ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.1035
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Advancing Road Infrastructure Management and Safety Through Pothole Classification Standards and Technology: A South Korean Perspective

Wonwoo SHIN[1], Kyubyung KANG[2] and Sungkon MOON[3]*

[1] *Department of Civil Systems Engineering, College of Engineering, Ajou University, 16499 Suwon, Republic of Korea,* E-mail address: wonwdoublo@ajou.ac.kr
[2] *School of Construction Management Technology, Purdue University, West Lafayette, IN 47907, United States,* E-mail address: kyukang@purdue.edu
[3] *Department of Civil Systems Engineering, College of Engineering, Ajou University, 16499 Suwon, Republic of Korea,* E-mail address: skmoon@ajou.ac.kr

Abstract: South Korea has seen an increased demand for road maintenance, since they experienced a rapid industrialization in 1960-70s. Between 2019 and the end of 2022, the total national expenditure on road maintenance steadily rose from KRW 3.4 trillion to KRW 4.5 trillion. Roads, responsible for about 80% of the nation's transportation, significantly affect ride quality, safety and maintenance costs. Among the different perspectives, this study focuses on the prevalence of potholes. Over 24,000 pothole instances are reported on highways in the past five years, which raises concerns due to various direct and indirect effects on road maintenance and safety issues. Various methods, including vision-based, vibration-based, and 3D reconstruction-based techniques, have been proposed for pothole detection and inspection. Vision-based methods effectively count and measure pothole shapes but which are sensitive to lighting conditions. Vibration-based methods offer cost-effectiveness, although it may not provide precise pothole shape information. 3D reconstruction-based methods deliver accurate shape measurements, while it comes with higher costs. To establish an effective road maintenance system, prioritization criteria for potholes is required to be established and applied. These criteria may vary across countries or regions. For example, in the United States, potholes are classified based on depth into Low (<25mm deep), Moderate (25 to 50mm deep), and High (>50mm deep). In conclusion, this research addresses this research challenge of road damage and potholes in South Korea by exploring various pothole classification standards and utilizing advanced technology to develop an efficient road maintenance system. The outcome would benefit improved road infrastructure management and enhanced safety.

Keywords: pothole, severity classification, infrastructure management, safety

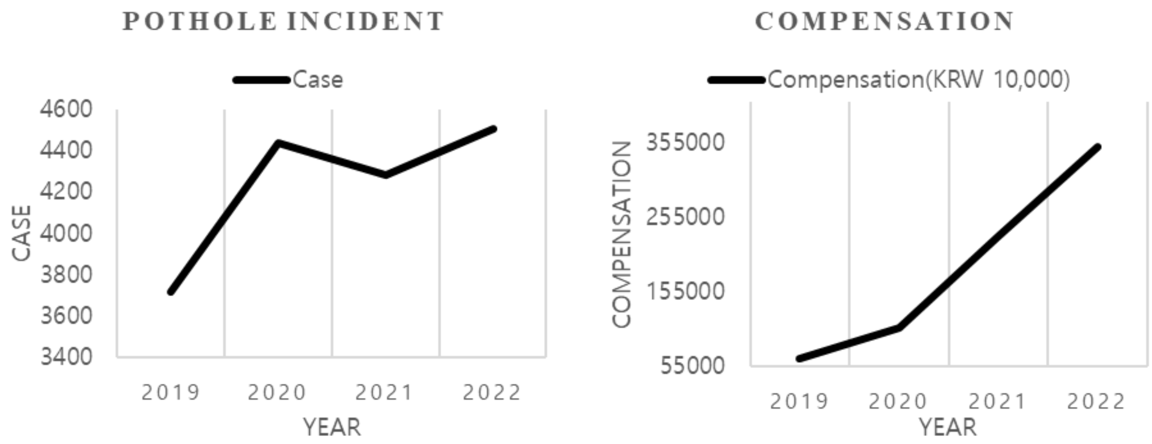
1. INTRODUCTION

Recent occurrences of potholes in South Korea have been increasing annually due to climate changes such as heavy rains and snow [1]. As shown in Figure 1, the number of pothole incidents has risen from 3,717 cases in 2019 to 4,509 cases in 2022, and the amount compensated by the government for damages caused by potholes has also significantly increased from 646 million KRW to 34.97 billion KRW [2]. Therefore, substantial social and economic losses are being incurred.

Currently, in Korea, the detection and repair of road damages such as cracks and potholes typically depend on reports from citizens, followed by manual repairs conducted by local governments [3]. Consequently, many researchers are exploring ways to automatically detect potholes, aiming to improve efficiency and road quality through preliminary surveys and immediate actions [4]. Existing methods for pothole detection include vibration-based methods [5, 6], 3D reconstruction-based methods [7-10], and vision-based methods [11-14].

The objective of this research is to formulate a set of classification standards for pothole repair to aid in decision-making processes. Initially, a comprehensive examination of current standards is conducted. Subsequently, pothole imagery is amassed through aerial footage captured by a drone. A classification system for potholes is then proposed, and this system is utilized to classify the gathered images and the pothole database in two dimensions.

Figure 1. Yearly trends in pothole incidents and associated compensation



2. RELATED WORKS

So far, there are not many works dedicated to the classification of pothole severity. In the United States, as shown in Table 1, potholes are classified into three levels based on the maximum depth below the pavement surface [15]. The classification is as follows: low (depth less than 25mm), moderate (depth between 25mm and less than 50mm), and high (depth of 50mm or more).

As seen in Table 2, China has classified the severity of potholes based on their area into two categories [16]. If the area is less than $0.1m^2$, it is classified as low, and if the area is $0.1m^2$ or above, it is classified as high.

Table 1. Pothole severity classification in the U.S.

Depth	Severity Levels
$< 25mm$	Low
$25mm$ to $50mm$	Moderate
$> 50mm$	High

Table 2. Pothole severity classification in China

Area	Severity Levels
$< 0.1m^2$	Low
$\geq 0.1m^2$	High

Unlike previous cases that considered only length or area, the Public Works Department of Malaysia [17] has established criteria that take into account both the depth and area of potholes, as shown in Table 3.

Table 3. Pothole severity classification in Malaysia

	Surface area of a pothole		
	<$0.1m^2$	$0.1m^2$ to $0.3m^2$	<$0.1m^2$
Depth	Pothole severity classification		

<25mm	Low	<25mm	Low
25mm to 30mm	Moderate	25mm to 30mm	Moderate
>30mm	Moderate	>30mm	Moderate

Moreover, the Northamptonshire County Council in the UK has defined pothole severity based on the location and network hierarchy of the asset, as shown in Table 4 and Table 5 [18]. Additionally, they have set maximum allowable times for pothole identification and defect repair according to priority [19]; Emergency: Response within two hours, Priority 1: Response within 24 hours, Priority 2: Response within 7 days, Priority 3: Response within 28 days, Priority 4: Response within 26 weeks.

Table 4. Pothole responses for carriage way.

Depth \ Hierarchy	**Local access road**	**Link road**	**Secondary distributor**	**Strategic route**
40mm to 50mm	No action		Priority 2	
50mm to 75mm, <30mph	Priority 2		Priority 1 or 2	Priority 1
50mm to 75mm, >30mph	Priority 1 or 2		Priority 1	
≥75mm	Priority 1			

Table 5. Pothole responses for footway.

Depth \ Hierarchy	**Little used rural**	**Busy rural**	**Busy urban**	**Main shopping**
<20mm	No action			
20mm to 30mm	Priority 2		Priority 1 or 2	
30mm to 40mm	Priority 2	Priority 1 or 2	Priority 1	
≥40mm	Priority 1 or 2		Priority 1	

3. POTHOLE SEVERITY CLASSIFICATION

As seen in Tables 6 and 7, a guideline for pothole classification based on length, and depth was established. This guideline was then utilized for the analysis of collected images and the 2D pothole database.

Table 6. Pothole classification by length of pothole

Classification	**Remarks**
$\leq 150mm$	X-axis: The direction perpendicular to the vehicle's direction of movement Y-axis: The direction parallel to the vehicle's direction of movement The length of a pothole is equal to the longest length in the longitudinal direction.
$> 150mm$	

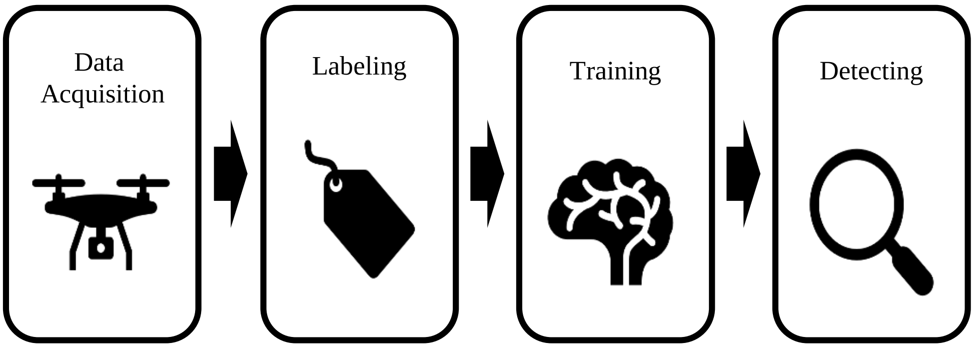
Table 7. Pothole classification by depth of pothole

Classification	Levels	Maintenance response time
$< 25mm$	Severity C	Warning
$25mm$ to $50mm$	Severity B	Maintenance
$> 50mm$	Severity A	Urgent Repair

4. DATA ACQUISITION AND APPLICATION

Following the pothole risk classification criteria set in Chapter 3, the process of data acquisition, labeling, training, and detecting for pothole classification was undertaken. These criteria were applied to the images and the 2D pothole database that had been collected. Figure 2 illustrates this process schematically.

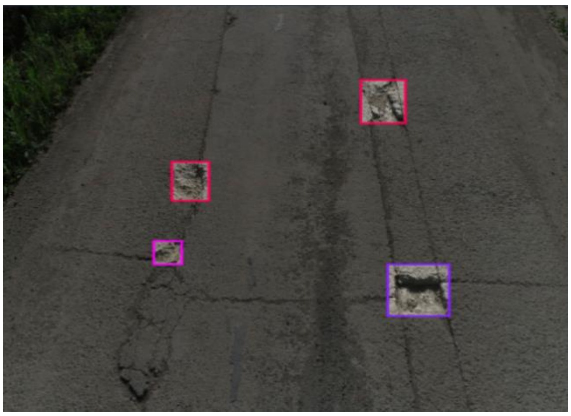
Figure 2. The process of data acquisition and application



Initially, the collected data targeted a provincial road in Gwangju City, Gyeonggi Province, South Korea using the standard camera of a DJI phantom 4 pro (1920*1080, 120f/s) to capture videos and photos of the concrete pavement section [20]. This section, frequented by freight vehicles for the transport of large warehouses and logistics, exhibits road damage that is visibly severe. For safe drone filming, a straight section of approximately 530 meters was selected. The drone maintained an altitude of 3 meters to collect the data.

Subsequently, the collected video data were segmented into 500 images. These images were then labeled into three risk categories: A, B, and C. Labeling was done to prepare the data for algorithm training, with the images resized to 640x640 for Training, Validation, and Test sets.

Figure 3. Labeling of collected data



The YOLO-V5 algorithm was utilized to detect potholes based on the collected video data. The essence of the YOLO algorithm is its small model size and fast computation speed. Simply inputting the data into the network yields the final detection results, allowing for the immediate output of labeled locations and object classes through the neural network [21].

Based on the labeled data, the object detection algorithm, specifically YOLO-V5, was employed to recognize potholes within the target section according to the set guideline and to classify them based on their severity.

Figure 4. Result of pothole detecting based on guideline

5. CONCLUSIONS AND FUTURE WORKS

This research aims to develop pothole classification criteria to improve pothole management and safety, applying it to the YOLO algorithm. Initially, an analysis of international standards on pothole severity was conducted. Data were then collected through drone-captured footage of roads prone to potholes, leading to the development and implementation of a pothole classification guideline based on the collected imagery and a 2D pothole database. The analysis showed accurate detection in 8 out of 9 test datasets, demonstrating the potential of the new classification system combined with the YOLO algorithm to support decision-making processes and significantly enhance road maintenance efficiency. This research provides a solid foundation for future road maintenance and repair efforts. However, the study identified limitations, including the need for accuracy improvement under varying lighting conditions and the expansion of the classification system to include other types of road damage, marking these as focuses for future research. This work holds the potential to contribute to policy-making, road maintenance, and safety improvement, offering a more strategic and efficient approach to road maintenance and ultimately enhancing road user safety and satisfaction. Future tasks include improving algorithm accuracy while avoiding overfitting and exploring applicability under diverse road conditions and environments, with the potential for global application in road infrastructure management and safety.

ACKNOWLEDGMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Grant Number: 2022R1F1A1074039)

REFERENCES

1. Ministry of Land, I.a.T. *Management of road frame repair work*. 2023.
2. Ministry of Land, I.a.T.R.o.K. *Data Integration Channel of Ministry of Land, Infrastructure and Transport*. 2024.
3. Technology, K.I.o.C.E.a.B., *Final-Report of the National Highway Pavement Management System 2021*. 2022.

4. Chun, C., et al., *Development and evaluation of automatic pothole detection using fully convolutional neural networks.* The Journal of the Korea Institute of Intelligent Transport Systems, 2018. **17**(5): p. 55-64.
5. Li, Y., et al., *A novel evaluation method for pavement distress based on impact of ride comfort.* International Journal of Pavement Engineering, 2022. **23**(3): p. 638-650.
6. Kırbaş, U. and M. Karaşahin. *Estimating PCI using vibration data for asphalt concrete pavements*. in *Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering (CSEE'17), Barcelona, Spain*. 2017.
7. Inzerillo, L., G. Di Mino, and R. Roberts, *Image-based 3D reconstruction using traditional and UAV datasets for analysis of road pavement distress.* Automation in Construction, 2018. **96**: p. 457-469.
8. Chu, C., et al., *An optimized fringe generator of 3D pavement profilometry based on laser interference fringe.* Optics and Lasers in Engineering, 2021. **136**: p. 106142.
9. Bruno, S., et al., *Pavement Distress Estimation via Signal on Graph Processing.* Sensors, 2022. **22**(23): p. 9183.
10. Liang, X., et al., *Automatic classification of pavement distress using 3D ground-penetrating radar and deep convolutional neural network.* IEEE Transactions on Intelligent Transportation Systems, 2022. **23**(11): p. 22269-22277.
11. Li, Y., et al., *Moving object detection via segmentation and saliency constrained RPCA.* Neurocomputing, 2019. **323**: p. 352-362.
12. Song, H., et al., *Vision-based vehicle detection and counting system using deep learning in highway scenes.* European Transport Research Review, 2019. **11**(1): p. 1-16.
13. Jin, Y., et al. *Fast detection of traffic congestion from ultra-low frame rate image based on semantic segmentation*. in *2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA)*. 2019. IEEE.
14. Laroca, R., et al. *A robust real-time automatic license plate recognition based on the YOLO detector*. in *2018 international joint conference on neural networks (ijcnn)*. 2018. IEEE.
15. Administration, F.H., *Distress Identification Manual for The Long-Term Pavement Performance Program (Fifth Revised Edition).* 2014: p. 18.
16. China, M.o.T.o.t.P.s.R.o., *Highway Performance Assessment Standard (JTG H20-2007).* 2007.
17. Raya, M.J.K., *A Guide to Visual Assessment of Flexible Pavement Surface Conditions*. 1992: Jabatan Kerja Raya.
18. Highways, N. *Categorisation of potholes*. 2014 [cited 2023; Available from: https://www.astonlewallsparishcouncil.gov.uk/uploads/potholes0001.pdf.
19. Council, N.N. *Report potholes or a highway problem*. 2023 [cited 2023; Available from: https://www.northnorthants.gov.uk/parking-roads-and-transport/report-potholes-or-highway-problem.
20. DJI, *Support for Phantom 4 Pro.* 2023.
21. Jiang, P., et al., *A Review of Yolo algorithm developments.* Procedia Computer Science, 2022. **199**: p. 1066-1073.