Automated Road Maintenance via Pothole Detection and Road Type Classification on the U.S. East Coast

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1 Introduction

Roads are a vital component of daily life in the United States, supporting the movement of an estimated 115 million vehicles each day as of 2016[1]. With a growing population and a heavy reliance on personal vehicles for transportation[2], road usage continues to rise, making the upkeep of road infrastructure increasingly important.

Poorly maintained roads, particularly those with potholes or uneven surfaces, pose significant safety and financial risks to drivers. Common vehicle damages include punctured tires, misaligned wheels, and compromised suspension systems—such as damaged springs, shocks, and struts[3]. Low-clearance vehicles are especially vulnerable, as potholes can cause scrapes to the undercarriage or damage to components like the exhaust system[4].

Beyond vehicle damage, potholes can also disrupt traffic flow. Drivers often slow down or change lanes abruptly to avoid road hazards, contributing to traffic congestion, delays[5], and in some cases, accidents[6].

The US road network spans approximately 4.1 million miles of public roads [7], yet around 39% of major roads are currently classified as being in poor or mediocre condition[8]. Potholes typically form due to the expansion and contraction of pavement caused by groundwater, rain, snow, and freeze-thaw cycles. Additionally, the constant pressure from heavy traffic accelerates the deterioration of road surfaces[9].

As such, maintaining roads by addressing potholes and uneven surfaces is of paramount importance to ensuring the safety of drivers, pedestrians, cyclists, and the general public. This project proposes a pothole detection system integrated with a road type classification model, designed to assist authorities in identifying roads requiring maintenance and prioritizing those with higher traffic volume and susceptibility to damage.

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[1] https://www.brookings.edu/articles/americans-commuting-choices-5-major-takeaways-from-2016-census-data/
[2] Ibid
[3] https://www.limegate.co.uk/blog/potholes-how-bad-are-they
[4] https://www.carx.com/blog/why-you-should-avoid-potholes-on-the-road/
[5] https://sunburyroadtech.com/the-link-between-potholes-and-traffic-congestion-understanding-the-ripple-effect/#:~:text=Potholes%20often%20lead%20to%20lane,the%20likelihood%20of%20congestion%20rises.
[6] https://www.mdpi.com/2076-3417/13/15/8677
[7] https://www.statista.com/statistics/183417/united-states-public-road-and-street-mileage-since-1990/#:~:text=In%202022%2C%20the%20total%20length,of%20the%20country's%20total%20mileage.
[8] https://infrastructurereportcard.org/cat-item/roads-infrastructure/
[9] https://www.carx.com/blog/why-you-should-avoid-potholes-on-the-road/

2 Methodology

Road data was obtained from Google Earth Engine and subsequently downloaded to a local machine for manual annotation. A total of 100 images were labeled using the LabelMe application, wherein potholes and uneven surfaces were identified and categorized under a unified 'pothole' class. The Mask R-CNN model was selected as the base model for its superior accuracy in object detection tasks. While alternative models such as YOLOv4 and SSD were also considered due to their faster processing speeds, they demonstrated lower accuracy in comparison. Therefore, Mask R-CNN was adopted to prioritize detection accuracy[10]. The model was fine-tuned using the manually annotated dataset to enhance its performance in identifying potholes (Figure 1).

Figure 1: Manually labelled image of potholes

In addition to pothole detection, the road images were classified into three main categories based on a functional road hierarchy commonly used in the United States: local roads, collector roads, and arterial roads[11] (Figure 2). This classification reflects the intended purpose and traffic characteristics of each road type. Local roads typically serve residential areas, accommodate lower traffic volumes, and support slower vehicle speeds. Collector roads function as intermediaries, linking local roads to arterial roads, and generally carry moderate traffic volumes. Arterial roads, including highways and major thoroughfares, are designed to handle high traffic volumes and support faster travel speeds.

[10] https://pubs.aip.org/aip/acp/article-abstract/2971/1/060044/3296342/A-comparative-study-on-faster-R-CNN-YOLO-and-SSD?redirectedFrom=fulltext
[11] https://lyt.ai/blog/on-the-road/the-road-classification-hierarchy-what-to-know/

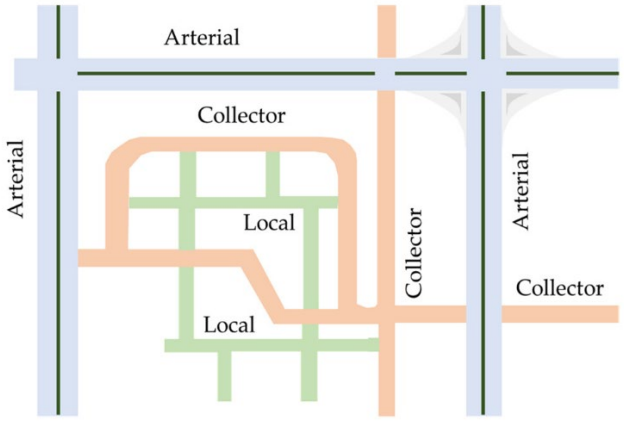

Figure 2: Road Hierarchy[12]

To perform this classification, the ResNet-18 architecture was employed as the foundational model. ResNet-18, a residual neural network, addresses the issue of vanishing gradients [13] by introducing shortcut connections that enable the training of deeper networks [14]. This allows for more robust feature learning and improves the model's ability to accurately classify road types based on image data. The two models were then combined to run on the images to get pothole detection and road type classification (Figure 3).

Figure 3: Combination of pothole detection and road type classification

[12] https://www.mdpi.com/2071-1050/13/22/12722
[13] https://www.restack.io/p/resnet-fine-tuning-answer-resnet-18-vs-resnet-50-cat-ai
[14] https://medium.com/@leonardofonseca.r/a-practical-comparison-between-cnn-and-resnet-architectures-a-focus-on-attention-mechanisms-cee7ec8eca55#:~:text=In%20contrast%2C%20ResNet%20benefits%20from,complex%20tasks%20like%20image%20classification.

3 Findings & Limitations

The primary finding of this project was that arterial roads were the most well-maintained, followed by local roads, while collector roads exhibited the highest number of identified potholes. This is particularly notable given that arterial roads carry the highest traffic volumes and support higher vehicle speeds, where the presence of potholes poses greater safety risks and could lead to more severe consequences if left unaddressed.

Additionally, road maintenance is an expensive process typically funded by municipal or state governments, which often operate under budget constraints[15]. In this context, the developed system has the potential to serve as a technological aid by supporting crowd-sourced data collection. If integrated with vehicle-mounted cameras and GPS, the pothole detection model could provide geolocated pothole data, enabling authorities to efficiently monitor road conditions. Combined with road type classification, this system would also allow for prioritization of maintenance on arterial roads, where the urgency and risk associated with road defects are significantly higher.

However, the model still faces limitations in accuracy. For instance, in one case, a vehicle's license plate was incorrectly detected as a pothole (Figure 3), indicating the presence of false positives. Reducing such misclassifications is crucial to ensure that public resources are not allocated to non-existent road issues. A contributing factor to this limitation is the quality of the imagery. Some images sourced from Google Earth Engine contain areas that are blurred, often due to privacy requests from property owners, which can extend onto road surfaces[16]. These visual obstructions not only hinder manual annotation but also reduce the model's ability to accurately detect potholes.

4 Conclusion

In summary, the proposed pothole detection and road type classification system has the potential to serve as a valuable crowd-sourcing tool for municipal and state governments in assessing road maintenance needs. With the rise of self-driving and connected vehicles, this technology could be further enhanced to automatically capture images of road conditions along with corresponding GPS data. Such integration would enable authorities to make more informed decisions regarding the severity, location, and urgency of pothole repairs based on the

[15] https://www.pavementmanagementgroup.com/post/unveiling-the-real-reasons-behind-america-s-road-complaints-exploring-the-unseen-truth

[16] https://www.maptive.com/why-are-some-houses-blurred-on-google-maps/#:~:text=As%20you%20might%20have%20noticed,property%20to%20be%20blurred%20altogether.

road type. By streamlining the data collection process and improving situational awareness, this system can support more efficient allocation of limited maintenance resources, ensuring that the most critical road issues are addressed promptly.