TRB Annual Meeting

Developing a Framework for a Pothole Management Program

--Manuscript Draft--

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Developing a Framework for a Pothole Management Program

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ABSTRACT

Addressing the issue of potholes is a primary concern for maintaining roadway infrastructure. The research team has developed a framework for a pothole management program. The program includes a mobile application and machine learning models. The mobile app enables users to upload images of potholes, report relevant information, and provide driving directions to pothole locations. 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 (PHMP), 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.

Keywords: Pavement condition, Pothole reporting, tracking, repair, management

INTRODUCTION

Maintaining transportation pavement conditions presents a significant challenge, with potholes being a primary concern for comfort, safety, and vehicle damage. The state of California's roadway 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 (*1*). 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 (*2*).

Potholes pose major challenges to urban infrastructure. For example, big cities such as Los Angeles have struggled to respond to the record number of pothole reports (*3*). 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 (*4*). Without proper repair, potholes can further damage other parts of the roadway at an accelerated rate (*5*).

The challenges faced by agencies, especially in financially constrained local governments, 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.

Managing roadway infrastructure is a challenging task, particularly in the context of pothole repair. While apps like RequestIndy (version 5.0) (*6*) have been instrumental in enabling cities like Indianapolis 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, and potential vehicle damage assessments. The absence of these functionalities in current applications represents a gap in the tools available to agency 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.

With the rapid development and improvement in Artificial Intelligence (AI) and computer vison, the research team integrated deep learning models for more accurate pothole detection, which can lead to prioritize the tasks and fix the critical potholes first. The research team also deployed an AI capability app to facilitate timely reporting. By leveraging the latest advancements in technology and making these tools available to all cities, regardless of size, an effective pothole management program can help improve roadway infrastructure and the overall quality of life for its residents.

Objective

The objective of this research is to develop a framework for a pothole management program that integrates modern technologies like smartphones and machine learning algorithms to support agencies on reporting, tracking, repairing, and managing potholes.

The development of a comprehensive pothole management program is a significant step towards enhancing the efficiency and safety of an agency'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 data driven approach allows for timely interventions, reducing the frequency and impact of vehicle damage caused by potholes. 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.

PROPOSED FRAMEWORK

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

As shown in Figure 1, the PHMP includes four major components: Pothole Reporting System, Pothole Tracking System, Pothole Management System, and Pothole Repair. The details of each component are described in the following sessions.

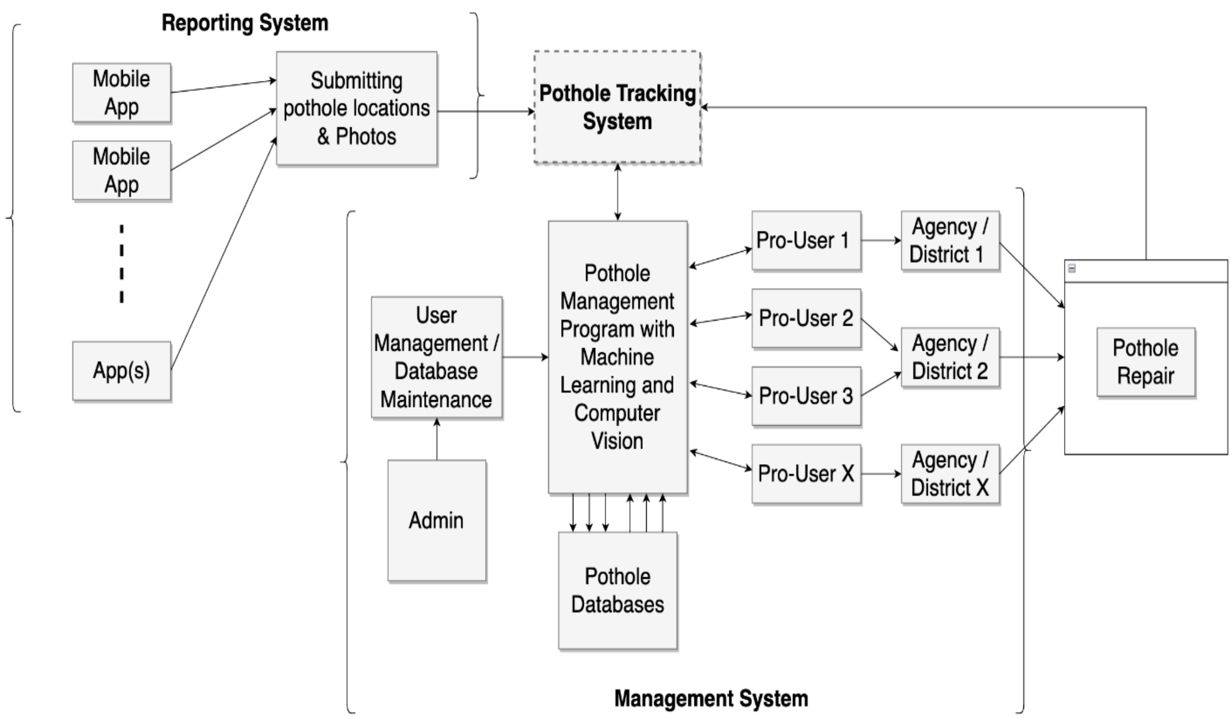
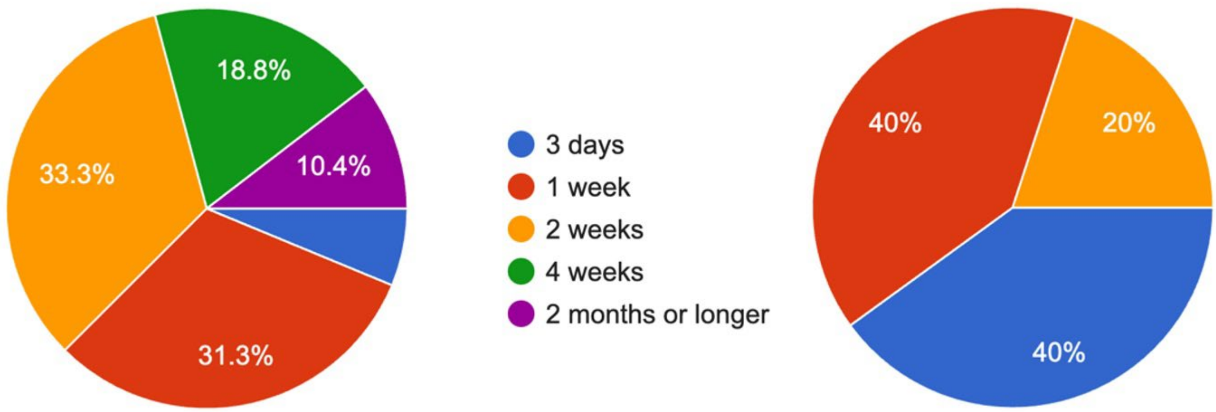


Figure 1 Framework of a Pothole Management Program (PHMP)

POTHOLE REPORTING SYSTEM

Pothole Survey

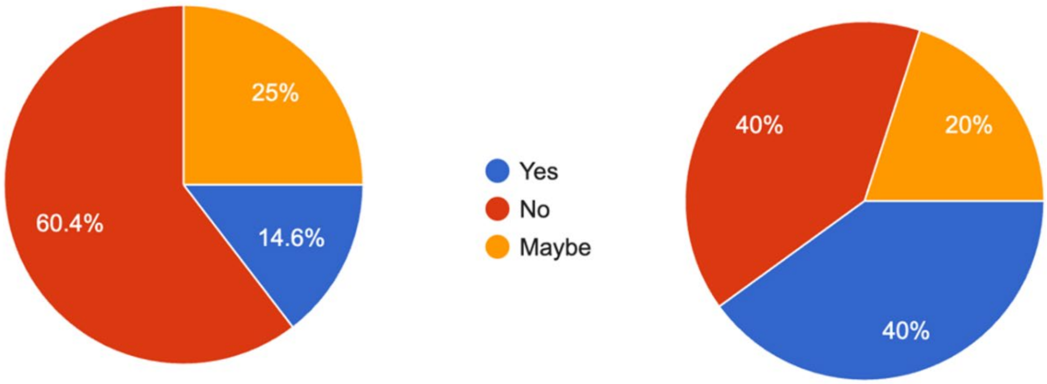
To gather views from both citizens and public officials on pothole repair issues, an online survey was conducted in the City of Chico in California in summer 2024. The survey was sent out to about 200 citizens and 20 city officials. There were 48 citizens and 5 city officials responded to the short survey. Here is a short survey summary. Survey question: For citizens, have you encountered any potholes that significantly impacted your daily commute or vehicle condition? Answers: 89.6% responded YES, while 10.4% responded NO. Survey question: How soon do you think that a pothole should be repaired after it is formed? The left pie chart of Figure 2 shows the responses from citizens, while the right pie chart shows the responses from the city officials. Based on the results, most citizen responses show that a pothole should be repaired in 1-2 weeks, while some potholes could be repaired in 4 weeks or longer. The majority of city official responses show that a pothole should be repaired in 3 days to 1 week; All potholes should be repaired in 2 weeks. Based on the results, the city officials try to do a better job than citizens expected.



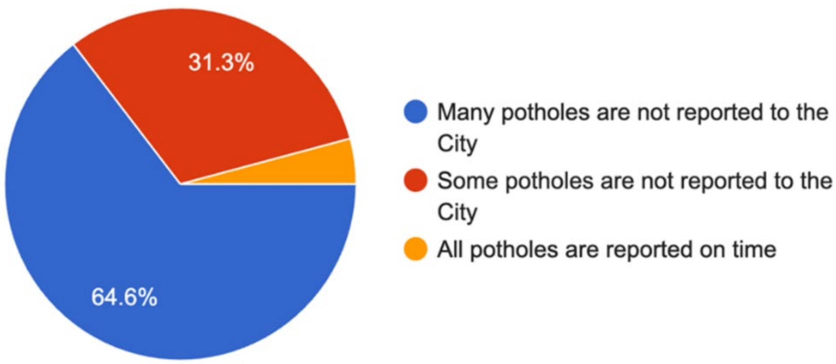
Citizen Responses   City Official Responses

Figure 2 Responses of How Soon a Pothole Should be Repaired

Survey question: Do you think that the City has done a good job repairing potholes on the roads? Figure 3(a) shows the responses from citizens, while Figure 3(b) shows the responses from the city officials. Based on the results, 60.4% of citizen responses show that the City didn't do a good job repairing potholes, while 40% of city official responses show that the City didn't do a good job. On the other hand, 14.6% of citizen responses show that the City did a good job repairing potholes, while 40% of city official responses show the City did a good job repairing potholes. Figure 3(c) show that 64.6% of citizen respondents feel many potholes were not reported to the City and 31.3% of citizen respondents think some potholes were not reported to the City.



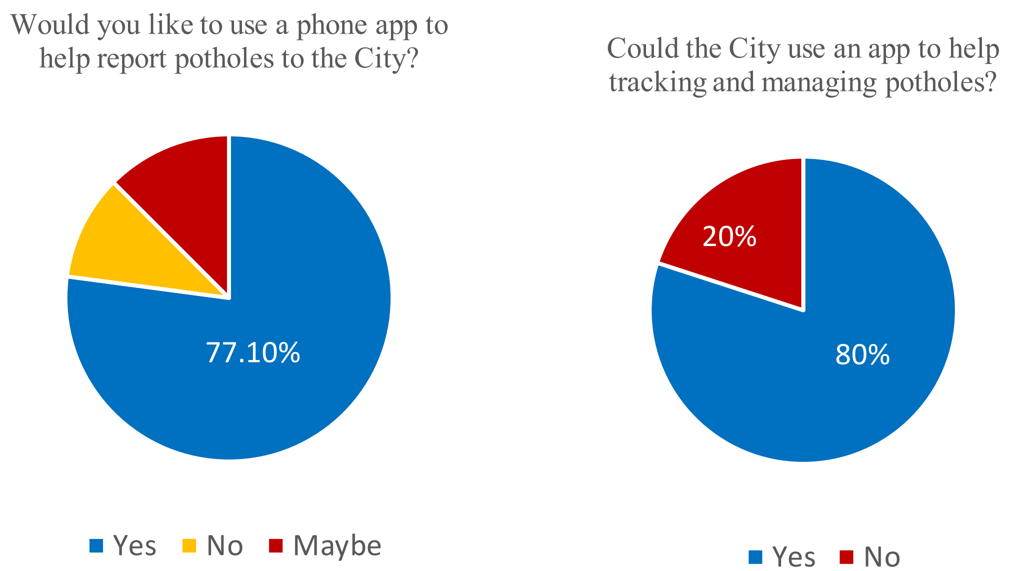
(a) Citizen Responses (b) City Official Responses



(c) Citizen Responses on Pothole Reporting

Figure 3 Responses of the City Did a Good Job to Repair Potholes on the Roads

Survey question: Would a phone app help reporting, tracking, and managing potholes? Figure 4(a) shows the responses from citizens, while Figure 4(b) shows the responses from the city officials. 77.1% of citizen respondents stated that they would like to use a phone app to help report potholes to the City, while 80% of city official respondents would like to use an app to help tracking and managing potholes. Overall, the survey shows that a pothole management app would be useful for pothole reporting, tracking, and managing purposes.



(a) Citizen Responses (b) City Official Responses

Figure 4 Would a Phone App Help Reporting, Tracking, and Managing Potholes

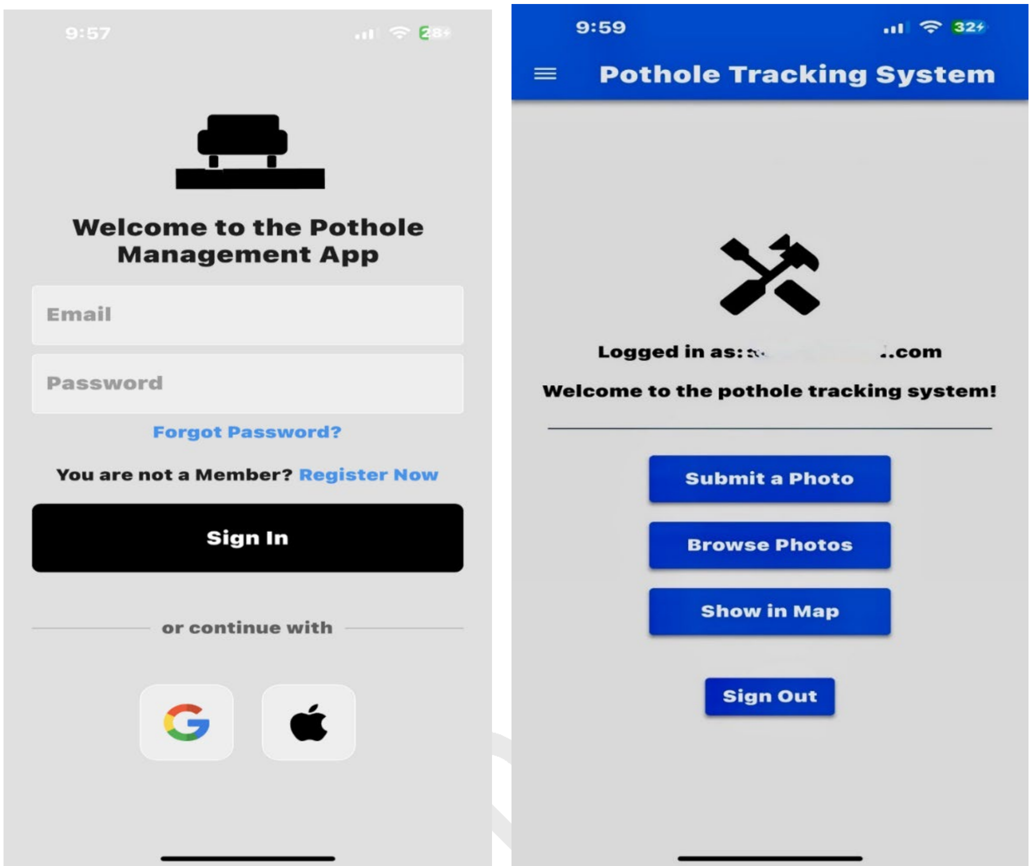
Pothole Management App

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 (*7*) have become a powerful tool for identifying and reporting problems like potholes. By empowering citizens to photograph and report potholes, the research 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 has developed an app, Pothole Management, 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 wants 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 and Home Page

Figure 5(a) shows the interface to create an account, and then log in 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 5(b) shows the homepage of the pothole management app. It has three main buttons: Submit a Photo, Browse Photos, and Show Pothole Locations on a Map.



(a) Sign In or Create An Account (b) Home Page

Figure 5 Create an Account and Home Page for Pothole Management App

Submit a Photo:

A user can submit a photo with pothole information as shown in Figure 6. There is a camera button at the lower right portion of the screen. The user can use the phone to take a photo or pick a photo from the phone. The user is also allowed to input some notes regarding pothole sizes and severity levels.

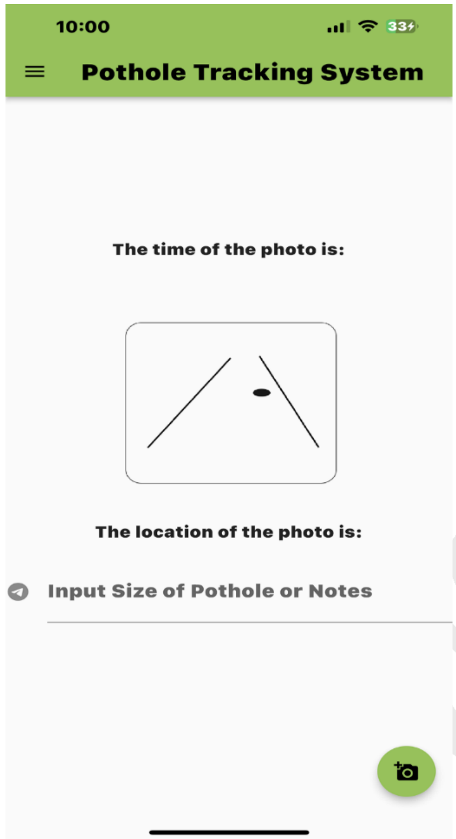
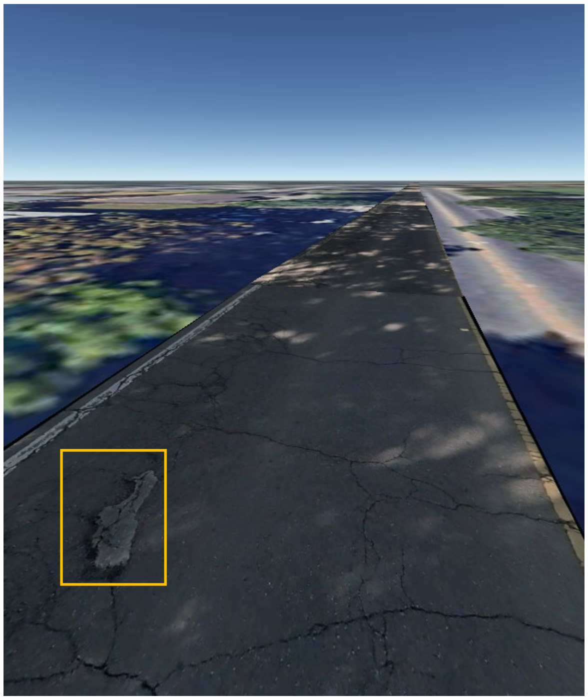


Figure 6 Submit a Photo

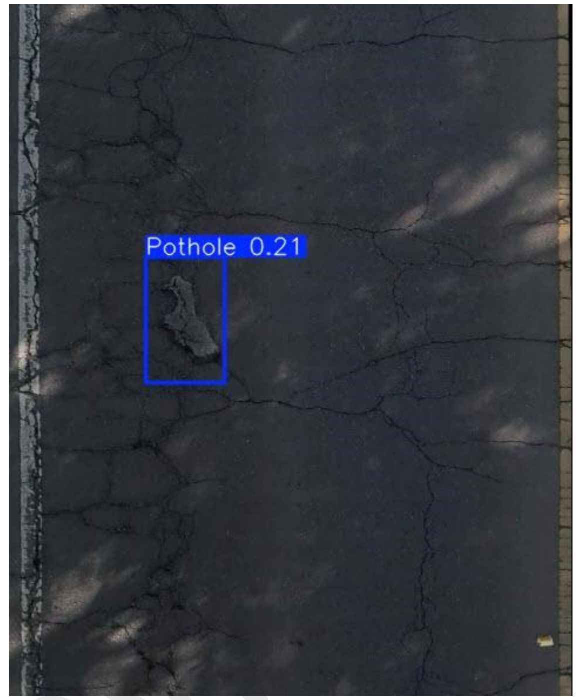
Submit Videos with Pavement Pothole(s)

A video, such as a .MP4 file with GPS location embedded, can be uploaded and processed. The research team has developed algorithms to extract frames from a GoPro video file, and then conduct perspective transformation to obtain top-down images. A stitching program was developed to generate a panorama view of roadway surface, which can be overlaid onto Google Earth program as shown in Figure 7(a). The transformed top-down image with GPS location as shown in Figure 7(b) can be uploaded through the Pothole Management app.

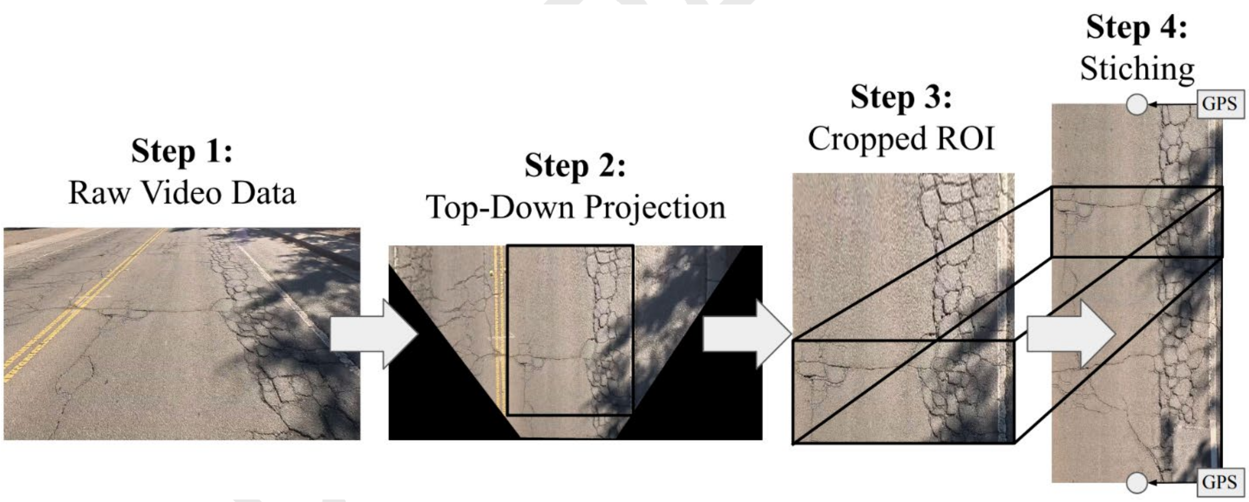
The video is processed by taking the raw video output data, performing a top-down homography projection on extracted frames, cropping this projection to obtain a region of interest (ROI), and stitching these images together to form a top-down scan of the road, Figure 9(c). The research team crops the top-down image projection because the pixels nearest to the camera are the highest quality. The Scale-Invariant Feature Transform (SIFT) algorithm was used for feature detection for its invariance to scale, rotation, illumination, and noise. Illumination and noise are the most important for finding correspondences in road images because sections of road often appear uniform and contain shadows. SIFT is also computationally efficient, making it a viable option for long scans. Stitching is synchronized with the Global-Positioning-System (GPS) read-outs of the camera. For example, the GoPro camera receives GPS read-outs every second. This allows the research team to determine the GPS positions for the beginning and end of every stitch.



(a) Display Roadway Surface on Google Earth



(b) Top-down view of a transformed video frame



(c) High-level video processing algorithm

Figure 7 Pothole Detection and Reporting from a Video

POTHOLE TRACKING SYSTEM

Several important parameters, such as GPS location and reporting timestamp of a pothole, are stored with submitted pothole photos. As shown in Figure 8, 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. The jurisdictional information, such as cities, county, zip codes, can be extracted by using reverse geocoding technique from GPS coordinates.

Other important parameters such as the following can also be stored in PHMP:

- Size and severity of a pothole

- Time of repair
- Repairing method and material
- Road name
- Agency name

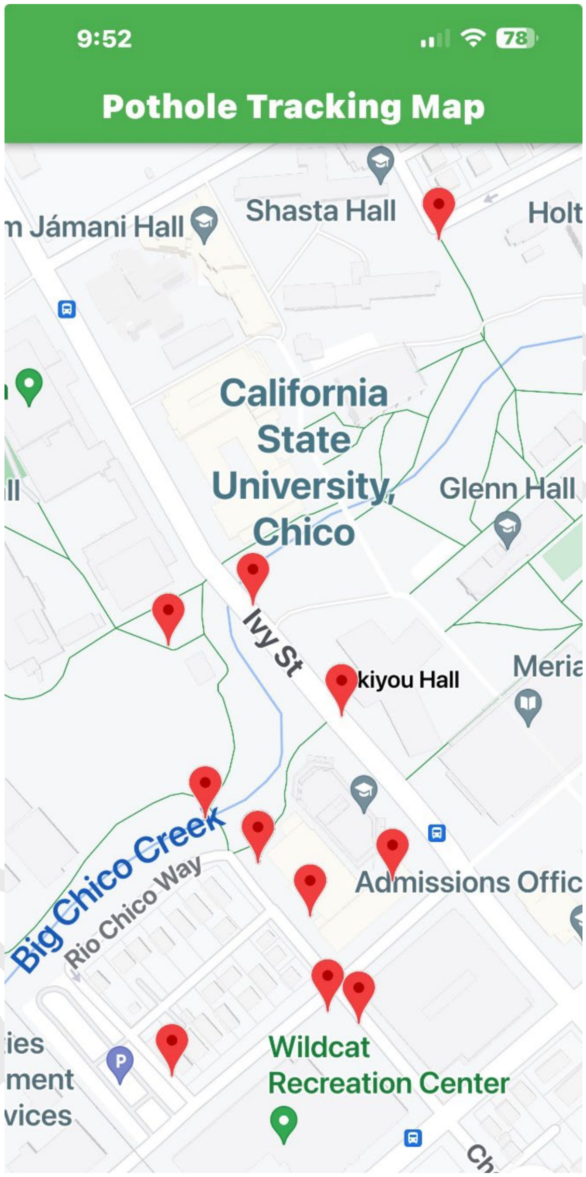


Figure 8 View Pothole Locations

POTHOLE MANAGEMENT SYSTEM

Machine Learning Models for Pothole Management Program - PHMP

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. Bosurgi et. al. developed an automatic pothole detection algorithm using 3D pavement data (*8*). Chougule and Barhatte developed smart pothole detection system using deep learning algorithms (*9*). 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 PHMP.

More than 6000 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 (*10*). 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 (*11*). 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.

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 ([12]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	Actual: No Pothole
Predicted	Pothole	0.97	0.05
Predicted	No Pothole	0.03	0.95

Object Detection Model

YOLOv8, developed by Ultralytics, is one of the most popular model architectures and object detection algorithms (*13*). 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 (*11*). 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 (*14*). As an example, Figure 9 shows that three potholes and their locations are identified in the photo.

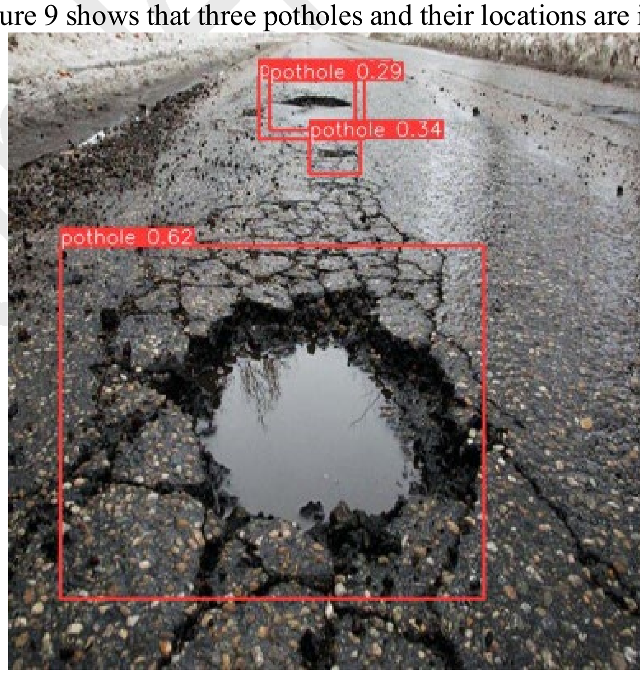


Figure 9 Example of Pothole Detection by the YOLO Model

User Management

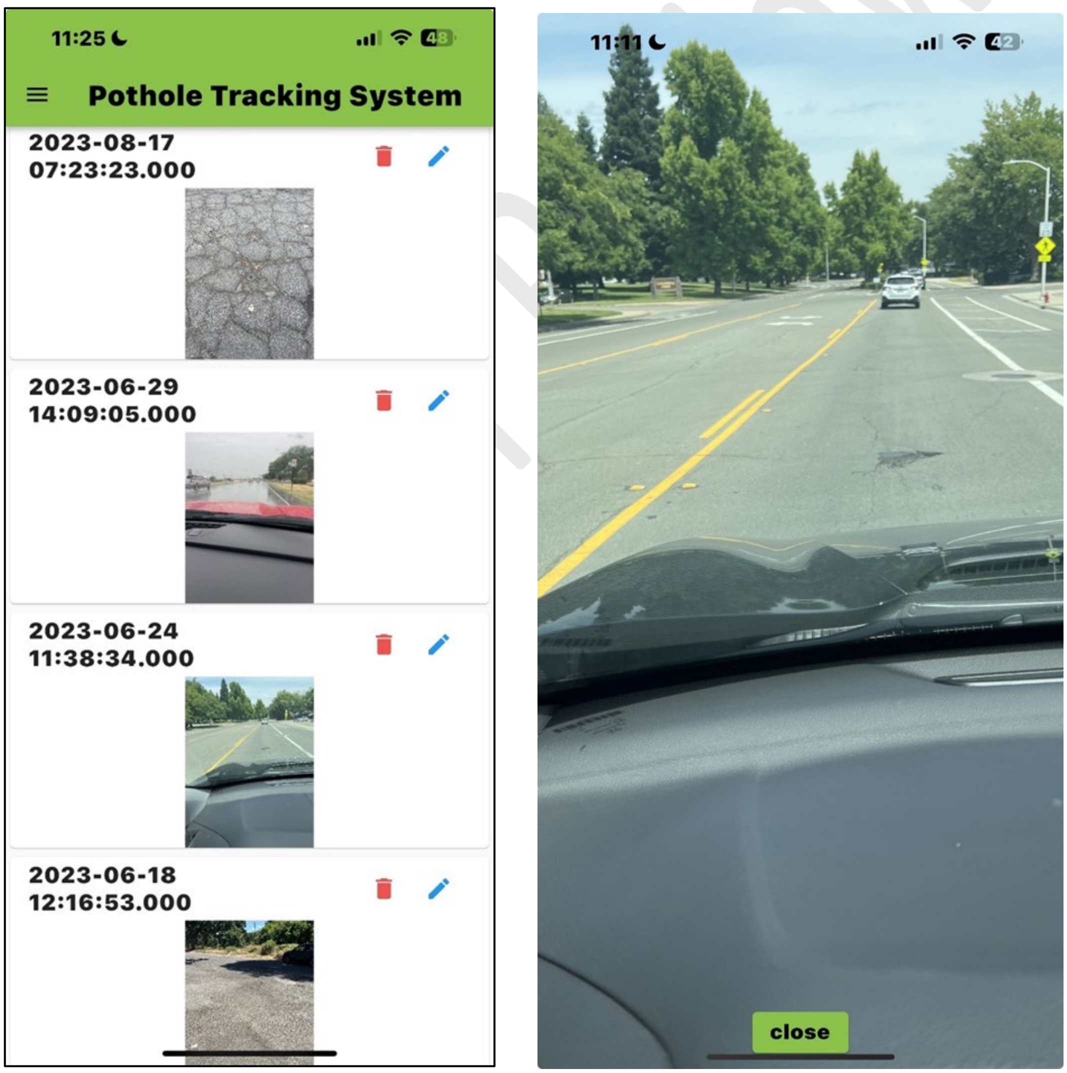
There are three user types in the PHMP: Admin User, Pro-User, and General User. An Admin User manages the users of their jurisdiction. An Admin User can modify the types of users in their agency. A Pro-User can browse, search, and edit potholes in their jurisdiction; while General Users, representing public, can submit and view the status of potholes submitted by themselves.

Pothole Database

An online database is used to store and manage pothole photos. Agencies can utilize the database to manage potholes in their jurisdictions.

Browse and View Potholes

General users can browse the photos that they submitted to the database. A Pro-User will be able to scroll/browse photos within an agency's jurisdiction, as shown in Figure 10(a). A Pro-User can also edit or delete the photos on the server. By tapping on the thumbnail of a submitted pothole photo, a user can view the enlarged photo as shown in Figure 10(b).



(a) Scrollable Page to Browse Photos (b) Enlarged View of a Photo

Figure 10 Browse Potholes and View Photo of a Pothole

Search or Edit Potholes

A Pro-User can search potholes based on location, time of reporting, or other filtering parameters. A Pro-User can also edit or update a submitted pothole photo as shown in Figure 11.

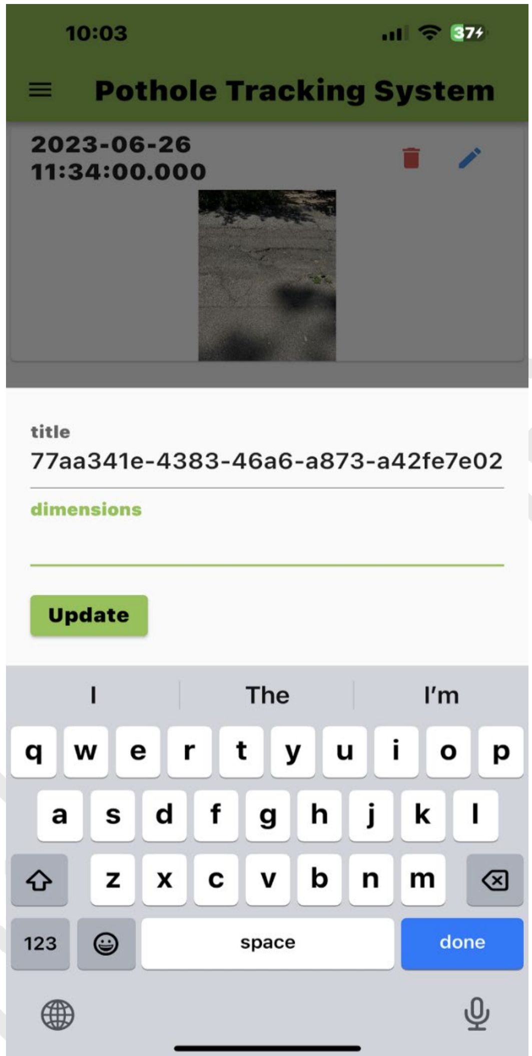


Figure 11 Update Pothole Photo Information

POTHOLE REPAIR

Driving Directions to a Pothole Location

As shown in Figure 12, by clicking on a pothole location marker, users can obtain the driving directions from their current location to the selected pothole. This feature is useful for any maintenance crew to find the location of a submitted pothole.

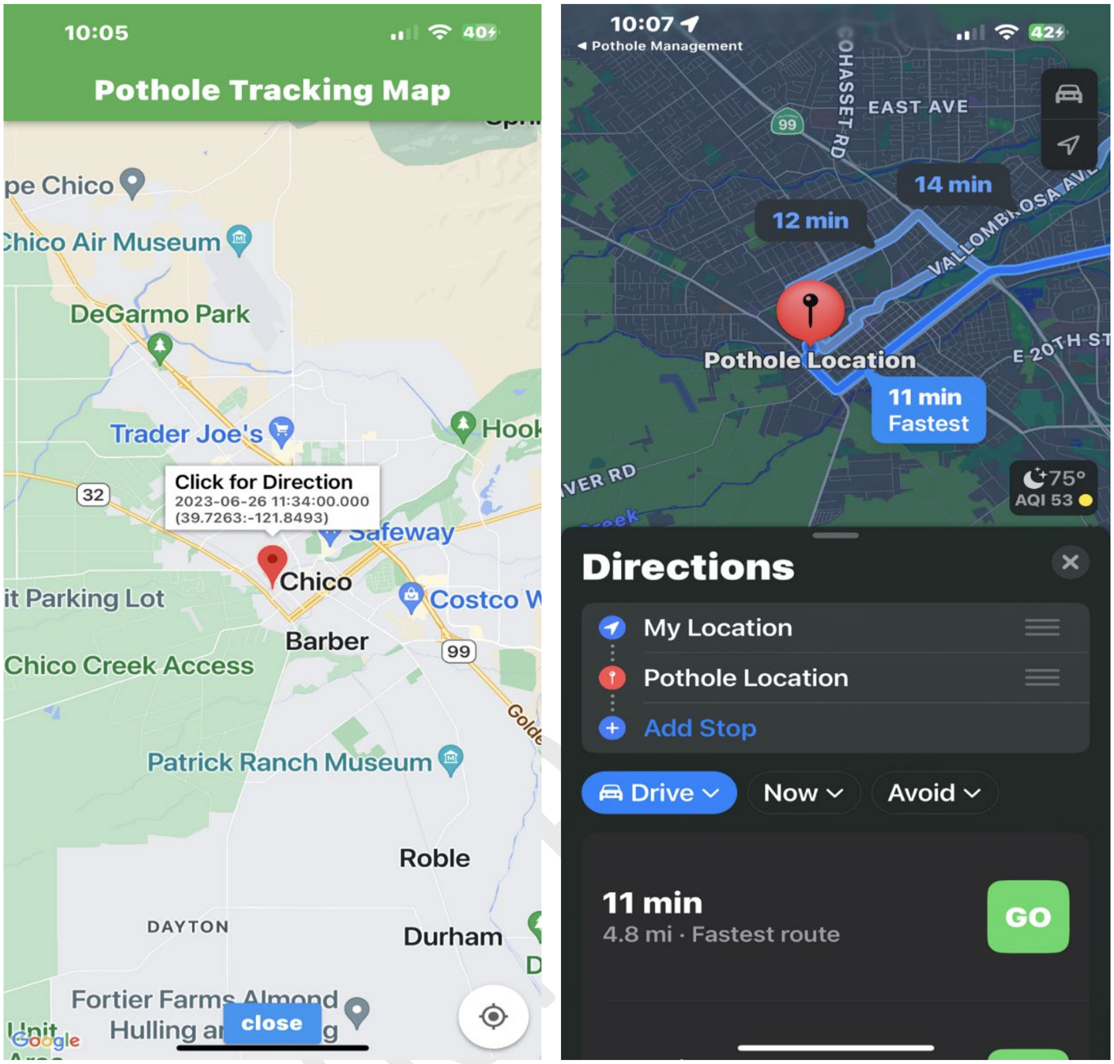


Figure 12 GPS Location (Left) of and Directions (Right) to a Pothole

Pothole Repair Materials and Techniques

PHMP can provide quick references to guide maintenance crew on the pothole repair materials and techniques. There are multiple factors to consider when repairing a pothole: concrete or asphalt, temporary fix with cold mix, hot mix pothole patching, etc. Cheng et. al. provide guidance on asphalt pavement pothole repair materials and methods (*15*). FHWA provided a practical manual for repair of potholes in pavement ranging from throw and roll, semi-permanent, to spray injection (*16*).

Submit Repair Record to Pothole Tracking System

After the maintenance crew completed a pothole repair, the pothole completion information should be updated and then uploaded to the PHMP through the mobile app.

CONCLUSIONS AND RECOMMENDATIONS

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

The following are conclusions from this study:

- 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.

- 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.
- 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.

The following are the recommendations from this study:

- The research team should improve the classification and object detection models to enhance the accuracy of their results.
- The research team should develop a segmentation model to estimate the sizes of potholes automatically. Currently, the PHMP can only manually estimate the pothole size from the photo. This information could help agencies determine the quantity of materials for pothole repair.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: all authors, data collection: Pablo Raigoza and Devin Cheng; analysis and interpretation of results: all authors; draft manuscript preparation: all authors. All authors reviewed the results, edited the paper, and approved the final version of the manuscript.

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