Revealing structures below vegetation using UAV based LiDAR

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ABSTRACT

LiDAR has been used for the last decade to create digital terrain models using Airborne Laser Scans (ALS) with about 10 points per square metre, mainly depending on flight altitude and speed. The data is used to produce elevation maps or digital surface models, calculate volumes and analyse the Earth's surface or objects above it. However, the resolution and elevation accuracy of about ± 0.3 m means that calculations are only estimates and ground features may not be identified. Unmanned aerial vehicle based LiDAR systems have some advantages over ALS data. Their lower altitude and speed allow the scanner to generate more points per square metre than an ALS. The more laser beams the scanner emits into the same area, the more beams pass through the vegetation and generate more points on the ground or other objects. This increases the level of detail in the digital terrain model.
Reference points are another way of increasing the accuracy of the LiDAR scan. These points are placed within the survey area and have known coordinates and elevations to control and fit the result of the LiDAR scan to the coordinate system of the reference points.
This data can be used for higher accuracy volume calculations and changes in the terrain structure (e.g. geological changes). Because the terrain is mapped at a high level of detail, it can also be used in explosive ordnance disposal to reveal hidden features such as trenches or bomb craters that may cause a problem for the project.

Keywords: LiDAR, UAV, ULS, DTM, DSM

1. Introduction of LiDAR

Light **D**etecting **A**nd **R**anging is an active remote sensing technique. The LiDAR system measures the time between the emitted laser pulse and the detected backscatter from the ground, objects or vegetation. This information is used to calculate the distance between the sensor and the surface. Thus each registered pulse is expressed as one point with an x-, y- and z coordinate as well as an intensity value. The whole scan is called a point cloud.

With the invention of the **g**lobal **n**avigation **s**atellite **s**ystem (GNSS) and **i**nertial **n**avigation **s**ystems (INS) the accuracy of positioning the platform where the LiDAR is mounted was increased. This also had a huge effect on the measured point cloud's accuracy.

1.1. Current use of LiDAR

Besides other non-surveying applications such as distance sensors for autonomous vehicles, laser scanning is a widely used geodetic technique. There are many different scanning platforms, both terrestrial and airborne. Terrestrial scanning platforms are tripods (static) or vehicles (mobile). Airborne platforms are aeroplanes, helicopters or **u**nmanned **a**erial **v**ehicles (UAV). The best-known airborne LiDAR scanning is **a**irborne **l**aser **s**canning (ALS). Mostly used from airplanes, it can cost-effectively cover large areas in a short period of time. The resulting point clouds can be used to create Digital Surface Models or, after classification, **d**igital **t**errain **m**odels (DTM), where only ground points remain in the model. Classification also allows to use the remaining points to create other object models such as vegetation or buildings among others.

In Germany, ALS data has accuracies better than ± 0.3 m in horizontal location and ± 0.15m in height. The data is georeferenced in ETRS89, UTM for horizontal location and in the German vertical datum DHHN2016 for height. The data is available as point cloud file (.laz). Data point density depends on the area scanned and can be at least 4 points per square metre or better (Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV), 2021). Any point cloud software can view this data and further convert it into DTMs. This model can be compared with other models or combined with other geodata of interest. ALS flights over Germany are regularly repeated at intervals of several years.

1.2. Advantages of ULS

The solution for higher accuracy cases is to use a UAV as a platform for LiDAR scanner, called **U**AV **l**aser **s**can (ULS). Due to the lower speed and altitude, the sensor can emit more laser beams and receives more returns from the ground, especially through vegetation.

(White, et al. 2010). This technique can be used to generate more than 1000 points per square metre (Wieser, et al. 2016), depending on the area. Such high point densities allow more detailed results of the area, for example structures below forests or power line cables. The second benefit is an increase in horizontal and vertical accuracy. These values depend on the design of the sensor. For example, the horizontal accuracy of the Zenmuse L1 is 0.10 m per 50 m altitude and the vertical accuracy 0.05 m per 50 m altitude (DJI 2024).

1.3. Georeferencing

Both ALS and ULS platforms are georeferenced by the on-board GNSS antenna. The way to increase the precision and accuracy of the platform and trajectory is to work with INS systems as well as real-time kinematic (RTK) corrections. A GNSS base station or a correction service via the mobile internet can provide these. Further improvements in data accuracy can be achieved using Ground Control Points (GCPs). Depending on their own accuracy (assuming a RTK measurement with high accuracy correction data), position accuracy can be as good as of 0.02 m and height accuracy of approximately of 0.05m (Riecken und Kurtenbach 2017). In post-processing, the point cloud can be very accurately and precisely transformed to the GCPs, especially in the vertical direction, to prove the quality of the measured data.

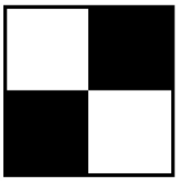

Figure 1: schematic picture of a ground control point

2. The use of LiDAR for UXO Surveys

During the Second World War (1939 to 1945) there were many ground battles in Europe. They often took place in dense forests, where soldiers could hide among the trees and protect themselves. Soldiers from both sides left weapons and ammunition on the battlefields, as well as other explosive ammunition that did not explode during the battle, known as unexploded ordnance (UXO). Unfortunately, most of these UXOs still lie in these forests. In recent decades, the UXOs began to detonate spontaneously or have been activated by fires. Influenced by criminals or careless people as well as favoured by climate change, forest fires have increased in Germany in recent years (Umweltbundesamt 2024). More and more detonations may happen because of these fires, which poses a particular risk to firefighters and rescue teams, especially if they have already entered the fire site. One solution is to search such battlefields by identifying craters of exploded munitions as these are common places to find UXO. So far, some authorities are doing this with the help of ALS (Brand- und Katastrophenschutz Mecklenburg-Vorpommern 2024).

3. Comparison to the ALS data

3.1. General differences between ALS and ULS data

ALS and ULS LiDAR scans generally use the same technique, but the actuality, georeferencing and flight speeds are different.

ALS data can be used to compare long-term changes in topography. However, small changes cannot be monitored with these data. Changes of less than 0.3 m in height may be due to errors in height accuracy, and movements of structures of less than 0.6 m may be due to errors in positional accuracy. Although these data are good for analysing the current situation over large areas, they may not be sufficient as a base surface for volume calculations, excavation plans or small craters. Depending on geo-zones and no-fly zones, drones can collect the most recent data in the required area. Due to the lower flight speeds of drones, GNSS positioning errors can be reduced and local reference stations can collect high quality correction data for RTK positioning. This improvement in accuracy compared to ALS data allows smaller changes in elevation of around 0.1 m to be detected with ULS data. Progress on excavations or changes in height due to erosion can be monitored in this way. The following example will compare a dataset of ALS and ULS data to see if craters of explosions can be identified.

3.2. Comparison of ALS Data with ULS Data near Wöbbelin to find craters of exploded munition

To compare ALS and ULS data, we present ALS data from 2021 and compare the results with ULS data from the same area collected later in the year. The comparison covers a forest area of approximately 12,500,000 m². These data show a forest near the town of Wöbbelin in eastern Germany. The aim of the dataset is to see the effects of forest fires on UXOs in the area of eastern Germany in 2021. Several munitions have exploded during these fires (Brand- und Katastrophenschutz Mecklenburg-Vorpommern 2024). It is assumed that ALS data can indicate potential explosion craters to identify areas of potential UXO contamination. The ULS data will be compared with the results of the ALS data.

ALS data were purchased in 2021 from the 'Geoportal MV' (Landesamt für innere Verwaltung -Amt für Geoinformation, Vermessungs- und Katasterwesen 2024). The datasets were collected between 2016 and 2017 (Landesamt für innere Verwaltung -Amt für Geoinformation, Vermessungs- und Katasterwesen 2024)[1] and are generally georeferenced in UTM, ETRS89 using Airplane GNSS and INS (Arbeitsgemeinschaft der Vermessungsverwaltungen der

[1] https://www.laiv-mv.de/static/LAIV/Abt3.Geoinformation/Dateien/ALS_Programm_2016-2017.pdf

Länder der Bundesrepublik Deutschland (AdV) 2021). ULS data were collected using the Zenmuse L1 LiDAR scanner below a UAV. System accuracy is ± 0.05 m for position and ± 0.1 m for height (DJI 2024). The point cloud is georeferenced using the UAV's internal RTK GNSS, which is capable of using corrections from a base station. In addition, GCPs were used to increase the accuracy of the position and elevation. Further the point cloud was classified using the software Terrasolid to identify ground points. Also the point cloud was cut to the area of interest.

ALS data shows several structures in the southern part of the survey area that may correspond to crater structures, represented by circular features with lower elevation values compared to the surrounding area. See Figure 2 for details.

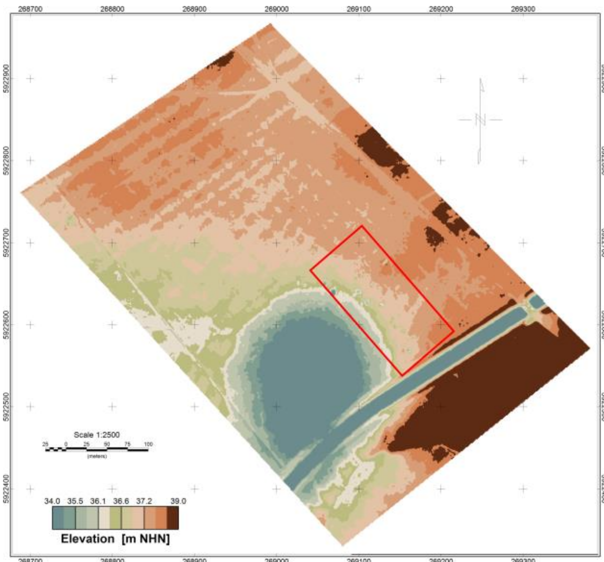

Figure 2: ALS-data of Wöbbelin forest, the area of interest marked with red rectangle

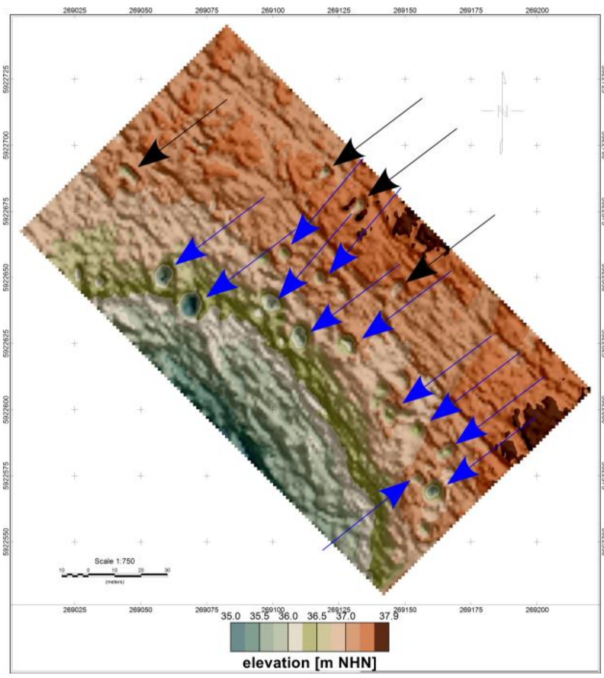

Figure 3: Detail of Figure 2; blue arrow: interpreted as crater, black arrow: interpreted as potential vehicle trench

In addition, four structures with higher elevations on two sides and a lower elevation in between may represent vehicle trenches but are not clearly visible, see Figure 3. This suggests that a battle has taken place or that munitions have recently been exploded in the area. This area is thought to be contaminated with UXOs left in the ground. There are also small features that may be artefacts due to processing or classification errors and are therefore not interpreted. The following Figure 4 shows the same area as Figure 2 but now from the ULS dataset.

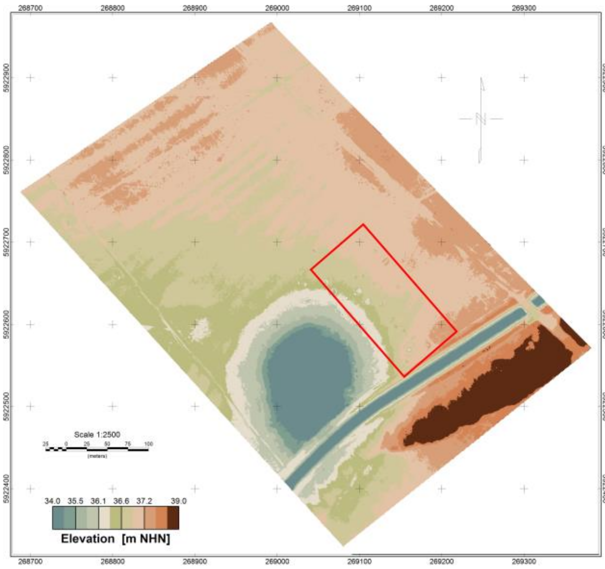

Figure 4: ULS-data of Wöbbelin forest, the area of interest marked with red rectangle

ULS data presented in Figure 4 from the same area show similar structures, but with detail. Craters are clearly visible. The vehicle trenches can be identified showing a trough surrounded by three higher walls. Smaller structures that are unclear in the ALS data can be seen as small holes that are not necessarily craters but maybe manholes.

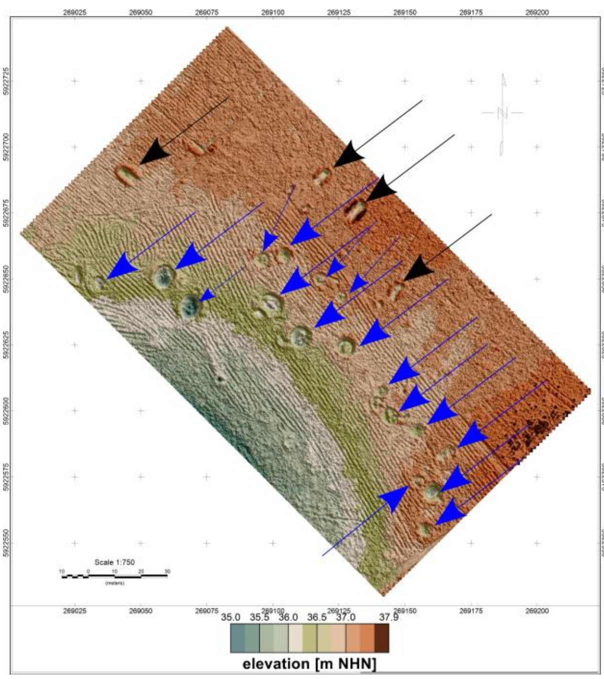

Figure 5: Detail of Figure 4; blue arrow: interpreted as crater or manhole, black arrow: interpreted as vehicle trench

The overall results are comparable, but the ULS data shows a higher level of detail (LOD) due to the ground point density. ALS ground point density generally varies between four and twelve data points for ALS data in Germany (Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV) 2021). In the survey area, ALS data points have a density of around 4 points per square metre to more, whereas ULS data can generate between 50 to more than 400 ground points per square metre. To show this difference in LOD a line is drawn trough two craters with a width of 0.6 m and each point on this line is visualised in Figure 6:

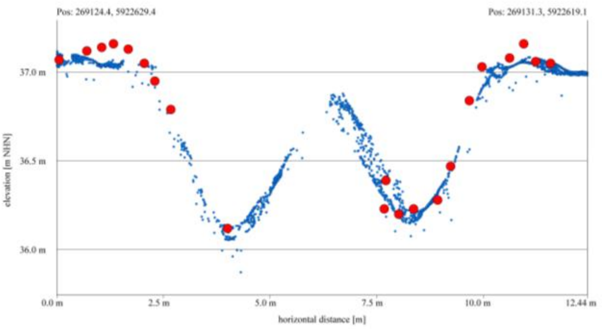

Figure 6: Cross section with of line ±0.3 m through a crater (with a pile in the middle) of two datasets ALS (red) and ULS (blue). Coordinates (in ETRS89, UTM33) on the top represent start and end of the line

Figure 6 shows the overall higher point density of the ULS data (blue) compared to the ALS data (red) due to the lower flight speeds height above ground level. The ULS dataset has covered each crater with multiple points and the depth can be estimated up to the noise level of the system. The ALS dataset shows only a few points, which may allow to identify the craters, but depth estimation is not possible. In the case of Figure 6 the two craters can only be identified as one larger crater in ALS point cloud. ULS data clearly identifies two distinct objects.

As a result of this case study, ALS data is sufficient to identify areas of explosion craters, but lacks detail and may contain some artefacts due to low ground point density. Also depth values derived from ALS data are inaccurate. ULS data provides higher LOD and can provide more information about each crater, such as depth and radius. The vehicle trenches in the ALS data are poorly imaged compared the ULS dataset. In addition, the ULS dataset can be controlled and corrected by GCPs. Higher accuracies of up to 0.02 m in the east and north are possible with GCPs, making comparisons more accurate as with the ALS data.

4. Two different flights in Wöbbelin forest – LiDAR use for monitoring

A second flight to collect ULS data was made over the same area two weeks later to see if any changes had occurred during this period and to highlight any limitations in comparing the data. The first dataset is the same as that is presented in Chapter 3.1, see Figure 4. The second survey was carried out with a UAV carrying the Yellowscan Mapper, which has comparable or better accuracies than the Zenmuse L1 (Yellowscan 2023). The results of the second survey are shown in Figure 7.

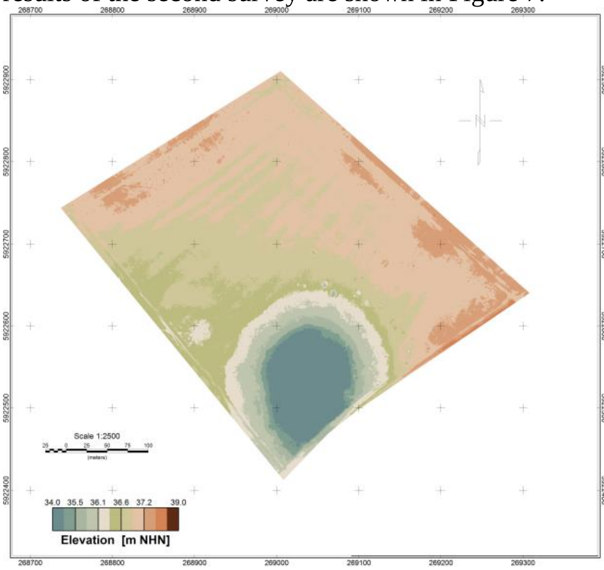

Figure 7: DTM two weeks after the scan shown in Figure 4

Geo-referencing is also carried out using RTK GNSS of the carrier system with a base station. GCPs were used to increase and control the accuracy. The used GCPs are not identical. So the setup and processing is similar to the first flight with the Zenmuse L1.

Comparing the two sets of data means that we have to take into account the accuracy of the position and elevation, as well as the point density of the ground points.

The point density of both scans ranges from 50 to over 400 points per square metre, which means that the average distance between two points is about 0.1 m or less. Analysis structures such as craters and trenches are structures of about a metre or more in size, so they should be easily visible if the height differences are large enough. This will not be a limiting factor when analysing craters or trenches.

The positional accuracy of both systems is less than 0.1 m (0.05 m from the scanner and 0.02 m from the RTK GNSS reference and control points), so changes in the position of structures of more than 0.2 m can be interpreted. Both sensors have a height accuracy of 0.1 m or better[2], and the reference height points vary by 0.05 m due to GNSS accuracy, so a difference of 0.3 m cannot be taken into account.

To visualize possible changes in the area, the difference of the first scan (Zenmuse L1) and the second scan (Yellowscan Mapper) is computed (Figure 8).

[2] At a flight height of 50 metres above ground level

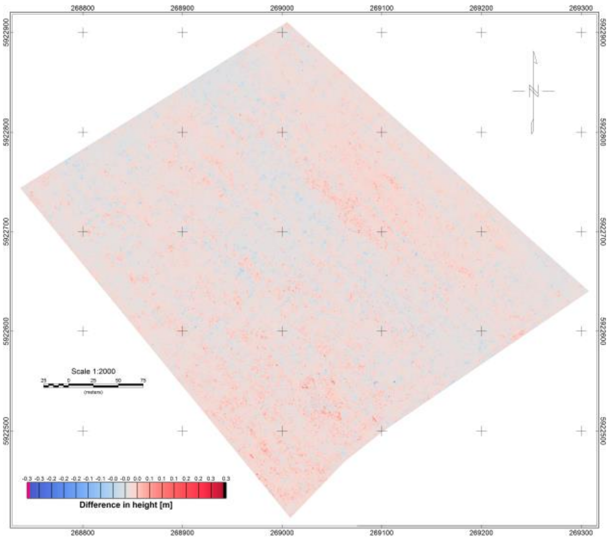

Figure 8: Result of the difference of DTM from Figure 4 minus DTM of Figure 7

As shown in Figure 8, only small changes can be detected, which may be due to positional errors of small features or due to changes in classification. Thus the data do not show any changes in the area over the two weeks that exceed the accuracies listed above. This can be interpreted to mean that there were no additional explosions and no changes of more than 0.3 m took place in the area.

Compared to ALS data, the height error is reduced by 50% as ALS data has a height accuracy of approximately 0.3 m per scan. Comparing two ALS scans would result in interpretable height differences of more than 0.6 m. The craters shown in Figure 6 are approximately about one metre deep. It may therefore be difficult to identify such craters when comparing two ALS data sets, bearing in mind that the maximum depth may not be scanned when only four ground points per square metre are recorded. Two different ULS datasets, such as the ones presented above, can reveal similar craters (1.25 m Radius and 1 m depth, see Figure 6) due to their higher accuracy. Even smaller craters with depth down to 0.5 m should be visible here, allowing smaller expositions or manholes to be recorded.

5. Possible improvements to compare two ULS datasets

As 0.3 m is a large uncertainty for volume comparisons, more accurate scanners are required. Scanners with accuracies of 0.05 m - 0.02 m are available on the market. With these accuracies changes in the range of 0.1 m can be analysed. In addition, the error of the GCPs can be compensated by using the same GCPs for each flight. This would allow changes in height of around 0.1 m to be monitored. Position errors would also be reduced to around 0.1 m. Even with the scanners used in chapter 4, the use of the same GCPs would reduce the uncertainty in height from 0.3 m to 0.2 m.

6. Conclusion

ULS scans are a very good solution in areas with dense vegetation such as forests. Here they are capable to monitor changes in topography because of weather or other events. Analysing accuracy boundaries it is also possible to reveal craters of explosions of UXOs with depth of about 0.5 m. Slow flying UAVs can still survey large areas that cannot be surveyed with conventional geodetic equipment. These scans can have a higher number of ground points that can be used to detect smaller features or changes in the area compared to ALS scans. The big advantage of ALS is cost and the areas scanned. It is much cheaper for authorities to obtain ALS data for really large areas.

A combination of ALS and ULS data is a very good solution for monitoring. As shown in Chapter 3, ALS data can be used to locate interesting features over large areas (1 km x 1 km for example) and define areas where ULS data needs to be collected to fill data gaps or to get more detailed information on structures found in ALS data.

Acknowledgements

The project was supported by the ‘Munitionsbergedienst Mecklenburg-Vorpommern’, ‘Most Robotics GmbH’ and ‘G-Tec Positioning GmbH’. We thank all partners for their collaboration. Point cloud data used for the study can be downloaded via https://www.dropbox.com/scl/fo/2ntju6pdto1nmdoi4s02k/h?rlkey=dffic94cbcwxrds85bpj6t5in&dl=0.

References

Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV). „Produktstandard für 3D-Messdaten, Version 1.1.“ Herausgeber: Arbeitsgemeinschaft der Vermessungsverwaltungen der Län-. München, 2021. 1-29.

Brand- und Katastrophenschutz Mecklenburg-Vorpommern. *Landesamt für zentrale Aufgaben und Technik der Polizei, Brand- und Katastrophenschutz Mecklenburg-Vorpommern.* 01. 02 2024. https://www.brand-kats-mv.de/Munitionsbergung/Luftbilddetailauswertung/.

DJI. *DJI.* 02. 02 2024. https://enterprise.dji.com/de/zenmuse-l1/specs.

Landesamt für Digitalisierung, Breitband und Vermessung. *Landesamt für Digitalisierung, Breitband und Vermessung.* 02. 02 2024. https://ldbv.bayern.de/produkte/3dprodukte/laser.html.

Landesamt für innere Verwaltung -Amt für Geoinformation, Vermessungs- und Katasterwesen. *Befliegungsprogramm-ALS.* 2024. https://www.laiv-mv.de/Geoinformation/Geobasisdaten/Oberflaechenmodelle/Befliegungsprogramm-ALS/.

Riecken, Jens, und Enrico Kurtenbach. „Der Satellitenpositionierungsdienst der deutschen Landesvermessung–SAPOS®.“ Herausgeber: Landesamt für Geoinformation und Öandmanagement ztv. *ZfV-Zeitschrift für Geodäsie*, 2017.

Umweltbundesamt. *Umweltbundesamt.* 01. 02 2024. https://www.umweltbundesamt.de/daten/land-forstwirtschaft/waldbraende#waldbrande-in-deutschland.

White, Russel A., Brain C. Dietterick, Thomas Mastin, und Rollin Strohman. „Forest Roads Mapped unsing LiDAR in steep forested terrain.“ *Remote Sensing*, 2010: 1120-1141.

Wieser, M., M. Hollaus, G. Mandlburger, P. Glira, und N. Pfeifer. „ULS LiDAR supported analyses of laser beam penetration from different ALS systems into vegetation.“ *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2016.

Yellowscan. „Datasheet Yellowscan Mapper.“ 2023.