Learning to Classify and Detect Potholes

Machine learning, a pivotal component of artificial intelligence, has made significant strides in recent years, transforming the way to approach and solve many complex problems. The development of a trained machine learning model to classify images of potholes is a prime example of this advancement. By leveraging vast datasets and sophisticated algorithms, such a model can learn to recognize the characteristics of potholes, differentiating them from other road anomalies, (i.e., alligator cracking or patching), or non-issues (i.e., shades) with remarkable accuracy. This streamlines the process of identifying necessary repairs and optimizes the allocation of resources, ensuring that maintenance efforts are directed where they are most needed. Furthermore, the automation of this task reduces reliance on human judgement, which can be subjective and inconsistent, and thereby enhancing the overall efficiency of road maintenance operations.

The cost-effectiveness of machine learning models comes from their ability to work tirelessly, analyze thousands of images rapidly, and adapt to new patterns over time, which are tasks that are considerably more time-consuming and expensive if performed by staff members. Additionally, the continuous improvement of these models through retraining and updating ensures that their performance only gets better with time, making them an invaluable tool for urban planning and infrastructure management. The integration of machine learning in such practical applications shows its potential to revolutionize various industries by providing smart, scalable, and sustainable solutions.

4. Results and Analysis

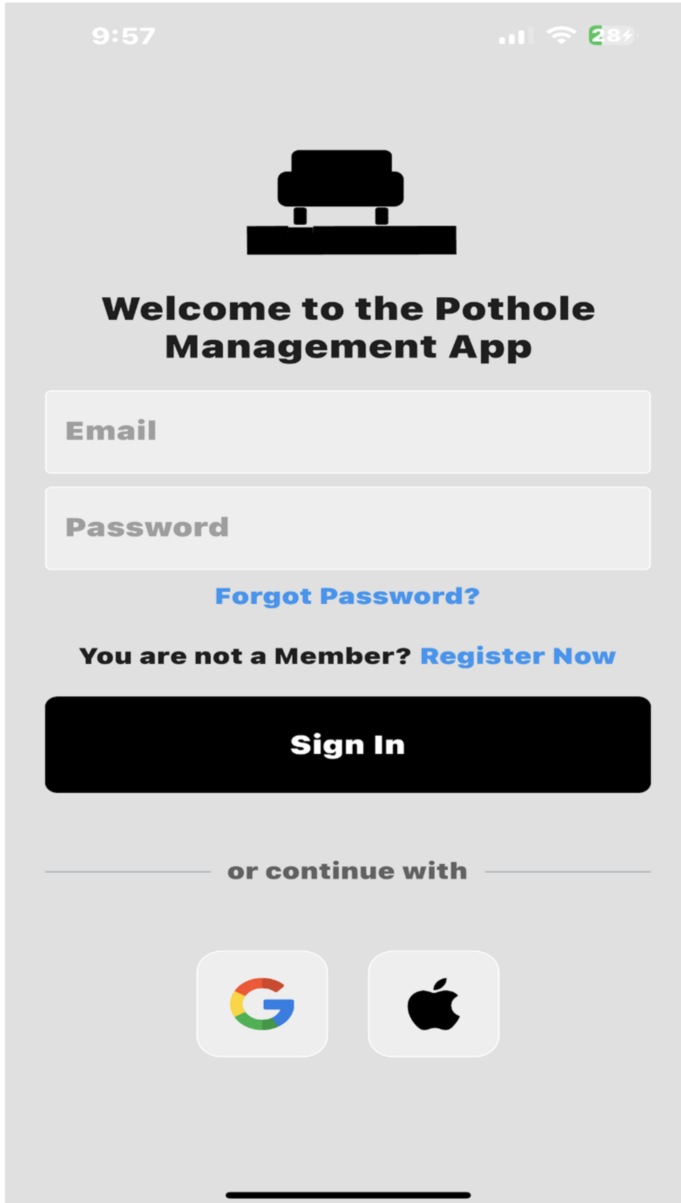
4.1 Mobile App for Pothole Management Program

The research team has developed an app for iPhone users to report and track pavement potholes, which is published in Apple's App Store. It has a nominal price to help set up the account and prevent people from randomly downloading and submitting non-pothole related photos to the research team's online database. Any citizen who want to report potholes can get the app for free by requesting it from the research team directly. The following section shows the major functions of the Pothole Management App.

Create Account:

Figure 2 shows the interface to create an account to use the app to report potholes. There are three options available: using an Apple account, a Google account, or creating a new email/password account.

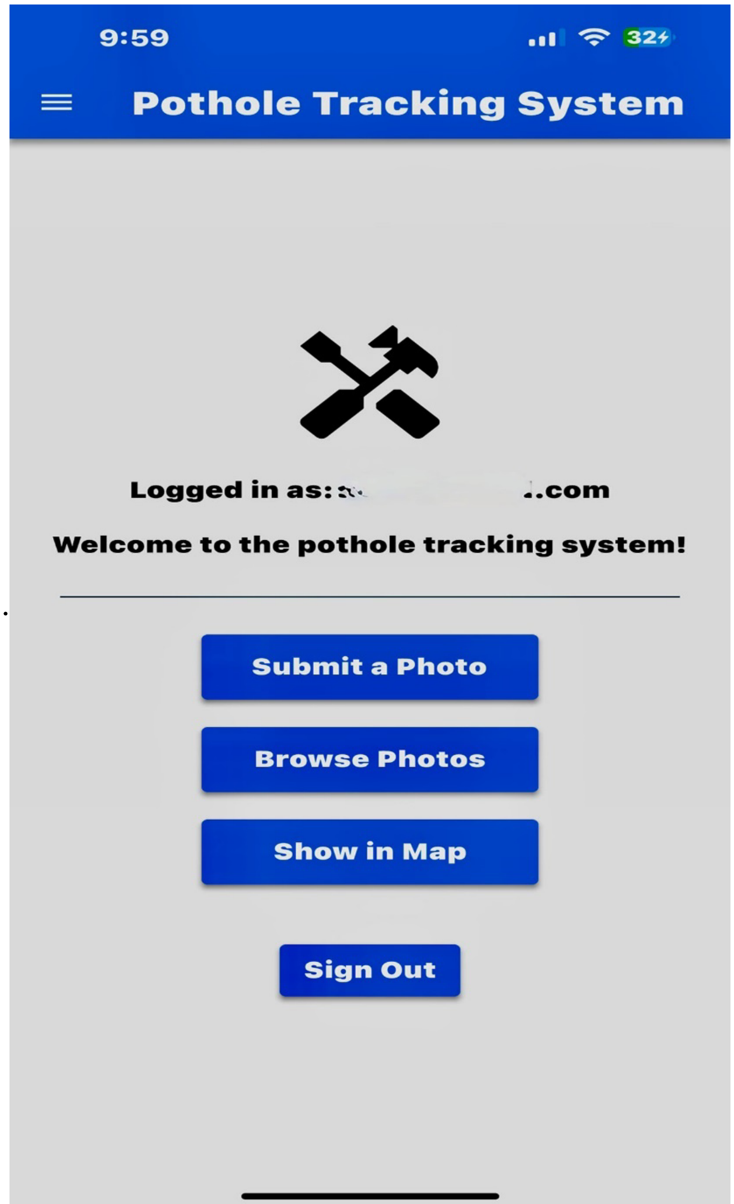
Figure 2. Create an Account for Reporting Potholes



Home Page:

Figure 3 shows the homepage of the pothole management app. It has three main buttons: Submit a Photo, Browse Photos, and Show Pothole Locations in a Map.

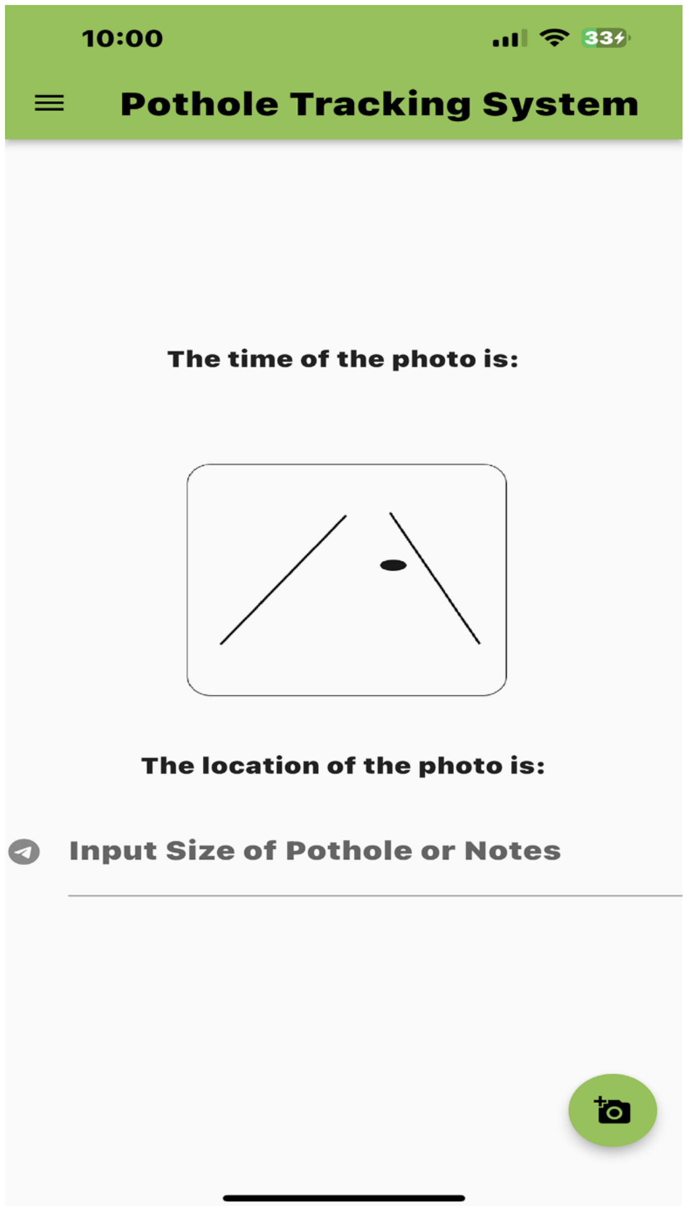
Figure 3. Home Page of the App



Submit a Photo:

A user can submit a photo with pothole information as shown in Figure 4. There is a camera button at the lower right portion of the screen. The user can use the phone to take a photo. The user is also allowed to input some notes regarding the pothole found and information about the size of the pothole.

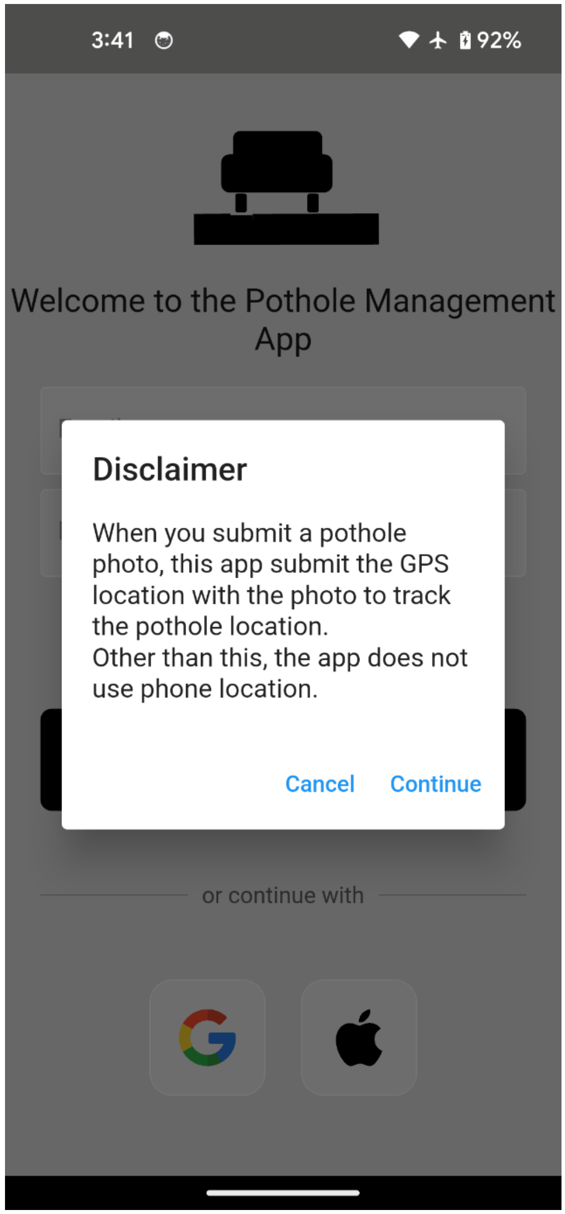
Figure 4. Submit a Photo



GPS Location:

Figure 5 illustrates that the app will need to use the GPS of the phone to help identify the location of a pothole. The disclaimer is to show a user that the app does not track the locations of the phone.

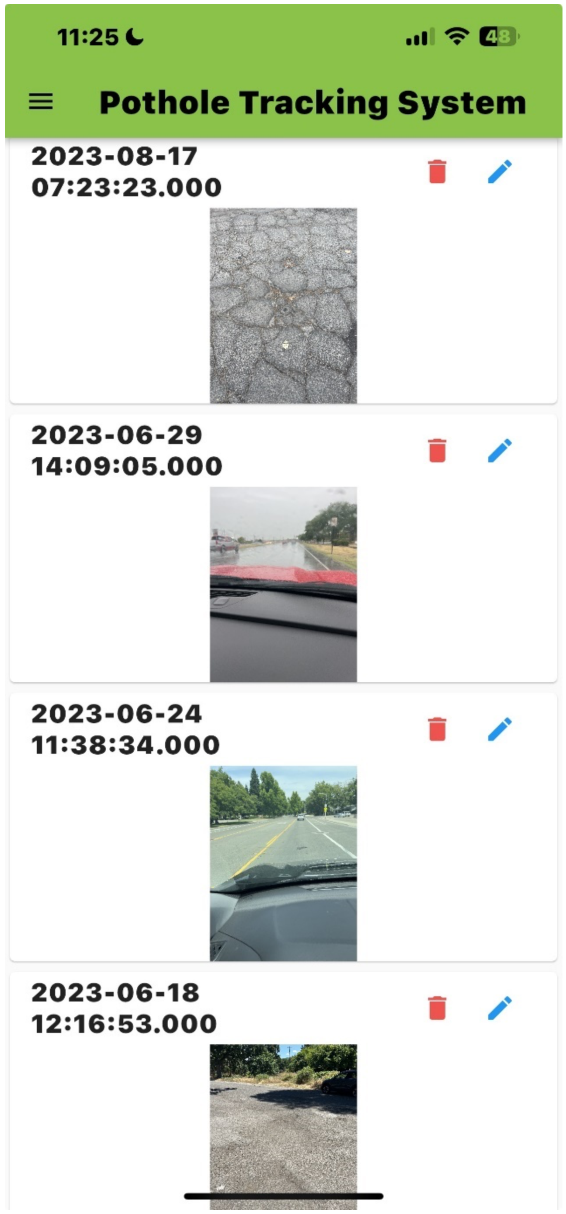
Figure 5.GPS Location



Browse Photos:

General users can browse the photos that they submitted to the server. A Pro-User will be able to browse all photos within an agency's jurisdiction, as shown in Figure 6. A Pro-User can also edit or delete the photos on the server.

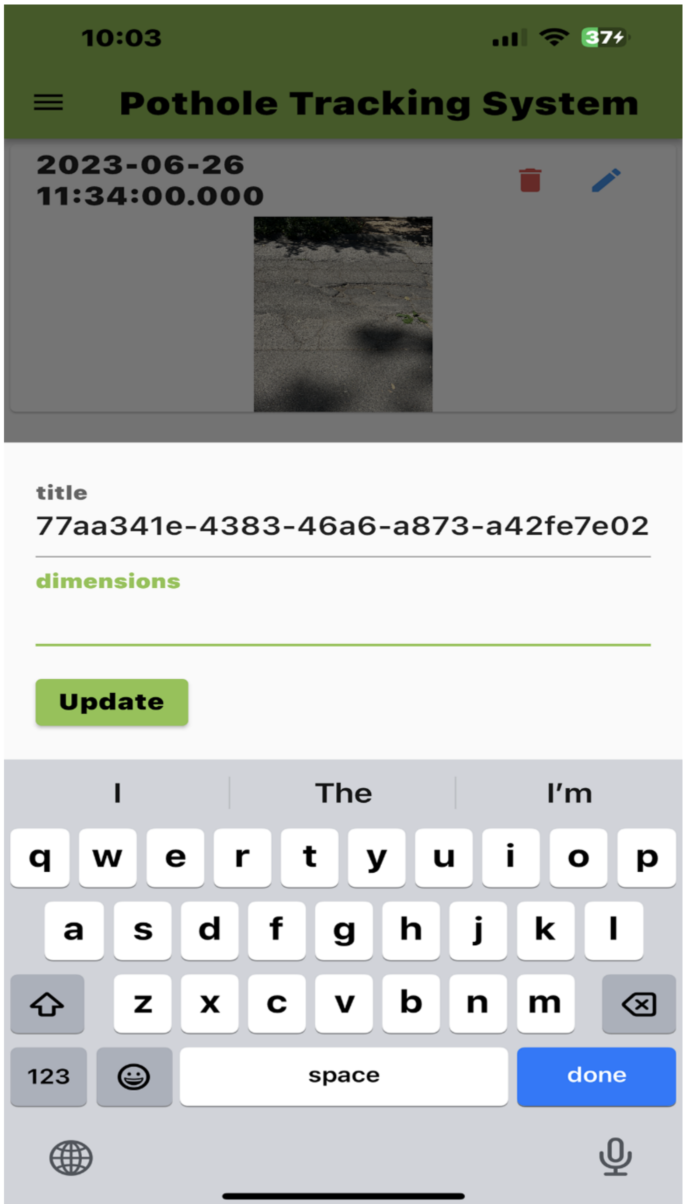
Figure 6. Browse the Photos Submitted



Update Photo Information:

As shown in Figure 7, a user can update the information of a submitted pothole photo. The user can edit the title and dimensions of the pothole and then update the submission.

Figure 7. Update Photo Information



View a Submitted Photo:

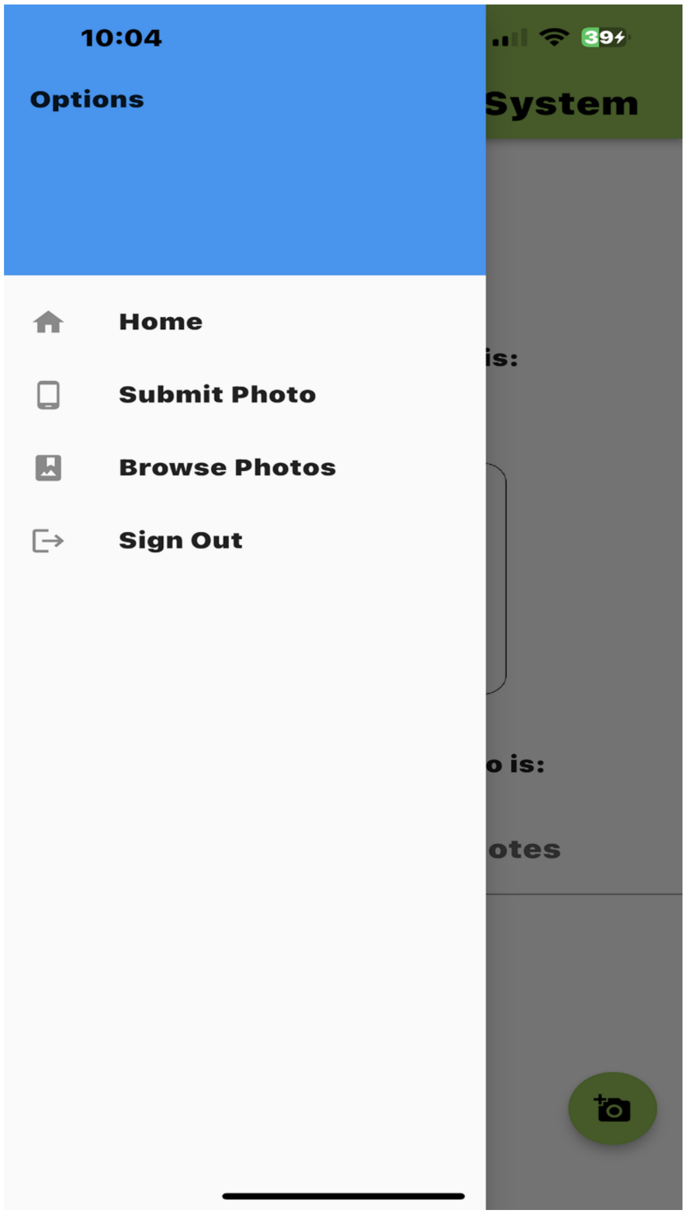
By tapping on the thumbnail of a submitted pothole photo, a user can view the enlarged photo as shown in Figure 8.

Figure 8. View a Pothole Photo Inside the App

Drawer for Menu:

As shown in Figure 9, there is a drawer button on the top-left of the phone's screen. By clicking on the drawer button, a user can access the major functions of the app from any page.

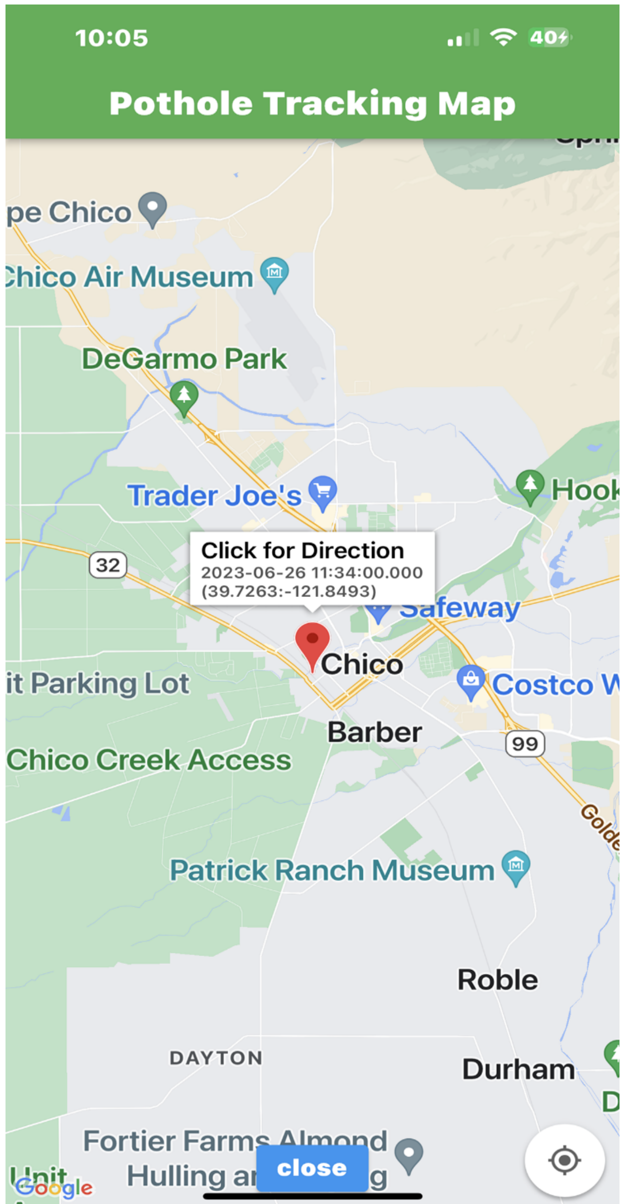
Figure 9. Drawer for Menu



View Pothole Locations:

As shown in Figure 10, users can view on a map the pothole locations that they have submitted. By tapping a pothole location, the user can see the timestamp and GPS coordinates of the pothole.

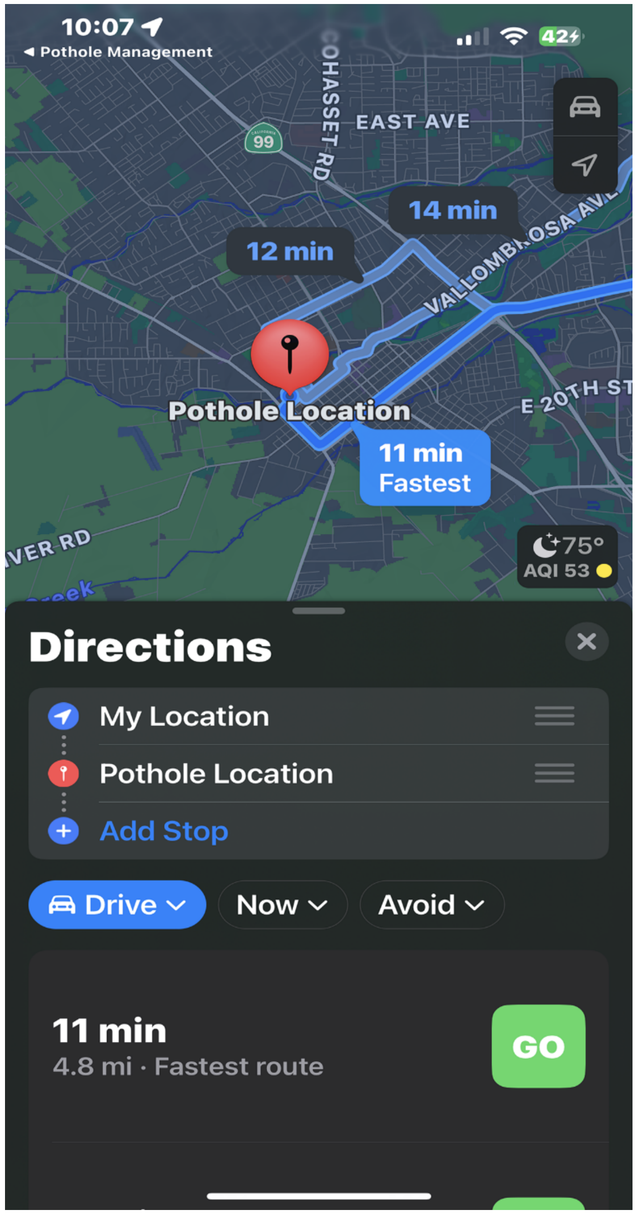
Figure 10. View Pothole Location



Directions to a Pothole Location:

By clicking on a pothole location marker, users can obtain the driving directions from their current location to the selected pothole as shown in Figure 11. This feature is useful for any maintenance crew to find the location of the submitted pothole.

Figure 11. Direction to Pothole



4.2 Machine Learning Models for Pothole Management Program

The method of manual checking whether a photo contains a pothole or not is time-consuming and ineffective since it requires human staff to review each photo. This can result in photos without potholes being sent to a responding agency. To resolve this problem, the research team is developing a solution that utilizes AI's machine learning techniques. The goal is to develop a system that can accurately identify photos with potholes, allowing for a more efficient and effective pothole management program.

The evolution of machine learning algorithms in recent years has been remarkable, particularly in the field of image recognition and classification. Algorithms have the ability to detect intricate patterns and anomalies after being trained. By utilizing advanced machine learning algorithms, the research team has developed machine learning models to classify and detect potholes on submitted photos.

More than 600 photos were collected from various sources to train machine learning pothole models. About 50% of the photos contain at least one pavement pothole, while the other 50% of the photos do not have any potholes. A supervised method was used for the training; therefore, all potholes were labeled. Two machine learning models have been developed for this research. The first model is a classification model using VGG16. VGG means Visual Geometry Group, which is a classical deep Convolutional Neural Network (CNN) architecture that excels in image recognition. Developed by the Visual Geometry Group at the University of Oxford, it is widely regarded as one of the best vision model architectures to date (Great Learning, 2021). The VGG16 model is used to determine if a submitted photo contains any pothole or not. The second model is an object detection model using You Only Look Once (YOLOv8) developed by Ultralytics (Ultralytics, 2023). This model is used to determine the number of potholes and their positions in a photo submitted through the Pothole Management App. Python codes were developed to train the models and predict the results. Following are details about the two machine learning models and their results.

4.2.1 Classification Model

VGG16 supports 16 convolutional layers in the model, which is a convolutional neural network model proposed by A. Zisserman and K. Simonyan from the University of Oxford (Simonyan & Zisserman, 2015). The VGG16 model achieves almost 92.7% top five test accuracy in ImageNet, which is a dataset consisting of more than 14 million images belonging to nearly 1000 classes. The images for this research were divided into a training group and a testing group. Each group has a class of "Pothole" and a class of "No Pothole."

The VGG16 classification model provided good results for classifying pothole photos. As shown in Table 1, the confusion matrix shows that 97% of pothole photos were correctly identified and 95% of no pothole photos were correctly identified (Raigoza et al., 2023). The Accuracy of the pothole classification is 0.961, which is calculated as (True Positive + True Negative)/(Total

Photos); The Recall of the pothole classification is 0.973, which is calculated as (True Positive)/(True Positive + False Negative); The Precision of the pothole classification is 0.923, which is calculated as (True Positive)/(True Positive + False Positive); In addition, F1 Score (F-Measure) is a machine learning model performance measure, which combines precision and recall into a single score. F1 Score is calculated as 0.947 based on the formula: F-score = 2 * (precision * recall) / (precision + recall).

Table 1. Classification Model Results – Confusion Matrix

Normalized		Actual	
		Pothole	No Pothole
Predicted	Pothole	0.97	0.05
	No Pothole	0.03	0.95

4.2.2 Object Detection Model

YOLOv8, developed by Ultralytics, is one of the most popular model architectures and object detection algorithms (Vina, 2024). It currently uses one of the best neural network architectures for its speed and accuracy. As a result, fast and accurate detection of objects in images can be achieved. Since its initial development, improvements have been made to successive iterations of the YOLO family. In January 2023, the YOLOv8 version was published by Ultralytics, with its applications including classification, object detection, segmentation, pose estimation, and tracking (Ultralytics, 2023). The YOLOv8 model has been selected for the task of detecting potholes within the submitted photos. The dataset was split into three sets: 70% training, 20% validation, and 10% testing.

The YOLOv8 model also provides good results for identifying location(s) of pothole(s) in photos (Raigoza et al., 2023). Table 2 shows the YOLO parameter results during the training process. An epoch represents one complete iteration over the entire training data. Multiple epochs allow the model to learn from the data gradually and refine its internal representations. In each epoch, the model computes predictions for each training sample, calculates the loss (error) between the predicted values and actual labels; and the optimizer of the model adjusts the model's parameters to minimize this loss. The number of epochs for training is an important parameter (hyperparameter). In machine learning, a hyperparameter is a parameter whose value controls the behavior of the learning algorithm and is set before the training, while a model parameter is learned during training. The practitioner sets up the epochs before the training begins. Too few epochs may result in underfitting, while too many epochs can lead to overfitting. To prevent overfitting, the research team has monitored the validation loss during the training. The number of epochs was set as 200; however, the model was stopped at 179 epochs due to early stopping. The precision in the table measures the ability of the model to identify true positives among all the predicted positive instances in the validation dataset. The recall assesses the model's capability to find all the true positives, asking the question: "Out of all the ground truth positive samples, how many did the model correctly detect?"

The mAP50 stands for Mean Average Precision at Intersection over Union (IoU) threshold 0.50. The AP is the area under the precision-recall curve for each class, and mAP is the mean of the AP values across all classes. The IoU 0.50 considers a detection as correct if the overlap between the predicted bounding box and the ground truth bounding box is at least 50%. The mAP50-90 extends the evaluation to a range of IoU thresholds. Instead of just considering IoU at 0.50, it computes AP values across a spectrum of IoU thresholds from 0.50 to 0.960. The final mAP50-90 is the average of these AP values. Higher mAP values indicate better object detection performance and are suitable for a broad assessment of model performance. The IoU is essential when precise object location is crucial.

As shown in Table 2, as epochs increase, all metrics including precision, recall, mAP50 and mAP50-90 also increase. In the end, these metrics level off or decrease with the increase of epoch; therefore, the training stops. At epoch 173, the precision, recall, mAP50 and mAP50-90 all reach the highest values. The training weights and results at epoch 173 are saved as the best parameters for the model.

Table 2. Results of YOLOv8 Training Parameters

epoch	metrics/precision	metrics/recall	metrics/mAP50	metrics/mAP50-95
1	0.00186	0.74359	0.05422	0.01775
10	0.26939	0.26923	0.18799	0.0568
20	0.42938	0.38462	0.40236	0.16326
30	0.46768	0.3717	0.36428	0.15289
40	0.64213	0.41026	0.51408	0.22785
50	0.6639	0.42308	0.49059	0.23345
60	0.56653	0.4359	0.47247	0.22719
70	0.91779	0.4359	0.55514	0.28961
80	0.63978	0.46154	0.51733	0.23704
90	0.6264	0.39744	0.46421	0.18096
100	0.70614	0.46213	0.54863	0.23693
110	0.76086	0.44872	0.50803	0.2273
120	0.73512	0.48718	0.54457	0.25134
130	0.70683	0.47436	0.53384	0.24621
140	0.76118	0.5	0.54644	0.25778
150	0.66839	0.51282	0.56577	0.24215
160	0.56218	0.44453	0.46996	0.19406
173	0.78693	0.48718	0.6062	0.27617
179	0.64677	0.44872	0.4777	0.22208

Figure 12 is the precision-recall curve of the object detection model. Generally, the higher the curve is in the upper right corner, the larger the area under the curve, indicating a higher Average Precision (AP) and better machine learning model. In this case, the AP for pothole class is 0.6 (60%), which means that the locations of most of the potholes can successfully be identified. As an example, Figure 13 shows that three potholes and their locations are identified in the photo.

Figure 12. Precision-Recall Curve of YOLOv8 Model

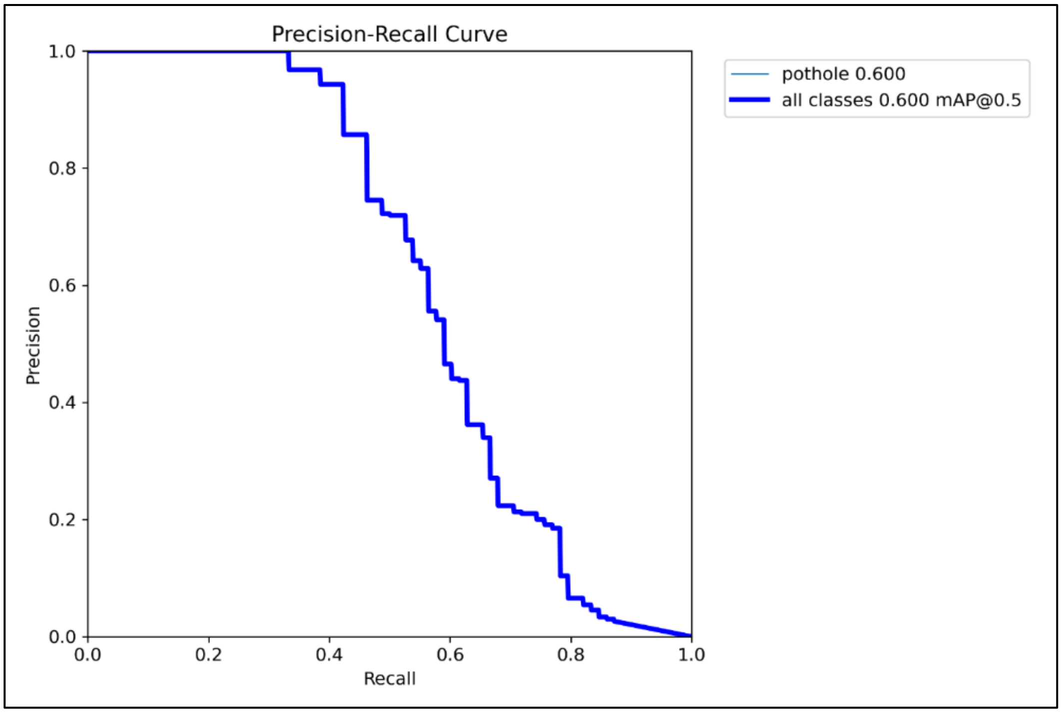


Figure 13. Example of Pothole Detection by the YOLO Model

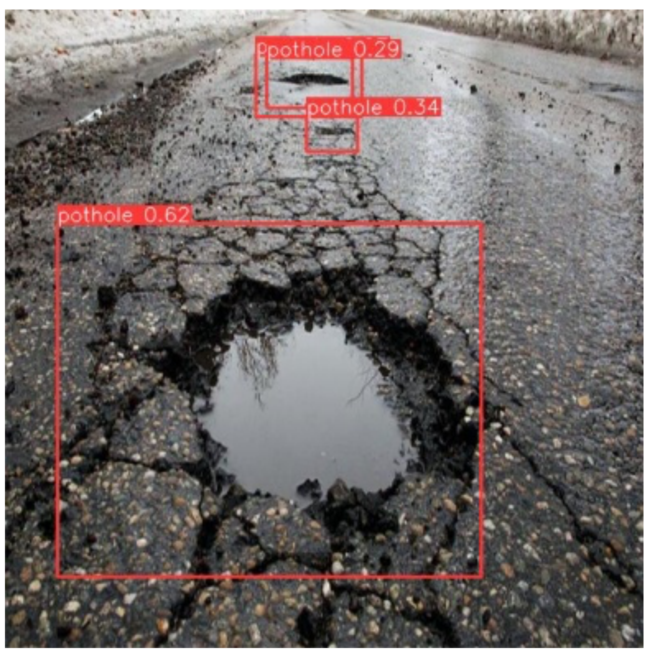
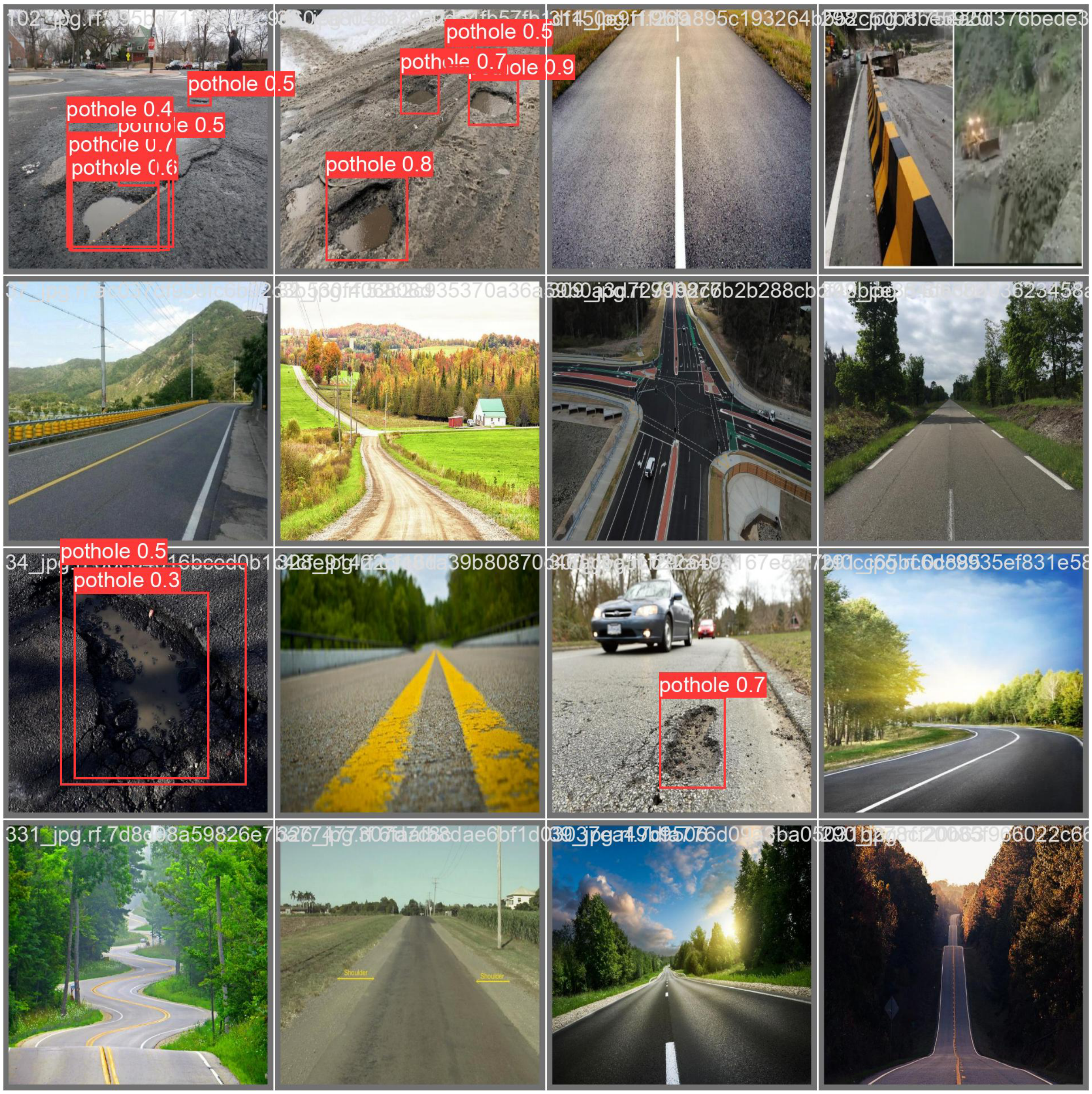


Figure 14 shows the pothole prediction results on one batch of 16 photos. For most of the photos, the developed YOLO model can identify all photos that do not have any potholes. The model is also able to identify all photos that have pothole(s). However, not all ground truth potholes are identified. For example, a few potholes in the second photo in the top row are missed by the model. Therefore, there is room for improvement in the pothole detection model.

Figure 14. Batch Prediction of Potholes on 16 Photos



5. Conclusions and Recommendations

In summary, a prototype of pothole management program has been developed which includes a mobile app and two machine learning models.

5.1 Conclusions

The following are conclusions from this study:

1. The Pothole Management Program incorporates a mobile application that facilitates the submission of pothole photographs, tracking of pothole information, and provision of driving directions to the identified potholes. This mobile application provides a user-friendly interface that streamlines the process of reporting and managing potholes.

2. A classification model has been developed to help determine if there are any potholes in a submitted photo. If there is no pothole in the photo, the photo will not be submitted to a responsible agency.

3. An object detection model has been developed using machine learning algorithms to show the number and location of potholes in any submitted photos. This information is useful for agencies to prepare maintenance repairing methods on potholes.

5.2 Recommendations

The following are the conclusions from this study:

1. In the forthcoming phases of the mobile application, advanced features that facilitate the process of reporting, tracking, and managing pothole repairs will be included. These features will enhance the efficiency and effectiveness of the application. Integrating these features will augment the user experience and streamline the overall process involved in pothole repairs.

2. The research team should improve the classification and object detection model in order to enhance the accuracy of its results. The objective is to achieve greater precision and reliability in classification and object detection outcomes, thereby providing agencies with a higher level of satisfaction.

3. The research team should develop a segmentation model to estimate the sizes of potholes. This information could help agencies determine the amount of materials for pothole repair.

4. Incorporation of costs and emission modeling into the pothole management program would provide valuable insights into the economic and environmental impact of roadway potholes, enabling more sustainable decision-making.

Bibliography

AAA. (2016). Pothole Damage Costs Drivers $3 Billion Annually Nationwide. American Automobile Association. http://news.aaa-calif.com/news/pothole-damage-costs-drivers-3-billion-annually-nationwide

ASCE. (2021). *Infrastructure Report Card*. https://infrastructurereportcard.org/cat-item/roads/

Auto Insurance. (2023). *The State of Potholes in the U.S.* https://www.autoinsurance.com/research/pothole-damage/

Caltrans. (2008). Maintenance Technical Advisory Guide, 2nd edition. Caltrans, CA.

Carino, M. M. (2021). *LA Struggles to Respond to Record Number of Pothole Reports*. https://www.scpr.org/news/2017/02/07/68852/la-struggles-to-respond-to-record-number-of-pothol/

Great Learning. (2021). *Everything You Need to Know about VGG16*. https://medium.com/@mygreatlearning/everything-you-need-to-know-about-vgg16-7315defb5918

MTC. (2021). *The Pothole Report: Bay Area Roads at Risk.* https://mtc.ca.gov/sites/default/files/Pothole%20Report%20III_September%202018.pdf

Pothole Info. (2021). *Citizen Pothole Reporting Via Phone Apps Take Off, But Can Street Maintenance Departments Keep Up?* https://www.pothole.info/2010/12/citizen-pothole-reporting-via-phone-apps-take-off-but-can-street-maintenance-departments-keep-up/

Raigoza, P., Cheng, D. X., Lopez, E. Y., & Cheng, D. X. (2024). *Utilizing Machine Learning in a Pothole Management Program. Data Science for Pavement Symposium 2024.* Turner Fairbank Highway Research Center. Mclean, Virginia.

SeeClickFix. (2021). *Better Neighborhoods Build a Better World*, New Haven, CT. https://seeclickfix.com/

Simonyan, K. & Zisserman, A. (2015). Very Deep Convolutional Networks for Large-Scale Image Recognition. *Computer Vision and Pattern Recognition*.

Ultralytics. (2023). *Ultralytics YOLOv8 Docs*. Home - Ultralytics YOLOv8 Docs

Vina, A. (2024). Ultralytics YOLOv8 Turns One: A Year of Breakthroughs and Innovations. Ultralytics YOLO.

About the Author

Ding Cheng

Dr. DingXin (Ding) Cheng is a professor at the Department of Civil Engineering, California State University, Chico, Director of the California Pavement Preservation (CP2) Center, and the Director of the Tire Derived Aggregate Technology Center. He has worked actively with the CP2 Center since he joined CSU Chico in 2006. He obtained his Ph.D. in pavement materials and transportation from Texas A&M University in College Station, Texas in 2002. He worked for Parsons Brinckerhoff in Houston, TX before joining CSU Chico. He has extensive experience in HMA materials and pavement preservation on both asphalt and concrete pavements. He has more than 55 peer-reviewed publications related to pavement materials and preservation for TRB, AAPT, ASCE, and other conferences. Ding has co-managed or managed more than $10 million in research projects funded by Caltrans, California Department of Resources Recycling and Recovery (CalRecycle), Metropolitan Transportation Commission (MTC), and other agencies and industry. He is a registered Professional Engineer in the State of Texas.

MINETA TRANSPORTATION INSTITUTE