LiDAR from UAV for Flood Forecast: related problems and quality

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Abstract:

The Flood Forecast and Alert System for *Águeda* Urban Area (FFAS) is a system that is being developed in the framework of a scientific project financed by the Operational Program of the Central Region. Its main aim is to improve flood prevention and mitigate economic losses of inhabitants in flood-prone areas of *Águeda* Municipality. FFAS intends to reduce direct tangible and intangible costs (physical damage in buildings and infrastructure, loss of human lives and of environmental resources) and indirect tangible and intangible costs (production losses of companies directly affected by floods, inconvenience at post-flood).

The system uses a hydrologic and hydraulic models that require geo-information, such as a Digital Terrain Model (DTM), building boundaries, bridge pillars, walls and vegetation locations, in raster format. This information may be derived from both aerial images and aerial laser scanning (LiDAR) data acquired with Unmanned Aerial Vehicles (UAV).

Although the use of aerial images acquired with UAV for geo-information extraction is becoming a standard procedure for several applications, the use of LiDAR is still in its infancy. Scientific literature reporting on the UAV LiDAR data quality is scarce and the problems that the production chain may encounter are not treated.

In this work, these issues are addressed by using the LiDAR data acquired with the Phoenix Scout-16 from Phoenix LiDAR Systems, carrying a Velodyne VLP-16 and mounted on a DJI Matrice 600 PRO Hexacopter for an area of 560 ha along an inundated-prone area of the *Águeda* River.

1. Introduction

Acquisition of geo-information using UAV is becoming a trivial procedure. In fact, the use of images acquired by UAV and of software based on computer vision technologies such as Structure from Motion and Multi-view Stereo is installed in various fields such as archaeology, agriculture, forestry, construction, mining, and large scale cartographic production. Accuracy of derived information, such as DTM may reach some cm, depending on the platform used, the quality of the aerial camera, the navigation system and the set-up of the flight (for example, the use of ground control points), but also on the characteristics of the terrain. In densely forested land, or in regions where the texture of the terrain cover is homogeneous, like in sand, the accuracy of the derived information will degrade. An alternative may be the use of a LiDAR system also transported in a UAV.

The use of LiDAR systems on board of an aircraft is well established in terms of accuracy and applications (Huising and Gomes Pereira, 1998; Gomes Pereira and Gonçalves, 2010; Gonçalves and Gomes Pereira, 2012). Nonetheless, its price is prohibitive to several users.

Laser scanning sensors developed in the field of collision avoidance for the automotive industry, such as the Velodyne VLP-16, which is a lightweight LiDAR sensor, together with the development of accurate and also lightweight IMU (Inertial Measurement Unit) and GNSS receivers (Global Navigation Satellite System) are pushing the development of commercial ultralight LiDAR systems mounted on UAV. Since 2014, companies like Trimble (with APX-15), SBG (with the Eclipse series) and NovAtel (with STIM300 and the SPAN series) have developed new solutions for the precise positioning of UAV by integrating a double-frequency GNSS receiver and a new generation of tactical-grade MEMS IMU, weighting less than 100 grams (Pilarska *et al.* 2016). As the developments are recent, there are only a few LiDAR systems for UAV available (Pilarska *et al.* 2016), and those that are low-cost, but still costly when compared to photogrammetric UAV, rely greatly on post-processing software to deliver satisfactory results (Bakula *et al*., 2017). In Portugal, as far as the authors are aware, there are still no survey companies offering geo-information acquired with such a system. This situation will probably change rapidly and thus, it is important to discuss and present related problems, solutions and the expected information quality. This is the purpose of this work supported on data acquired with the Scout Fenix Lidar Systems mounted on a DJI Matrice 600 PRO HexaKopter. This system, together with the description of the study data are presented in section 2. Section 3 reports on the quality assessment, whilst section 4 addresses the conclusions.

2. Study area and data

In the following subsections, the study area is presented and the data acquisition and post-processing processes are described.

2.1 Study Area

The study area is situated in the river basin of *Vouga* (Centre region of Portugal) where flooding frequently occurs. It has around 560 ha and a 9.8 km reach of the *Águeda* River (Figure 1).

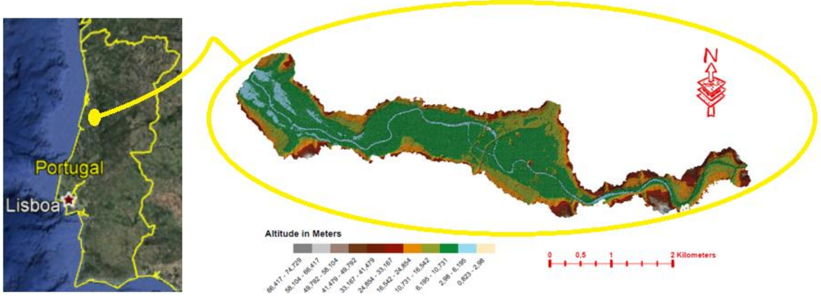


Figure 1 – Study area

This area has, along the riverbanks, mainly agricultural fields, which are surrounded by hills some with steep slopes. It also contains *Águeda* downtown. The margins of the stretch along the river have a great density of vegetation. The terrain altitude varies from around 0.8 m to 75 m (Figure 1).

2.2 LiDAR Data

The LiDAR data acquisition was outsourced and was carried out during the week of the 22nd until the 25th of January 2018. Forty-two flights were executed at a mean terrain height of 50 m (Figure 2), except in some areas because of the existence of trees, high voltage electric power lines and constructions (in these cases the mean flight height varied from 55 m to 70 m). The mean velocity of the UAV was 5 m/s, which allowed capturing, in mean 180 points/m^2 in a total of 1 569 829 680 points. Figure 3 shows a small part of the point cloud.

Figure 2 – Flight lines of the 42 flights

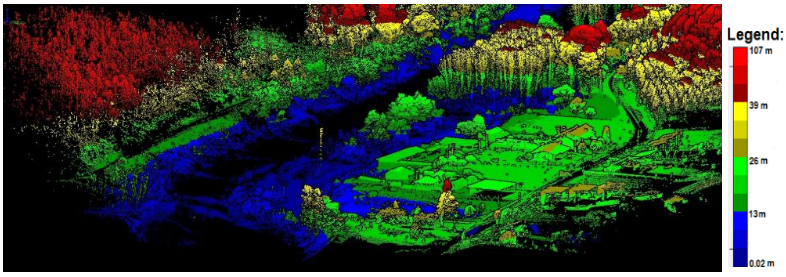


Figure 3 – A part of the point cloud, coloured by the altitude value

The company that acquired the data executed the post-processing using the software LiDARMill of Phoenix LiDAR Systems. This software starts by combining the IMU and GNSS data to generate smoothed and accurate trajectories. Afterwards it automatically detects and omits turns and calibration patterns. The processing is completed by geo-referencing the data, minimizing offsets from multiple flight lines, and by exporting aligned data in the industry-standard LAS format. The geo-referencing of the data, in the projection system PT-TM06 ETRS89 and the Altimetric Datum of Cascais, was done by using 25 GNSS base stations of the company that acquired the data as well as the closest RNEP (*Rede Nacional de Estações Permanentes*) station (AGUE). The method used was PPK (Post-Processed Kinematic).

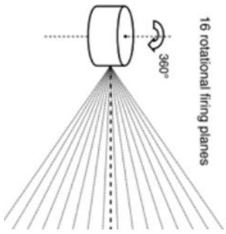
The system utilized to acquire the LiDAR data consists of a platform, the UAV DJI Matrice 600 Pro Hexacopter, the LiDAR system Scout-16 that has a Velodyne VLP-16 multiple spinning sensors (technical specification in Table 1), the IMU OEM-ADIS16488 and 3 GNSS antennas NovAtel OEM6 (Figure 4). Velodyne VPL-16 is a multichannel laser scanner that irradiates 16 laser beams with an equally spaced angular division of two degrees in the front and rear with respect to the flight direction, and scans 360º in the direction perpendicular to that of the flight to obtain the data (Figure 5). It is, therefore, expected that in densely forested areas the ground acquisition rate can be improved due to the penetration of the 16 laser irradiations with different incident angles (Nakano *et al.,* 2018).

3. Quality assessment

The first delivery of the data had 55% of erroneous points that were later removed. These points had either negative altitude values and/or intensity values equal to zero. Some resulted from a firmware problem other from spurious reflections normally in the atmosphere. An example of these points is illustrated in Figure 6 (a) whereas Figure 6 (b) shows the respective clean point cloud. The clean point cloud, with a point density per m^2 of 97.14, is made of 713 777 230 points that occupy 19GB of disk space.

Figure 4 – The LiDAR data acquisition system

Table 1 – Technical specifications of the LiDAR system (Phoenix LiDAR Systems, 2018)

Sensor	Laser	Performance Specifications	Other
LiDAR sensor VLP-16	Class 1 Eye safe	Measurement rate ~300,000 pts/s	Net weight 590 g
No. of lasers/planes 16	Wavelength 903 nm	Max. operation range 100 m	Power consumption 8 W
Horizontal field of view 360°	Dual Returns (strongest and last)	Max range accuracy ±3 cm	
Vertical field of view -15° to +15°	Beam Divergency 3mrad	Range resolution 2mm	 **Figure 5** – Scheme of the Velodyne VLP- 16 sensor
Horizontal Resolution 0.1° – 0.4°	Firing Repetition Rate 55.296 μs/18.2 KHz	Footprint at 100m 30 cm	
Vertical resolution 2°	Maximum output energy 31 watts (0.19 micro joules)		
Rotation Rate 5 Hz – 20 Hz			

The erroneous points were removed with the software 3DReshaper by the company that acquired the data but the associated number of the return, that was either 1 or 2, was lost. The company claimed this to be a limitation of the software.

Rainfall during the day before the data were acquired contributed to gaps in the point cloud for there were several puddles mainly in the agriculture fields along the riverbanks. These, together with the resulting muddy soil in the next days created conditions for the beams of the Class 1 laser sensor not to be reflected.

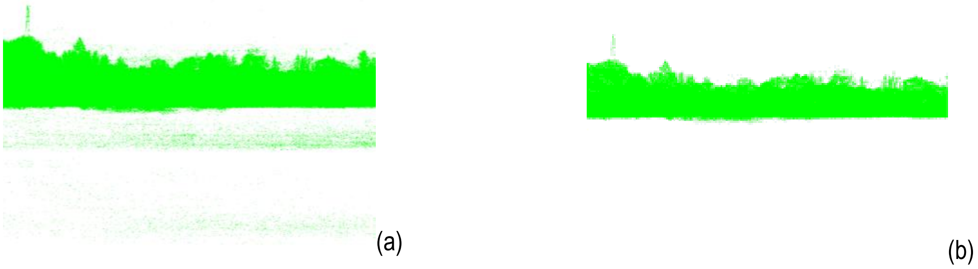

(a) (b)

Figure 6 – Erroneous points (a) and the clean point cloud (b)

The penetration of the LiDAR beams in areas with vegetation was inspected visually. Figure 7 portrays a profile of the point cloud in areas with vegetation under which the terrain appears represented by points.

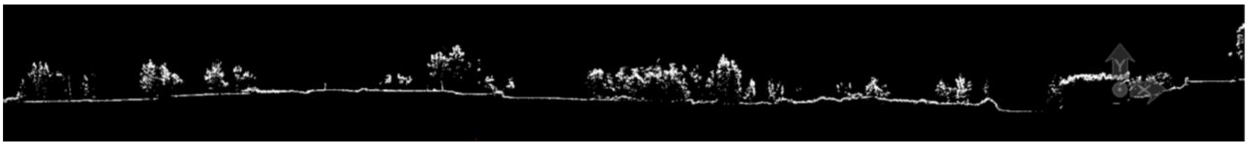


Figure 7 – Penetration of the laser beams in areas with vegetation

The visual analysis of the point cloud with the software TerraScan of the Finish company Terrasolid also showed that along roads of asphalt or paved with stone, the density of the point cloud is reduced of about 30%, as exemplified in Figures 8 (a) and (b). Figure 8 (b) also illustrates a situation of almost no reflection for a football field covered with synthetic grass.

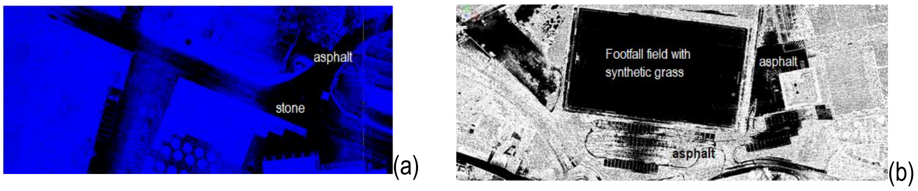


Figure 8 – Point cloud along asphalted roads and roads paved with stone

Figure 9 shows a curious situation in which three roofs of small sheds covered with the same material, zinc painted in dark green (Figure 9 (a)), reflect the laser beams in different ways. While the middle roof with the tiles oriented in a direction near to that of the swiping reflects the laser beams, the other two, with the tiles oriented in a perpendicular direction reflect much less

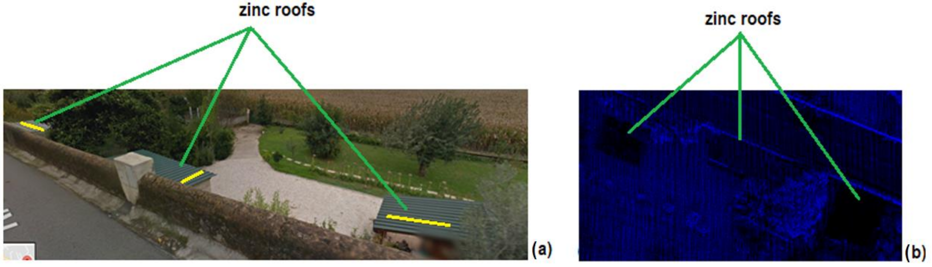


Figure 9 – Point cloud on top of three zinc roofs. In (a), the yellow lines on top of the roofs represent the orientation of the tiles

Using TerraScan, the visual analysis of profiles collected on portions of the point cloud, and of the point cloud itself, permitted the detection of shifts in planimetry. The shifts were either relative, i.e. among neighbouring strips (Figure 10) and/or absolute, i.e. in relation to the coordinates of ground control points (Figure 11). The latter were estimated in two different ways: by using prominent features on an orthophoto produced with an accuracy in XY of 5 cm (Figure 11 (a)) (Mayer *et al.*, 2018) and well-identified ground control points (Figure 11 (b)). Although these features and the corresponding in the point cloud have no direct point-to-point correspondence, their shifts can be estimated. This was done by, first, fitting linear segments to the points in the cloud that were considered to represent the feature. The distance between corresponding points on the two features was then measured manually using TerraScan. The value encountered with both methods was systematically in the order of 50 cm in X and in Y. The shifts in planimetry were reduced by post-processing the data, once again, using strip adjustment without the use of ground control points. In this way, the shifts were reduced to around 15 cm, distributed in every direction without having significant systematic effects. Figure 12 illustrates the improved situation.

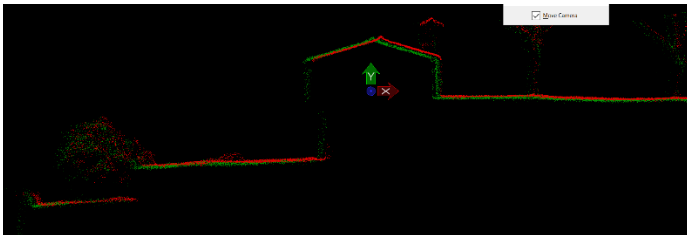
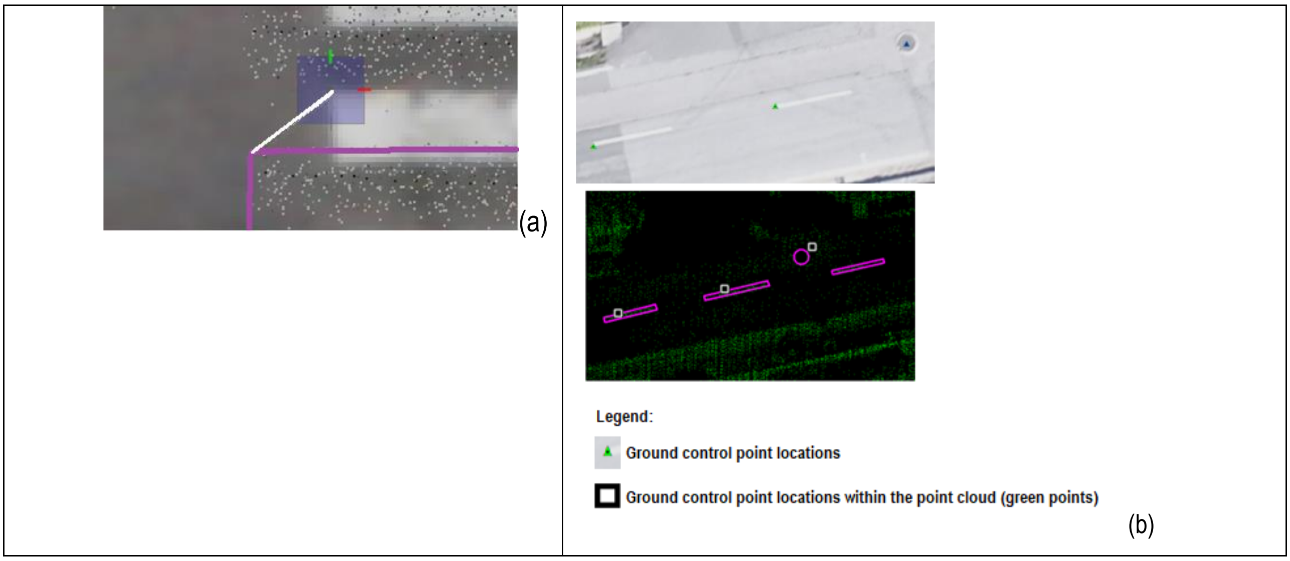


Figure 10 – Shift in planimetry among two neighbouring strips (red and green coloured)



(a)

(b)

Figure 11 – Shift in planimetry when using prominent points on an orthophoto (a) and the coordinates of ground control points (b)

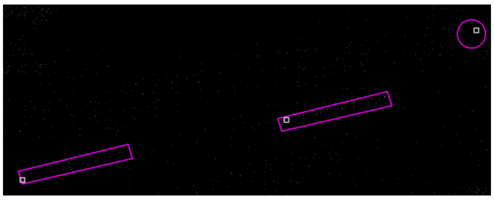


Figure 12 – Planimetric shifts after strip adjustment

Although the assessment of the planimetric shifts in the point cloud is desirable, it is not always possible. It requires that within the surveyed area there are conspicuous features in planimetry, measured by GNSS means that are also well visible in the point cloud. For our particular case, whereas the urban area, predominantly flat has several of those features, the other regions do not. Therefore, it is pertinent to verify the impact of the encountered shifts in the altimetric accuracy. To this end, there were used two parts of the point cloud, where shits were detected, of around 0.01 ha each, that differ on topography for whilst one represented flat terrain, the other portrayed terrain with slopes. This assessment in altimetry was carried out using the coordinates of ground control points measured with GNSS (85 points for the flat area and 10 points for the other. This difference in the number of the control points is due to the fact that they were collected for other purposes. In the ambit of the project, and knowing that the data were been corrected there was no need, and time, to measured specifically points to this end). The residuals in Z were obtained by using the software TerraScan by which the Z values for points located at the same X and Y locations as the ground control points were interpolated using the triangle facets made with the three closest points in the cloud. To avoid erroneous interpolation when using points located other than in the terrain surface, the point cloud was first filtered to remove obstacles. The results are listed in Table 2. As it can be seen in that table, the shift in XY of 50 cm introduced a bias in Z of around -0.08 m. It should be noted that this value is only indicative for the area used is rather small.

Table 2 – RMSE in altimetry and other related quality data

Part	Mean (m)	RMSE (m)	Minimum and maximum residuals (m)
Flat Terrain	-0.08	0.13	-0.38; 0.34
Terrain with slopes	-0.07	0.15	-0.30; 0.17

Being the data reprocessed with the strip adjustment, as stated above, the final accuracy in altimetry was assessed for all the study area by using 277 ground control points (Figure 13) and the same method as described above. Table 3 lists the obtained RMSE and other related quality data. It should be noticed that the filtering process has a big impact on the final accuracy. Filtering based on the Axelsson filter (Axelsson, 2000), implemented in TerraScan was used, but manual editing had to be performed.

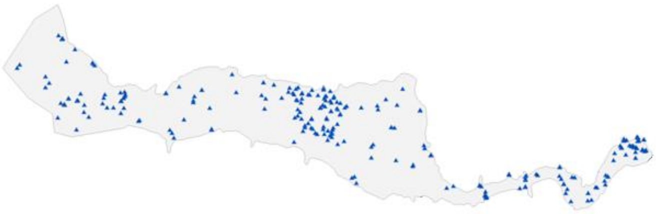


Figure 13 – Ground control points used for the assessment of the accuracy in altimetry

Table 3 – Final RMSE in altimetry and other related quality data for all the study area

Mean (m)	RMSE (m)	Minimum and maximum residuals (m)	Percentage of the residuals smaller than 0.40 m
-0.04	0.15	-0.49;0.60	99%

To have an idea of the DTM accuracy compared with that of a DTM produced by UAV photogrammetry, was further produced a DTM with 4565 images. These were acquired with the camera FC6310_8.8_4864x3648 (RGB) mounted in a Phantom 4 Pro, on October 2017, with two flights at an average height of 110 m and 150 m. The point cloud, produced with the software Pixe4D, was treated in the same way as that produced with LiDAR by using the TerraScan. The obtained RMSE was 0.44 m, with a residual average of -0.08 m. The minimum and maximum residuals have the values -2.42 m and 2.55 m, respectively. Also 96% of the residuals are smaller than 0.40 m.

4. Conclusions

The first delivered LiDAR point cloud had some issues that were easily solved. Firstly, 55% of the points were erroneous due to a firmware problem already resolved and to spurious reflections. Those type of returns are easily detected, because the corresponding altitude values are absurdly high or low for the area and, therefore, easily removed.

Secondly, the first treatment of the data did not include strip adjustment, which led to the existence of planimetric shifts, of the order of 50 cm, in some parts of the point cloud. When reprocessing the point cloud by making the adjustment of the strips, without using ground control points, the shifts were substantially reduced to 15 cm.

The final accuracy in altimetry of a DTM produced with the LiDAR data, in TIN format, was assessed by using the coordinates of 277 ground control points. The RMSE has a value of 15 cm which is sufficient for many applications. If strip adjustment was executed with ground control points, this figure would be reduced, as stated in Nakano *et. al*., (2018) where it was shown that altimetric accuracy was reduced from 10 cm to 4 cm (in an area of 0.02 km^2 there were used 9 ground control points). For applications demanding high accuracy, the company Phoenix Systems recommends the use of ground control points well distributed within the surveyed area amounting to 10 in 1 km^2. This amount of ground control points not only increases the price of the LiDAR data acquisition by a UAV as may make it impractical in situations of densely forested or inaccessible areas. Nonetheless, that amount of ground control points does not appear to be founded in scientific considerations. This aspect needs to be further investigated.

The LiDAR data acquired with an UAV can be four times less expensive than that acquired with an aircraft, while resulting in comparable accuracy. The obtained accuracy of 15 cm in altimetry is conform to the standards for the production of DTM at large scales. It is superior to that obtained by means of UAV photogrammetry with a consumer grade camera (44 cm).

When only the raw point cloud is purchased, economic considerations have to be done related to the post-processing software. This has to permit data filtering and DTM production. Another important factor to consider is the amount of data versus the processing time. In this study, the filtering of the point cloud and the production of a DTM took around a week using a portable workstation with 32 GB of RAM, a processor Intel i7-7820HQ 2.9GHz and a Solid-State Drive (SSD) disk HP Z Turbo Drive 512GB PCI.

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References

Axelsson, P. (2000). DEM generation from laser scanner data using adaptive TIN models. International Archives of Photogrammetry and Remote Sensing, Vol. 35, Part B4/1:236-241.

Bakuła, K; Salach, A.; Wziątek, D. Z.; Ostrowski, W.; Górski, K; Kurczyński, Z. (2017). Evaluation of the accuracy of lidar data acquired using a UAS for levee monitoring: preliminary results. International Journal of Remote Sensing, 38:8-10, 2921-2937

Gomes Pereira, L.M; Gonçalves, G.R. (2010). Accuracy of a DTM derived from full-waveform laser scanning data under unstructured eucalypt forest: A case study. XXIV FIG International Congress.

Gonçalves, G.R.; Gomes Pereira, L.M (2012). A thorough accuracy estimation of DTM produced from airborne full-waveform laser scanning data of unmanaged eucalypt plantations IEEE Transactions on Geoscience and Remote Sensing 50 (8), 3256.

Huising, J.; Gomes Pereira, L.M. (1998). Errors and accuracy estimates of laser data acquired by various laser scanning systems for topographic applications. ISPRS Journal of photogrammetry and remote sensing 53 (5), 245-261.

Mayer, C.; Gomes Pereira, L.M.; Kersten, T.P. (2018). A Comprehensive Workflow to Process UAV Images for the Efficient Production of Accurate Geo-information. IX National Conference on Cartography and Geodesy.

Nakano, K.; Suzuki, H.; Omori, K.; Hayakawa, K.; Kurodai, M. (2018). On a fundamental evaluation of a UAV equipped with a multichannel laser scanner. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2, 2018 ISPRS TC II Mid-term Symposium “Towards Photogrammetry 2020”, 4–7 June 2018, Riva del Garda, Italy, 753-758.

Pilarska, M.; Ostrowski, W.; Bakuła, K.; Górski, K.; Kurczyński, Z. (2016). The Potential of Light Laser Scanners Developed for Unmanned Aerial Vehicles - the Review and Accuracy. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII–2/W2: 87–95.

Phoenix LiDAR Systems, https://www.phoenixlidar.com/wp-content/uploads/2018/04/180420-Scout-16-Data-Sheet.pdf, consulted on 15 of July 2018.