Mersin Photogrammetry Journal
https://dergipark.org.tr/en/pub/mephoj
e-ISSN 2687-654X

Assessing road roughness using UAV-derived dense point clouds

Nizar Polat [1], **Şeyma Akça** *[1]

[1]*Harran University, Department of Geomatics Engineering, Türkiye*

Keywords
UAV
S*f*M
Point cloud
Road infrastructure
Roughness

Research Article
DOI:10.53093/mephoj.1358902

Received:12.09.2023
Revised: 10.10.2023
Accepted:13.10.2023
Published:17.10.2023

Abstract

The quality and safety of road networks are of paramount importance in modern transportation infrastructure. Road surface conditions, particularly road roughness, significantly impact vehicular travel safety, user comfort, vehicle operating costs, and overall road infrastructure maintenance. Traditional methods for road roughness analysis, such as manual inspections or image annotation, often present limitations in terms of data completeness, efficiency, and cost-effectiveness, especially for extensive road networks. This study investigates the potential of Unmanned Aerial Vehicles (UAVs) equipped with Structure-from-Motion (S*f*M) derived point clouds to transform road roughness assessment. By leveraging the capabilities of UAVs, including rapid data acquisition and high-resolution imagery, and employing S*f*M to generate detailed point clouds, this research aims to provide a comprehensive analysis of road surface conditions. The study, conducted on a road segment within the Harran University Osmanbey campus, systematically examines road roughness at different kernel sizes: 30 cm (*smaller*), 50 cm (*moderate*), and 75 cm (*larger).* Through this investigation, insights are gained into how different scales of analysis influence roughness measurements. The findings highlight the potential of UAV-derived point clouds as a promising avenue for road roughness analysis, offering transportation authorities and road administrators an efficient and cost-effective means of maintaining and enhancing road networks. The integration of this technology could lead to the development of safer, more efficient, and economically sustainable road transportation systems, benefiting both road users and infrastructure managers. As research and technological advancements in UAV-based road roughness assessment continue to progress, the potential for revolutionizing road management practices becomes increasingly apparent, ultimately leading to improved road quality and enhanced travel experiences for road users.

1. Introduction

The quality and safety of road networks are paramount concerns in modern transportation infrastructure [1]. The condition of road surfaces, particularly their roughness, plays a pivotal role in ensuring safe and efficient travel for road users [2, 3]. Road roughness not only affects the comfort and safety of vehicular travel but also impacts vehicle operating costs, fuel consumption, and overall road infrastructure maintenance [4]. Therefore, precise and comprehensive assessment of road roughness is essential for transportation authorities and road management agencies [1].

One of the key metrics used for road roughness assessment is the International Roughness Index [IRI], which quantifies the deviations or irregularities in the road's longitudinal profile [1, 6]. These irregularities are closely linked to ride quality, vehicle safety, and overall road network efficiency. By incorporating IRI into road roughness analysis, transportation authorities can gain valuable insights into road conditions and prioritize maintenance and repair efforts effectively. Traditionally, road roughness analysis has relied on manual inspections or the digital annotation of images captured along road corridors [6, 7]. While these methods have provided valuable insights, they often present limitations in terms of data completeness, efficiency, and cost-

---

* **Corresponding Author**

(nizarpolat@harran.edu.tr) ORCID ID 0000 – 0002 – 6061– 7796
*(seymakca@harran.edu.tr) ORCID ID 0000 – 0002 – 7888 – 2020

Cite this article

Polat, N., & Akça, Ş. (2023). Assessing road roughness using UAV-derived dense point clouds. Mersin Photogrammetry Journal, 5(2), 75-81

effectiveness, particularly when dealing with extensive road networks. To address these challenges and enhance the accuracy of road roughness assessment, recent advancements in remote sensing technologies, particularly those involving Unmanned Aerial Vehicles (UAV*s*), have opened up new avenues for data acquisition and analysis [8, 9].

Unmanned Aerial Vehicles, equipped with cameras, have the capability to rapidly capture detailed and high-resolution aerial photographs. These images, when processed using the Structure-from-Motion (S*f*M) method to generate point clouds, offer a wealth of information about the road's geometry, surface conditions, and roughness [10]. As such, UAV-based point clouds derived from aerial photographs present an enticing opportunity for road roughness analysis, offering distinct advantages in terms of speed, cost-efficiency, and data coverage [11].

This study, carried out on a road within the Harran University Osmanbey campus, focuses on the utilization of point clouds generated using the S*f*M method from aerial photographs collected by UAV to conduct a comprehensive analysis of road roughness. By leveraging the advantages of UAV technology, the S*f*M method, and advanced point cloud analysis techniques, this research endeavors to develop an accurate and efficient methodology for characterizing road roughness conditions. The primary objective is to investigate the feasibility of UAV-derived point clouds, including the IRI metric, as a valuable resource for road management and maintenance, with an emphasis on enhancing road safety, optimizing maintenance schedules, and minimizing operational costs.

Through the integration of UAV technology, the S*f*M method, and advanced point cloud analysis techniques, this study aims to contribute to the field of transportation infrastructure management. By exploring the potential of S*f*M-derived point clouds, it seeks to provide transportation authorities and road administrators with a practical and cost-effective solution for maintaining and improving the quality of road networks. Ultimately, this research endeavors to foster safer, more efficient, and economically sustainable road transportation systems.

2. Method

In this section, we outline the methodology employed for the generation of point clouds using the S*f*M approach from aerial photographs collected by the UAV and subsequent roughness analysis. We describe the steps involved in S*f*M-based point cloud generation, followed by the specific procedures for assessing road roughness using different kernel sizes.

2.1. S*f*M based point cloud generation

UAVs have revolutionized the field of remote sensing by providing a versatile platform for collecting high-resolution aerial images [12]. The methodology employed in this study harnessed the S*f*M approach for extracting point cloud data from the aerial photographs collected by the UAV. This process entailed a series of technical steps to ensure the accuracy and precision of the obtained 3D point cloud. First and foremost, the UAV's camera underwent a meticulous calibration procedure to ascertain its intrinsic parameters, including focal length and lens distortion coefficients. The subsequent phase involved the systematic acquisition of high-resolution aerial images during the UAV flight, thoroughly covering the targeted road segment within the Harran University Osmanbey campus from diverse angles and viewpoints. Key features, often referred to as keypoints, were then meticulously extracted from these images to facilitate the establishment of correspondences between overlapping images.

When coupled with the S*f*M technique, UAV-based imagery can be efficiently processed to derive valuable three-dimensional (3D) information [13]. S*f*M, a computer vision methodology, plays a pivotal role in this process by analyzing common features across a series of overlapping 2D images captured from different angles. By leveraging camera parameters such as focal length, distortion, camera position, and orientation, S*f*M calculates the 3D coordinates of these features, ultimately generating a point cloud [14]. This point cloud represents the spatial layout of the objects and terrain within the surveyed area in a highly detailed and accurate manner.

The extracted features from multiple images were matched to identify common points visible from various perspectives. With this correspondence in place, S*f*M algorithms accurately determined the positions and orientations of the UAV camera for each image, thus enabling the creation of a 3D point cloud through triangulation. Initially, a sparse point cloud was generated to provide a basic approximation of the scene's structure. However, this sparse cloud was further refined through bundle adjustment techniques, which minimized discrepancies between observed feature positions and their corresponding 3D positions in the point cloud.

Subsequently, the sparse point cloud was densified to create a detailed and comprehensive representation of the road surface. This densification process involved interpolating and adding additional 3D points to enhance the point cloud's richness. Finally, to ensure the alignment of the point cloud data with real-world geographic coordinates, georeferencing techniques were employed, culminating in a precisely calibrated and spatially referenced point cloud dataset. These technical steps collectively laid the groundwork for the subsequent road roughness analysis, empowering the study to draw meaningful insights from the UAV-derived point cloud data.

2.2. Roughness analysis

At this point, we have to remind that the roughness analysis was performed in Cloud Compare software. To initiate the roughness analysis, a crucial step involved the definition of a 'kernel' and its corresponding 'kernel size'. This 'kernel' represented a neighborhood radius around each point within the point cloud dataset. The 'kernel size' determined the spatial extent within which neighboring points were considered for roughness calculations. By strategically defining these parameters, the study ensured that the analysis captured variations in road roughness across the entire dataset effectively [15].

The core metric for assessing road roughness was the distance between each point and the best fitting plane computed using its nearest neighbors within the designated 'kernel'. This distance, measured orthogonally to the plane, provided a quantitative measure of surface irregularities. The selection of this 'best fit plane' approach allowed for a robust evaluation of the road's topographical variations, ensuring that the analysis was sensitive to even subtle changes in surface height.

The roughness calculation further delved into the differences in elevation between each central point and the average height of its neighboring points. This 'height difference' parameter was computed along the specified 'vertical' orientation, enabling the study to capture vertical deviations in the road surface. The use of this parameter allowed for a multi-dimensional assessment of road roughness, considering both horizontal and vertical variations.

In scenarios where there were insufficient neighboring points to reliably compute a least-squares (LS) plane-typically fewer than three neighbors-the study systematically assigned an invalid scalar value (NaN) to those points. This precautionary measure ensured that roughness calculations were only performed on points with a sufficient neighborhood context, maintaining the integrity of the analysis.

3. Results and Discussion

Within the scope of the study, ground control points were established before flying with the UAV in the field. Then a photogrammetric flight plan was prepared. According to the plan, an altitude of 20 m was preferred for a road segment of approximately 185 m in length. No lower altitude was flown because it was considered a serious risk that trees and lighting lamps in the median could jeopardize the flight. 143 aerial images were obtained over the study area by using DJI Mavic 2 Pro. The overlap ratios were set to 80% in the flight plan. Thus, the maximum level of detail was wanted to be captured. The point cloud obtained as a result of the study contains more than 6 million points. All photogrammetric process were performed in Agisoft Metashape (Figure 1).

Figure 1. UAV flight lines and point cloud of the study area.

Within the scope of the study, it is necessary to decide on the kernel size, as stated in the method section, in order to determine the rough areas from the point cloud. The road roughness level varies depending on the selected kernel size. As seen in Figure 2, a defect that can be noticed visually and should be considered in terms of comfort and safety is not very rough in the small kernel size (10 cm in our study). However, as the kernel size increases, roughness or defects are detected.

Since the applied algorithm takes into account the height information of the points remaining in the kernel, examining the data set carefully and filtering outliers, if any, by pre-processing will yield more accurate results. In our case, the statistical outlier filter was performed. Apart from this, it would be rational to determine for what purpose the roughness analysis will be made.

The kernel size, also referred to as the neighborhood radius, is a critical parameter that significantly affects the calculation of road roughness from point cloud data. It essentially determines the scale at which roughness is assessed. Considering that the contact area of rubber-tired vehicles with the road surface typically falls within the range of 30 to 70 cm^2 [16], we selected specific kernel sizes for our study. To elaborate, we investigated three distinct kernel sizes: 30 cm, considered as *"smaller"*; 50 cm, denoted as *"moderate"*; and 75 cm, categorized as *"larger"*. The subsequent section delves into the manner in which road roughness reacts to variations in core size. The roughness result of 30 cm kernel size is given in Figure 3.

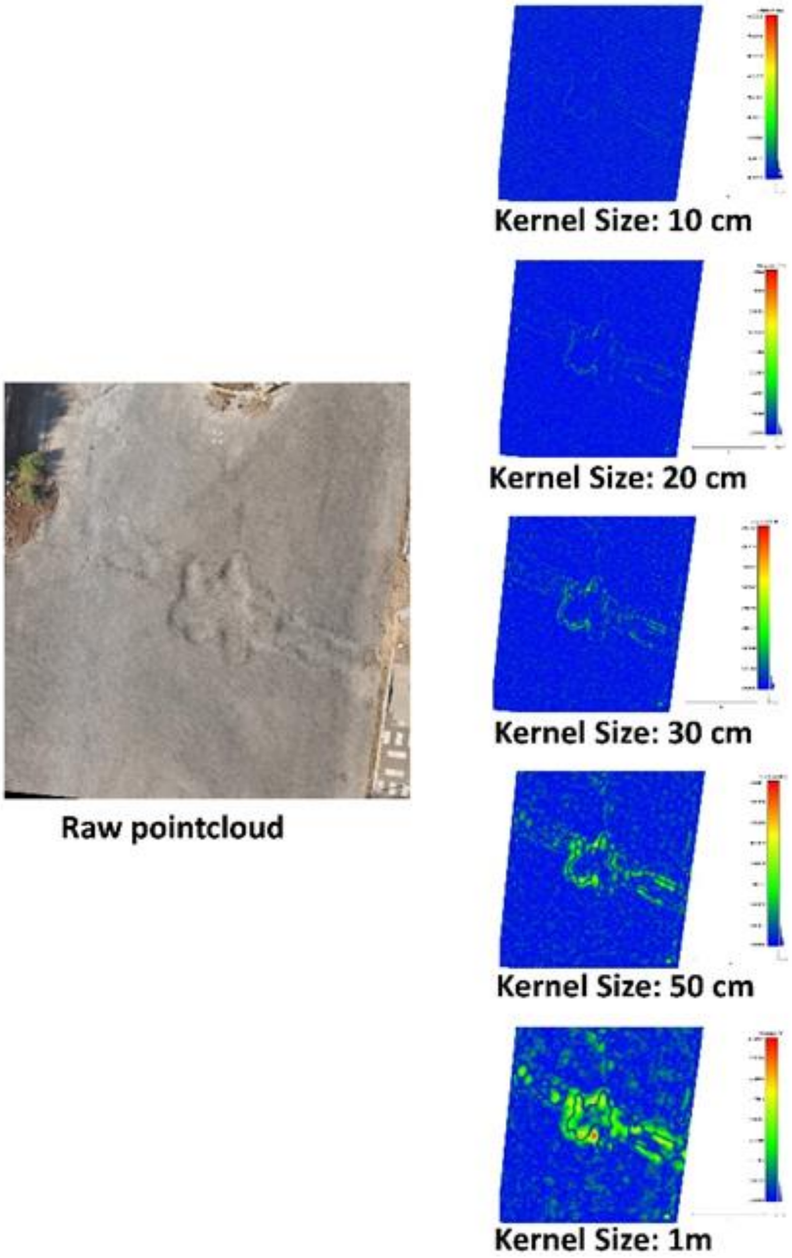

Figure 2. Roughness results of different kernel sizes.

Figure 3. Roughness result of 30 cm kernel size.

According to Figure 3, it is possible to say that smaller kernel sizes typically have a radius that covers only a limited area around each point in the point cloud. Moreover, with smaller kernel sizes, the analysis focuses on fine-scale variations in the road surface. This level of detail is particularly useful for identifying and quantifying small-scale irregularities, such as minor cracks, tiny potholes, or subtle surface texture variations. Smaller kernel sizes provide a highly detailed assessment of road roughness and are preferred when capturing fine-grained features is crucial.

The roughness result for a moderate kernel size (50 cm) is given in Figure 4.

As seen in Figure 4, the moderate kernel sizes strike a balance between capturing fine details and assessing broader trends on the road surface. This kernel sizes encompass a moderately sized area around each point, providing a more generalized view of roughness. It is possible to say that the analysis with moderate kernel sizes can effectively highlight medium-scale features like undulations, rutting, or larger cracks. Moderate kernel sizes are versatile and are often chosen when a comprehensive yet manageable assessment of road roughness is required.

The roughness result for a larger kernel size (75 cm) is given in Figure 5.

As shown in Figure 5, the larger kernel sizes involve a radius that covers a substantial area surrounding each point. With this larger kernel size, the analysis focuses on capturing the overall road condition, smoothing out localized variations. These kernel sizes are effective at assessing the road's macro-level characteristics, including large undulations, dips, or extensive surface defects. Larger kernel sizes are chosen when the primary interest is in understanding the general road roughness pattern and identifying major road surface issues.

In the end, the selection of a specific kernel size depends on the objectives of the road roughness analysis. Smaller kernel sizes are ideal for detailed inspections, moderate sizes offer a balanced view, and larger sizes provide a broader perspective of road conditions. Researchers and practitioners can tailor their choice based on the level of detail required and the specific characteristics of the road being evaluated.

Figure 4. Roughness result of 50 cm kernel.

Figure 5. Roughness result of 75 cm kernel.

4. Conclusion

In this study, we explored the potential of UAVs equipped with S*f*M-derived point clouds to revolutionize the assessment of road roughness. Road roughness is a crucial parameter affecting road safety, user comfort, vehicle operating costs, and infrastructure maintenance. Traditional methods of road roughness analysis, relying on manual inspections or image annotation, often suffer from limitations in data completeness, efficiency, and cost-effectiveness, especially for extensive road networks. Our investigation, conducted on a road segment within the Harran University Osmanbey campus, demonstrated the efficacy of UAV technology combined with S*f*M-derived point clouds as a robust and practical solution for road roughness assessment. By harnessing the advantages of UAVs, such as rapid data acquisition and high-resolution imagery, and employing S*f*M to generate detailed point clouds, we were able to provide a comprehensive analysis of road surface conditions.

Through a systematic examination of road roughness at varying kernel sizes, specifically 30 cm (*smaller*), 50 cm (*moderate*), and 75 cm (*larger*), we gained valuable insights into how different scales of analysis impact roughness measurements. This research not only contributes to the field of transportation infrastructure management but also underscores the significance of UAV technology in enhancing road safety, optimizing maintenance schedules, and minimizing operational costs.

Our findings suggest that UAV-derived point clouds offer a promising avenue for road roughness analysis, providing transportation authorities and road administrators with an efficient and cost-effective means of maintaining and enhancing road networks. By leveraging this technology, we can work towards the development of safer, more efficient, and economically sustainable road transportation systems.

As we move forward, further research and technological advancements in UAV-based road roughness assessment have the potential to revolutionize road management practices, ultimately leading to enhanced road quality and improved travel experiences for road users.

Author contributions

Nizar Polat: Conceptualization, Methodology, Software, Writing Reviewing and Editing **Şeyma Akça:** Data curation, Visualization, Investigation, Software, and Validation.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. King, B. A. (2014). The effect of road roughness on traffic speed and road safety. Master's Thesis. University of Southern Queensland.
2. Bester, C. J. (2003). The effect of road roughness on safety. 82nd Annual Meeting of the Transportation Research Board, Washington, DC.
3. Davies, R. B., Cenek, P. D., & Henderson, R. J. (2005). The effect of skid resistance and texture on crash risk. Proceedings Surface Friction Roads and Runways, Christchurch, 1-4.
4. Wu, J., & Song, X. (2020). Review on smart highways critical technology. Journal of Shandong University (Engineering Science), 50, 52-69
5. Ihs, A. (2005). The influence of road surface condition on traffic safety and ride comfort. 6th International Conference on Managing Pavements 19–24 October 2004. Brisbane Convention & Exhibition Centre, Queensland Australia, 11-21.
6. Kumar, P., Lewis, P., McElhinney, C. P., & Rahman, A. A. (2015). An algorithm for automated estimation of road roughness from mobile laser scanning data. The Photogrammetric Record, 30(149), 30-45. https://doi.org/10.1111/phor.12090
7. Hesami, R., & McManus, K. J. (2009). Signal processing approach to road roughness analysis and measurement. TENCON 2009-2009 IEEE Region 10 Conference, 1-6. https://doi.org/10.1109/TENCON.2009.5396085
8. Zhou, Y., Guo, X., Hou, F., & Wu, J. (2022). Review of intelligent road defects detection technology. Sustainability, 14(10), 6306. https://doi.org/10.3390/su14106306
9. Yiğit, A. Y., & Uysal, M. (2021). Yüksek çözünürlüklü insansız hava aracı (İHA) görüntülerinden karayolların tespiti. Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 10(3), 1040-1054. https://doi.org/10.17798/bitlisfen.900817
10. Uysal, M., Toprak, A. S., & Polat, N. (2015). DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler Hill. Measurement, 73, 539-543. https://doi.org/10.1016/j.measurement.2015.06.010
11. Akca, S., & Polat, N. (2022). Semantic segmentation and quantification of trees in an orchard using UAV orthophoto. Earth Science Informatics, 15(4), 2265-2274. https://doi.org/10.1007/s12145-022-00871-y
12. Smith, A., & Sarlo, R. (2022). Automated extraction of structural beam lines and connections from point clouds of steel buildings. Computer-Aided Civil and Infrastructure Engineering, 37(1), 110-125. https://doi.org/10.1111/mice.12699
13. Snavely, N., Seitz, S. M., & Szeliski, R. (2008). Modeling the world from internet photo collections. International journal of computer vision, 80, 189-210. https://doi.org/10.1007/s11263-007-0107-3
14. Toprak, A. S., Polat, N., & Uysal, M. (2019). 3D modeling of lion tombstones with UAV photogrammetry: a case study in ancient Phrygia

(Turkey). Archaeological and Anthropological Sciences, 11(5), 1973-1976. https://doi.org/10.1007/s12520-018-0649-z

15. https://www.cloudcompare.org/doc/wiki/index.php/Roughness
16. Gillespie, T. D. (2021). Fundamentals of vehicle dynamics. SAE international.