Advanced LiDAR

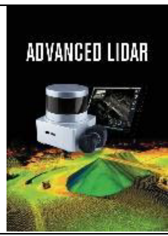
Research Article

2022: 2(2); 48-53

Advanced LiDAR

http://publish.mersin.edu.tr/index.php/lidar/index

e-ISSN 2791-8572



Detection of Road Distress with Mobile Phone LiDAR Sensors

Mustafa Zeybek*[1], Dilay Ediz[2]

[1]Selçuk University, Güneysınır Vocational School, Konya, Türkiye
[2]Kantonsschule Zürich Nord, Zurich, Switzerland

Keywords
Mobile Phone,
LiDAR,
Road, ,
Pothole.
Rut.

ABSTRACT

Comfort and safety on urban roads are two important and desirable factors in road transport networks. When it comes to providing road comfort, potholes, which emerge on the road surface for different reasons, are one of the problems that we do not want to encounter in our daily transportation. Although different techniques are already being applied to detect deformations on road surfaces, developments in measurement technologies gradually bring alternative techniques with them. The best example for this are the small size LiDAR sensors which have newly been added to mobile phones, and the subject of this study is whether they can be used in detecting such problems. The data collected from the field survey enabled a detailed examination of the road potholes with the proposed methodology based on region growing and plane fitting. According to the results, the 3D sensor technologies will take a new place in measurement technologies by providing high dense data and visualisations in small-sized projects, thus facilitating instant decisions. In the study, potholes on the road surface were determined with 4 different data sets obtained in Denizli province Pamukkale district Karahayıt neighbourhood and detailed information about their characteristics was collected. As a result, with this study, the LiDAR sensor released to the market by Apple on iPhone 12 and following versions has developed an alternative measurement technique and methodology that can be used in the implementation of small-sized projects on road surfaces. It is clear that the use of mobile phone-based LiDAR sensors in road repair services has significant potential in the near future.

1. INTRODUCTION

Highways undoubtedly play an important role in connecting cities. The geometric standards of the transportation networks and the safety of the road surface ensure that the people using the transportation network have a problem-free and high comfort journey. However, continuous monitoring of highways from planning to a sustainable network design also poses a significant economic burden. Undoubtedly, the Turkish General Directorate of Highways, together with the local administrations, spend a great deal of effort on these issues and always try to keep the road safety at a high level. Testing whether the safety standards of the highways are in place with the traditional methods and classical mapping processes used cause high costs. However, modern technological equipment has become available in order to make such measurements cheap.

Today, it is possible to access technologies that provide dense data with low-budget planning. Although the hardware that can perform light detection and ranging (LiDAR) with laser signals constitutes a significant budget, its reliability in small-scale projects with the required high accuracy with terrestrial and even mobile equipment attracts the attention of researchers (Vosselman & Maas, 2010; Yılmaz & Yakar, 2008). Simultaneously, applying necessary measurements on images with remote sensing, image processing, computer vision and photogrammetric methods, which provide intensive data by using passive sensors and then processing the field data, constitute potential innovative measurement techniques.

* **Corresponding Author**

*(mzeybek@selcuk.edu.tr) ORCID ID 0000-0001-8640-1443

Cite this;

Zeybek, M. & Ediz, D. (2022). Detection of Road Distress with Mobile Phone LiDAR Sensors. Advanced Geomatics, 2(2), 48-53.

Research Article

Received: 12/09/2022; Accepted: 30/09/2022

These technologies are not only limited to data supply, but also have the ability to process data instantly thanks to cloud computing. In this way, it has become possible to make necessary analyses even during field surveys. This saves time, reduces the need for labour, and thus provides significant savings in project costs (Gollob, Ritter, Kraßnitzer, Tockner, & Nothdurft, 2021).

Deformations caused for different reasons are observed on highways (Findley et al., 2022). Common road surface deformations; potholes, ruts and cracks (Islam & Tarefder, 2020). On the other hand, the reasons for the deterioration of road surfaces are the pressure exerted by high-tonnage vehicles on the asphalt surfaces, rapid temperature changes, precipitation, infrastructure works and the use of asphalt components that do not comply with the standards.

Considering the different application platforms and purposes in literature, the existence of important studies is substantial (Wang, Heenkenda, & Freeburn, 2022). In particular, the extraction of the surface of highways and the detection of road networks are made with data obtained from satellite imaging techniques, aerial platforms and ground surveys (Li, Ling, Sun, Xu, & Huang, 2019; Wei, Tsai, Chang, & Wang, 2022). The main contribution of this study is the detectability of potholes/collapses on road surfaces with the LiDAR sensor in mobile phones. The methodology and materials applied for this are given in detail in the following sections.

2. METHOD

Two basic data analyses were used in the proposed approach. The first stage is the determination of the application with which the data will be obtained on the mobile phone followed by the detection of the points where the plane detection will be made with the region growing algorithm, the plane fitting process and the determination of the deformations on the road surface.

2.1. Apple Applications

Currently, LiDAR sensor is only integrated on iPhone 12 Pro, 12 Pro Max, 13 Pro, 13 Pro Max, iPad Pro 2020 and iPad Pro 2021 with M1 support (https://www.apple.com/). "Measure" application comes first among the measurement applications. As the name suggests, the Measure app is used for simple measuring operations. It is also very easy to measure the distance between two points and perform the scale operation. Distances can be measured both vertically and horizontally. The measured points remain fixed in the augmented reality (AR) environment.

Besides the given measurements, the app automatically tests and measures rectangles and even automatically calibrates peoples' height. You can take pictures of these measurements to store the data and share them as images.

Another important application is SiteScape – 3D scanning application. After installing the SiteScape application on the iPhone 12 pro mobile phone, an account must be opened from the SiteScape Application. While a limited number of scans are made free of charge in a certain period of time, an unlimited number of scans can be made after the membership fee and synchronisation with the cloud is made. Detailed information can be found at https://www.sitescape.ai/.

Another widely used application, which is also used in this study, is the 3D Scanner App (https://3dscannerapp.com/). With this application, a 5x5m wide outdoor environment is scanned in a single scan. This feature is a sufficient technical feature for the study carried out in this research. Point clouds can be exported directly in *LAS* file format. Point clouds also contain *RGB* (Red, Green, Blue) radiometric information.

2.2. Ground Image Based Reconstruction

Another method widely used in geosciences to obtain point clouds and to measure on them is a structure from motion (SfM) image processing-based method. Images were obtained with the same Apple iPhone 12 Pro mobile phone and the analyses were processed with Agisoft Metashape software (https://www.agisoft.com/). After obtaining the images using the iPhone, a file format with HEIC extension was encountered. These files were later converted to *JPG* format with the R *magick* package (Ooms, 2021; Team, 2021). In this way, images were transferred into Agisoft software. After the images are imported into the software, the general process flow is aligning images, constructing dense point clouds and a mesh surface model, generating texture, creating digital terrain model and orthomosaic. Other enhanced analyses were performed on point clouds containing the road surface.

2.3. Calculation of Deviations from the Plane

The depth level of the pothole was determined based on the points around the point clouds for each separate test data. For this, the region growing algorithm (Rabbani, Van Den Heuvel, & Vosselmann, 2006; Vo, Truong-Hong, Laefer, & Bertolotto, 2015) was applied first, followed by the plane fitting algorithm. Region growing methods are widely used on basically 2D images (Chang & Li, 1994). It is checked whether the neighbouring pixels determined near a region have similar properties, and if the given criteria are met, the clustering process is applied. The basic principle is to classify a point or pixel by comparison with its neighbours. In this study, 4 points were determined and a plane was created according to the surface points determined by the region growth algorithm of said points. The generated plane and raw point cloud data were evaluated by point-plane comparison.

After the region growing points were determined, the surface normals of the plane were obtained. Given any point P, there is an infinite plane containing the point P. However, if the normal vector of the plane is detected in three-dimensional space (R^3), the plane is defined in this way. Surface normal means the vector perpendicular to the plane.

A point on the plane (red point) and green (surface normal) are given in Fig. 1.

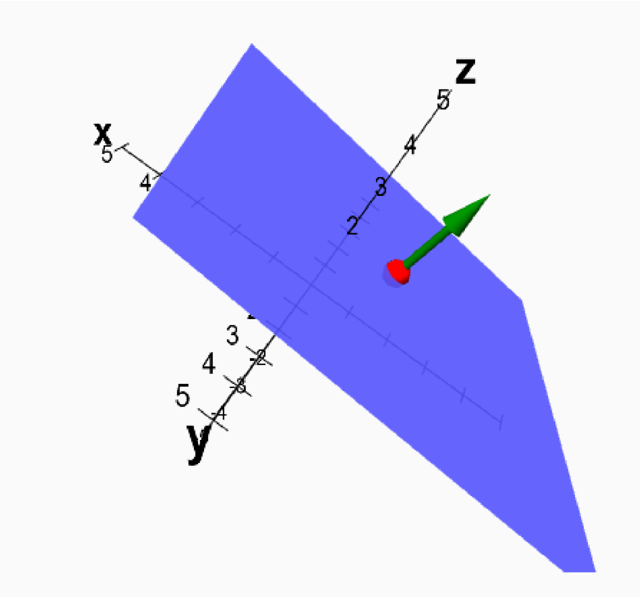


Figure 1. The basic parameters that make up a sample plane are a point in the plane (red dot) and plane surface normal (green arrow)

After the points forming the plane and the plane are determined, the deviations of all points from this plane should be determined. To detect the deviation of a point from the plane, that point must be projected into the plane. That is, the point on the plane must be found. Thus, the distance of the points in the closest perpendicular direction to the plane is found. The distance from any point P to the plane is defined as the length of the projection of the coordinate differences on the surface normal.

It is assumed that the local potholes formed on the road surface do not change much in a small area and are created with a 3D plane model as below (George B. Thomas, Weir, Hass, Heil, & Behn, 2016; Strutz, 2011).

$$Ax + By + Cz + D = 0 \quad (1)$$

where, *A, B, C, D* represent the surface normal parameters. *x,y,z* are point coordinates. The least squares estimation (LSE)(Strutz, 2011) and *A,B,C,D* estimation were made with the *lm* function of the R program (Team, 2021). As mentioned before, with the assumption that the road surface has not changed much and the region growing algorithm, the plane settlement was performed on the points outside the pothole, and thus the depth information of the pothole was obtained.

The distances (*d*) to the plane model given above (Eq.1) were calculated with the following formulas (George B. Thomas et al., 2016).

$$d = v \cdot n \quad (2)$$

$$d = \frac{|Ax1+By1+Cz1|}{\sqrt{A^2+B^2+C^2}} \quad (3)$$

2.4. Test Area

As the study area, 4 road potholes were selected on the 134th street in Denizli province Pamukkale district Karahayıt neighbourhood (Fig. 2). The images were collected together with the LiDAR measurement in 2 road potholes. In this way, both SfM and LiDAR evaluations could be made.

Infrastructure work is estimated to be the main cause of three of the road potholes. The other pothole is estimated to have emerged after the asphalt lost its properties and was neglected.

Figure 2. Study area location of Denizli province

These road surface stresses, which are thought to have occurred after the infrastructure work in the study area, can be detected by both LiDAR sensor and image processing methods (Fig. 3). Here, it is important that the repair work suitable for the road surface is prioritised in the maintenance processes to be made later. This has a significant impact on road comfort. The data obtained for this purpose is used as important information in applications such as asphalt volume calculation, depth detection and asphalt levelling.

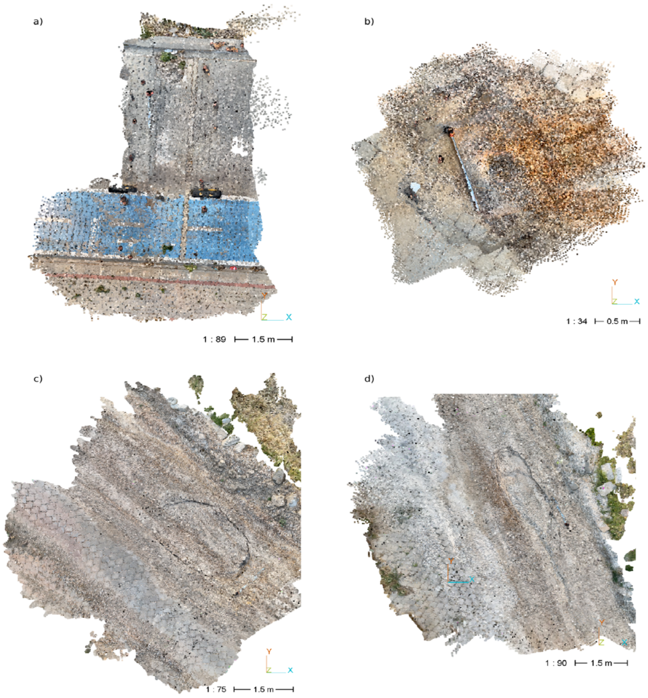


Figure 3. Point clouds obtained with the iPhone 12 pro LiDAR sensor

After Fig.3c and d were brought to the same coordinate system with the best fitting transformation of LiDAR and SfM point clouds, respectively, point-to-point comparison was made and the result in Fig. 4. was obtained. According to these results, it was observed that LiDAR data were not as detailed as SfM. The main reasons for this are that the images have a better resolution than the LiDAR sensor, the iPhone inertial measurement unit (IMU) sensor measurement precision is low, the image matching algorithms determine with high accuracy and detect homologues points on the images.

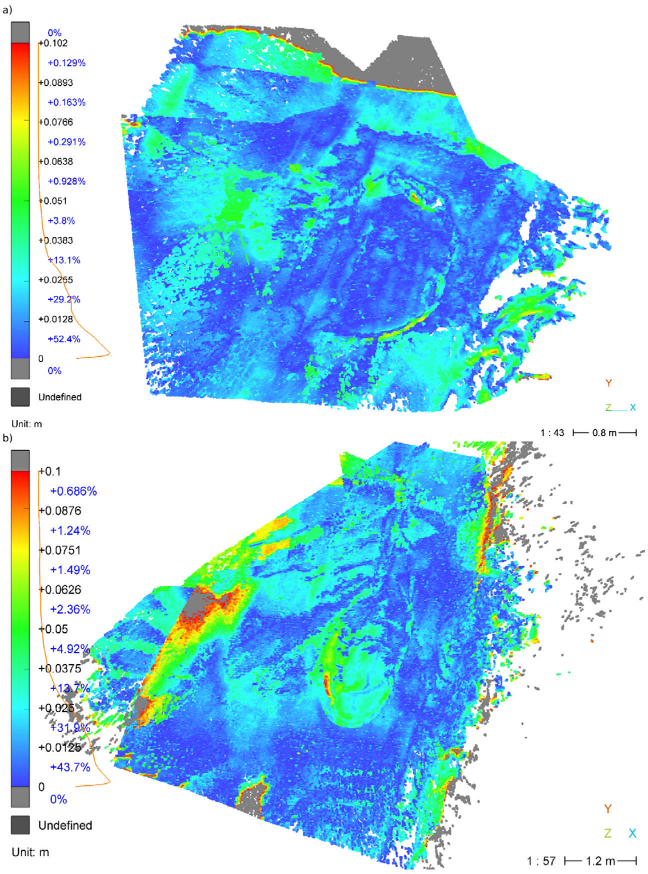


Figure 4. iPhone 12 pro LiDAR sensor vs. SfM point clouds cloud-cloud

3. RESULTS

Within the scope of the approach proposed in the methods section, two different data were obtained. They are point clouds with LiDAR sensors and based on SfM. The region growing algorithm applied to these point clouds was established on the plane in the area determined after the growth and the depths of the potholes were attained.

According to the results obtained, the region growing algorithm has eliminated an important problem. This is the problem of where to get the suitable fitting plane points and region. Although there is manual determination at this stage, the plane can be determined even by selecting at least 1 seeding point from the regions close to the plane and close to the pothole edge. However, it is visible that choosing at least 4 points is more beneficial. It is clear that the LSE estimation is sufficient for plane formation. Determining the differences from the plane as positive or negative according to the surface normals also allowed the investigation of the pits' maximum depths and whether there are points higher than the leveling in the surrounding areas.

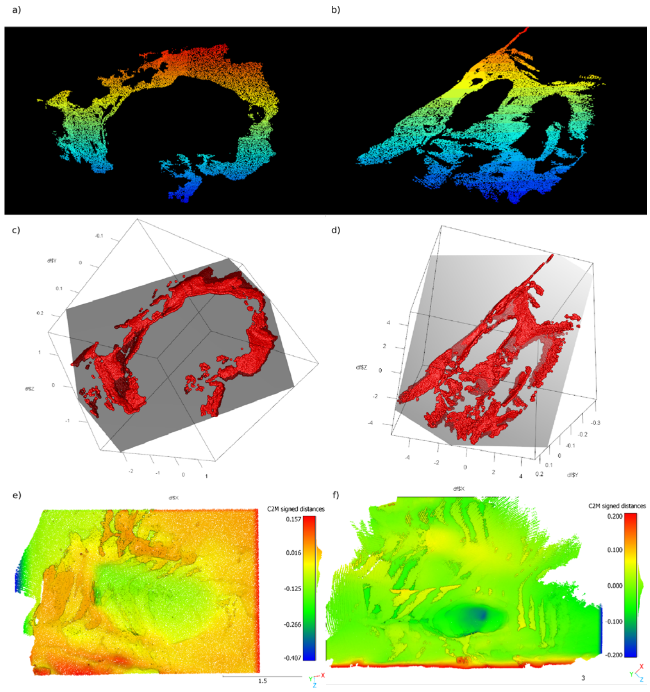


Figure 5. Analysis of the depressions that emerged after the roadwork, two different data sets are shown a,b) The surface points determined by the Region growing algorithm, these points were determined with a tolerance of 1 cm. c,d) fitting the LSE based plane of planar points, e,f) distance of all point clouds to the plane (deviation)

An important result obtained is the presence of alignment errors in the LiDAR data, which emerged both in the comparison of SfM point clouds with LiDAR point clouds and in the analysis of deviations from the plane. In this case, it has been revealed that these points are points that have the error of combining with the overlapped measurements. These points should be deleted or ignored.

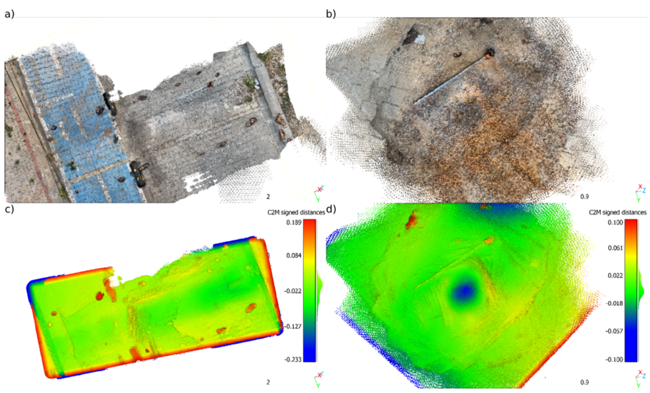


Figure 6. The analysis of the depressions after the roadwork and as a result of neglect, two different data sets are shown a,b) Although there is RGB information when the point clouds are viewed from above, one can see that the depressions cannot be determined but c,d) appear after the plane deviations.

According to Fig.5e, the presence of potholes deviating from the plane around 12 cm and 10 cm could be detected. In addition, alignment errors, which are thought to be caused by the IMU, have occurred at a high rate.

According to Fig.5f, serious depressions reaching a maximum depth of 15 cm were detected. In addition to these depressions, noisy points were also encountered in this data set.

According to Fig. 6, depressions at a level that could be difficult to see with the naked eye could be detected on the road surface at the field stage. These deviations were determined to be in the range of 3 to 8 cm.

4. DISCUSSION

In recent years, laser scanning devices integrated into mobile phones and tablets have been used as a data collection tool. In this regard, Aslanlı Fountain research has been carried out recently using the same LiDAR sensor but a top model cell phone iPhone 13 pro lidar sensor (Aslan & Polat, 2022). According to the results of the study, although it is mentioned that the iPhone 13 lidar sensor can be used to collect data about short-term outdoor objects and it is possible to rescan to increase the data density, it is seen that IMU errors occur. For this reason, if the object dimensions are over 5x5 m, data with iPhone LiDAR should be taken piece by piece and merged, not in an overlay point cloud. In the same study, it was mentioned that it can be used when integrated with photogrammetric data. In this study, it was revealed that the sensitivity of photogrammetric data was better. However, iPhone LiDAR is seen as useful in small-scale studies where instant viewing and fast results are required. Combining it with photogrammetric data will make point clouds noisier. In addition, it seems that this will not be needed from the perspective of many disciplines. LiDAR data generates RGB information.

Another study was done by Kuçak, Erol, and Alkan (2023). During the scanning of objects with too much detail compared to Kuçak et al. (2023), better quality point clouds could only be obtained if measurements were made from a distance of approximately 1 meter with the appropriate scanning options of the software used. Since Kuçak et al. (2023) only made distance comparisons in his study, he did not mention the absolute positional change due to angular accuracy. In fact, making angular examinations besides the distance creates IMU-induced errors in repeated measurements in overlapping areas. The main reason for this is that the measurement fineness of the IMU sensor in iPhone and iPad devices is a rough sensor and designed for virtual reality applications, not for geomatic engineering purposes.

According to the studies examined, mobile cell phone LiDAR sensors, which are promising in distance and 3D modelling studies, can also be used in engineering and road works, but the current user requires experience before measurement and engineering knowledge to be able to analyse after measurement. It should be noted that iPhone sensors are not produced to collect data with very high accuracy and density. Measurements made in this context should be done meticulously, data transformations and analyses should be evaluated in accordance with statistical information such as Kuçak et al. (2023). The ignored limit and tolerance of the errors that occur are also dependent on the user's knowledge. Since the applications used in this study were obtained from open access and free versions, the units working with memberships were not evaluated. In the future, it is expected that better results can be achieved by developing SLAM-based applications which export trajectory information besides IMU, post-processing with GPS time, loop closure and SLAM based on trajectory information.

5. CONCLUSION

This study investigated the inquiry of depressions on road surfaces using the iPhone LiDAR sensor. In four different datasets, the detection and analysis of road potholes were completed with the LiDAR point cloud region growing algorithm-based and plane-fitting process. At the same time, 3D analysis and LiDAR point clouds were compared with the help of images using SfM-based software in the data set. After comparison, it has been determined that SfM-based point clouds produce more sensitive data. In the point clouds obtained from LiDAR sensors, offsets were detected in the overlapped misalignment measurements. However, when these misalignments were excluded from the evaluation, it was possible to carry out and interpret the relevant study. As a result, it has been seen that LiDAR sensors in mobile phones have the potential to be used in small engineering projects. It is foreseen that these problems can be reduced in the near future with improvements in sensor technical features and algorithms. Therefore, it is clear that instant solutions of road surfaces can be possible in bringing instant and fast solution suggestions.

Author contributions

MZ contributed to the writing of the article with the idea of the article, field study and analysis. DE contributed to the fieldwork and article writing.

Conflicts of interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

REFERENCES

Aslan, İ. & Polat, N. (2022). Availability of Iphone 13 Pro Laser Data in 3D Modeling. *Advanced LiDAR, 2*(1).

Chang, Y. L. & Li, X. (1994). Adaptive image region-growing. *IEEE Trans Image Process, 3*(6), 868-872. doi:10.1109/83.336259

Findley, D. J., Cunningham, C. M., Thomas H. Brown, J., Cahill, L. M., Yang, G. & Huntsinger, L. F. (2022).

Highway Engineering Planning, Design, and Operations.

George B. Thomas, J., Weir, M. D., Hass, J., Heil, C. & Behn, A. (2016). *THOMAS' CALCULUS Thirteenth Edition in SI Units*.

Gollob, C., Ritter, T., Kraßnitzer, R., Tockner, A. & Nothdurft, A. (2021). Measurement of Forest Inventory Parameters with Apple iPad Pro and Integrated LiDAR Technology. *Remote Sensing, 13*(16). doi:10.3390/rs13163129

Islam, M. R. & Tarefder, R. A. (2020). *Pavement Design Materials, Analysis, and Highways*: McGraw Hill.

Kuçak, R. A., Erol, S. & Alkan, R. M. (2023). iPad Pro LiDAR sensörünün profesyonel bir yersel lazer tarayıcı ile karşılaştırmalı performans analizi Comparative performance analysis of the iPad Pro LiDAR sensor with a professional terrestrial laser scanner. *Geomatik Dergisi, 8*(1). doi:10.29128/geomatik.1105048

Li, X. N., Ling, S. X., Sun, C. W., Xu, J. X., & Huang, T. (2019). Integrated rockfall hazard and risk assessment along highways: An example for Jiuzhaigou area after the 2017 Ms 7.0 Jiuzhaigou earthquake, China. *Journal of Mountain Science, 16*(6), 1318-1335. doi:10.1007/s11629-018-5355-x

Ooms, J. (2021). magick: Advanced Graphics and Image-Processing in R (Version R package version 2.7.3). Retrieved from https://CRAN.R-project.org/package=magick

Rabbani, T., Van Den Heuvel, F., & Vosselmann, G. (2006). Segmentation of point clouds using smoothness constraint. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 36*(5), 248-253.

Strutz, T. (2011). *Data Fitting and Uncertainty*: Springer Vieweg.

Team, R. C. (2021). R: A Language and Environment for Statistical Computing. Retrieved from https://cran.r-project.org/

Vo, A.-V., Truong-Hong, L., Laefer, D. F., & Bertolotto, M. (2015). Octree-based region growing for point cloud segmentation. *ISPRS Journal of Photogrammetry and Remote Sensing, 104*, 88-100. doi:10.1016/j.isprsjprs.2015.01.011

Vosselman, G., & Maas, H.-G. (2010). *Airborne and Terrestrial Laser Scanning*: Whittles Publishing.

Wang, F., Heenkenda, M. K., & Freeburn, J. T. (2022). Estimating tree Diameter at Breast Height (DBH) using an iPad Pro LiDAR sensor. *Remote Sensing Letters, 13*(6), 568-578. doi:10.1080/2150704x.2022.2051635

Wei, C. T., Tsai, M. D., Chang, Y. L., & Wang, M. C. J. (2022). Enhancing the Accuracy of Land Cover Classification by Airborne LiDAR Data and WorldView-2 Satellite Imagery. *ISPRS International Journal of Geo-Information, 11*(7). Retrieved from <Go to ISI>://WOS:000834409700001

Yılmaz, H. M., & Yakar, M. (2008). Lidar (Light Detection And Ranging) Tarama Sistemi. *Yapı Teknolojileri Elektronik Dergisi, 2*, 23-33.