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Pothole Volume Estimation Using LiDar-Based 3D Reconstruction

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***Abstract*—Potholes on road surfaces present significant safety hazards and demand reliable methods for detection and quantification. This study introduces a LiDAR enabled, smartphone-based approach for estimating pothole volume through three-dimensional reconstruction. Depth data captured via LiDAR sensors is processed into a point cloud representation of the road surface, which is subsequently converted into a continuous mesh using Poisson surface reconstruction. The pothole volume is determined by comparing the reconstructed mesh against a reference road plane, enabling precise volumetric assessment. The proposed framework offers a low-cost, scalable, and automated solution for road condition monitoring, making it well-suited for real world infrastructure management and maintenance applications.**

***Index Terms*—Pothole Volume Estimation, LiDAR Sensing, Three-Dimensional Reconstruction, Point Cloud Processing, Poisson Surface Reconstruction, Road Surface Condition Assessment, Infrastructure Monitoring.**

I. INTRODUCTION

Road surface deterioration in the form of potholes is a major concern for transportation systems, leading to vehicle damage, reduced ride quality, and increased risk of accidents. Effective maintenance of road infrastructure requires accurate assessment of pothole dimensions, particularly volume, which is a key parameter for repair planning and resource allocation. However, traditional methods of pothole measurement are manual, time-consuming, and often lack precision.

Recent advancements in computer vision and sensing technologies have enabled automated approaches for road condition monitoring. Image based methods using photogrammetry can reconstruct three-dimensional models from two-dimensional images, but they often suffer from inaccuracies due to lighting conditions, texture variations, and lack of reliable depth information. To overcome these limitations, depth-sensing technologies such as LiDAR have been increasingly adopted. In this work, a smartphone-based LiDAR approach is utilized to capture accurate depth data and generate a three-dimensional point cloud of the pothole surface. The captured data is processed using surface reconstruction techniques to obtain a continuous representation of the pothole geometry. The volume is then estimated by comparing the reconstructed surface with a reference road plane.

The proposed method aims to provide a low cost, scalable, and efficient solution for pothole volume estimation, suitable for real-world road maintenance applications.

II. PROPOSED SYSTEM

The proposed system aims to estimate pothole volume using a three-dimensional reconstruction approach based on image data. The overall workflow of the system is illustrated in Fig. 1

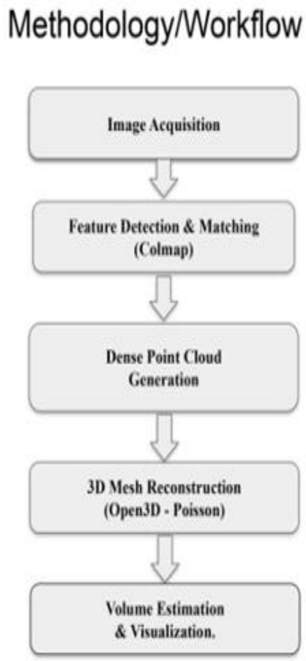

Fig. 1. the overall workflow of the system is shown in

The process begins with image acquisition, where multiple images of the pothole are captured from different viewpoints. These images are processed using COLMAP for feature detection and matching, enabling the identification of common points across images. Based on these correspondences, a sparse reconstruction is generated, which is further refined into a dense point cloud representing the pothole surface.

The generated point cloud undergoes preprocessing to remove noise and improve quality. Subsequently, Poisson surface reconstruction is applied using Open3D to convert the discrete point cloud into a continuous triangular mesh. This mesh provides a detailed representation of the pothole geometry.

To estimate the volume, a reference plane corresponding to the undisturbed road surface is approximated. The deviation of the reconstructed surface below this plane is computed, and the total volume is obtained by summing the contributions of individual mesh elements.

Fig 2. The geographic locations of the collected pothole sample.

The proposed system offers a cost-effective and scalable solution for pothole volume estimation, leveraging image-based reconstruction techniques and numerical integration principles for accurate volumetric analysis.

III. SYSTEM ARCHITECTURE

The system architecture of the proposed pothole volume estimation method is shown in Fig. 1. It consists of multiple stages, including image acquisition, feature detection and matching, point cloud generation, surface reconstruction, and volume estimation. Initially, multiple images of the pothole are captured from different viewpoints to ensure sufficient coverage of the surface. These images are processed using COLMAP, where feature detection and matching are performed to identify corresponding points across images. Based on these correspondences, a sparse reconstruction is generated, which is further refined into a dense point cloud representing the pothole surface. The dense point cloud is then processed to remove noise and improve data quality. Using Open3D, Poisson surface reconstruction is applied to convert the point cloud into a continuous triangular mesh. This mesh provides a detailed geometric representation of the pothole. For volume estimation, a reference plane corresponding to the undamaged road surface is approximated. The depth difference between the reconstructed surface and the reference plane is calculated, and the total volume is obtained by summing the contributions of individual mesh elements.

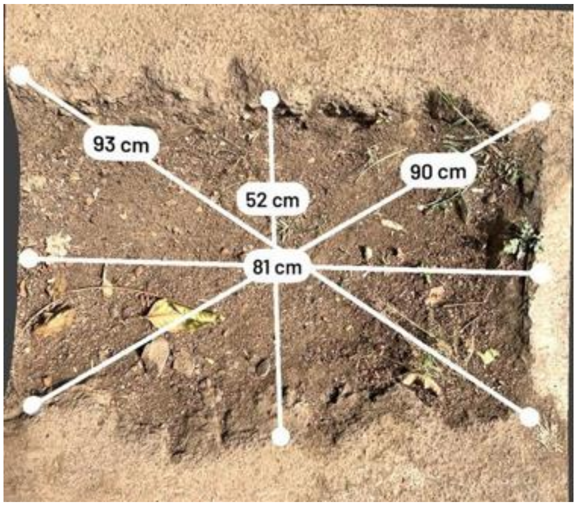

Fig. 3. Sample pothole images captured for processing are shown

While LiDAR based methods provide direct depth measurements and higher geometric accuracy, they require specialized hardware and may increase system cost. In contrast, the image-based approach using COLMAP offers a cost effective and scalable solution, making it more suitable for practical deployment using standard smartphone devices. Despite minor limitations in depth accuracy, the method achieves reliable results for pothole volume estimation.

IV. HARDWARE CONFIGURATION

The proposed system requires minimal hardware for data acquisition. An Apple iPhone 13 Pro equipped with a LiDAR sensor is used to capture depth enabled images of pothole surfaces. LiDar (Light Detection and Ranging) operates by emitting laser pulses and measuring the time taken for reflected signals to return, thereby providing accurate depth information. The Scanniverse application is utilized for generating 3D scans and exporting point cloud data. The use of a smartphone based LiDar system eliminates the need for expensive specialized equipment, making the approach cost effective and easily deployable. No additional external sensors or hardware components are required for the implementation of the proposed method.

Fig 4. Camera system and lidar scanner on iPhone 13 Pro.

V. DISCUSSION

The proposed pothole volume estimation approach is based on the 3D surface reconstruction and numerical approximation principles. The irregular pothole geometry is represented as a dense point cloud and subsequently converted into a continuous mesh using Poisson reconstruction. This process ensures surface smoothness and enables reliable volume computation; however, it may introduce minor interpolation errors, particularly in regions with sparse or noisy data. The accuracy of volume estimation is evaluated by comparing computed values with manually approximated volumes. The deviation between these values is used to define an acceptable error threshold, which reflects the combined influence of reconstruction quality, reference plane approximation, and discretization. It is observed that most samples fall within a consistent error range, indicating the stability of the proposed method. Furthermore, a comparison between LiDar based and image-based acquisition highlights that LiDar provides more precise depth measurements due to direct sensing. In this study, LiDar assisted data capture using a smartphone enhances depth accuracy, while COLMAP based reconstruction ensures flexibility and cost effectiveness.

Overall, the system achieves a balance between accuracy and practicality. The observed errors are primarily influenced by environmental conditions such as lighting, surface texture, and image overlap, yet the method remains reliable for real world pothole assessment.

VI. RESULTS

The proposed pothole volume estimation system was evaluated using multiple real-world samples acquired through smartphone based LiDar assisted scanning. The captured data was processed using COLMAP to generate dense point clouds, followed by Poisson surface reconstruction to obtain continuous 3D mesh models. Representative outputs of the reconstruction process, including point cloud and mesh visualizations.

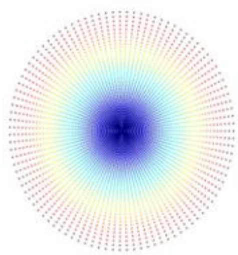

Fig. 5 Showes point cloud module generated by our method.

The point cloud visualization illustrates the variation in depth across the pothole surface. The dark blue region at the center represents the deepest points (lowest Z-values), while cyan and green shades indicate intermediate elevations. The outer regions, represented by yellow to red colors, correspond to higher surface levels near the pothole boundary. This gradient effectively captures the geometric profile of the pothole.

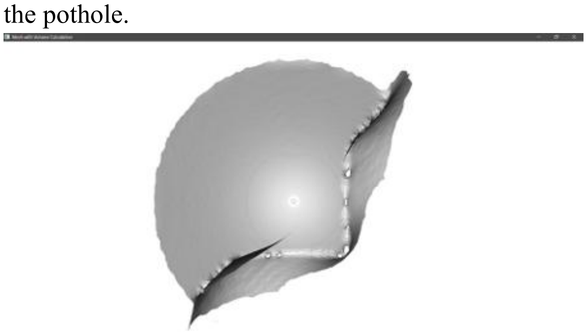

Fig. 6. The above image represents the 3D reconstructed mesh of a surface

The reconstructed mesh, generated using the proposed pipeline, represents the final structural mode of the pothole. It is obtained after point cloud preprocessing, surface normal estimation, and mesh generation using Poisson surface reconstruction. This mesh serves as the basis for volume estimation. The estimated volumes were computed by evaluating the deviation of the reconstructed pothole surface from a reference plane. These values were compared with manually approximated volumes, and the results are summarized in table I. It is observed that the computed volume closely follows the trend of the actual measurements across all the samples.

To further validate the accuracy of the proposed approach, the reconstructed models were also analyzed using Cloud Compare, an established 3D point cloud processing tool. This comparison enabled cross verification of volume estimation and error measurement against an existing standard tool. The results obtained from the proposed method show strong agreement with those generated using Cloud Compare, indicating the reliability of the implemented algorithm. Although minor deviations are present, the overall variation remains within an acceptable range for practical applications. These differences can be attributed to factors such as point cloud density, surface smoothing during Poisson reconstruction, and slight inaccuracies in reference plane selection.

Overall, the results demonstrate that the system is robust, accurate, and suitable for real world pothole volume estimation and road condition assessment.

Table I. Summarized results

SR NO.	Cloud Compare Software (Litres)	Our Method (Litres)	Actual Calculation (Litres)
Sample1	1.0	1.1	1
Sample2	1.0	1.10	1
Sample3	0.22	0.48	0.61
Sample4	0.421	0.77	0.9
Sample5	1.65	1.69	1.5
Sample6	1.02	1.02	1.01
Sample7	0.88	1.00	1.2
Sample8	1.71	1.73	1.9
Sample9	1.25	1.25	1.5
Sample 10	2.10	2.12	2.5
Sample 11	1.20	1.24	1.366

VII. CONCLUSION

This work presents a practical and efficient approach for pothole volume estimation using 3D reconstruction techniques. By integrating smartphone based LiDar assisted data acquisition with image-based processing using COLMAP, the system successfully generates accurate point clouds and corresponding 3D mesh models. The application of Poisson surface reconstruction enables reliable surface modeling, forming the basis for volume estimation. The experimental results demonstrate that the estimated volumes closely align with manually calculated values, with deviations remaining within an acceptable range. Validation using Cloud Compare further confirms the accuracy and robustness of the proposed method. Compared to traditional manual and specialized equipment-based approaches, the system offers a cost effective, scalable, and easily deployable solution. Future work focuses on improving reconstruction accuracy under challenging conditions and enabling real-time large-scale road monitoring.

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