Flying Parameters Experiment of a UAV LiDAR over a Winter Wheat Field-trial

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Abstract: The study aimed to study how flying parameters of Unmanned Aerial Vehicle (UAV) Light Detection and Ranging (LiDAR) influences the retrieval of winter wheat plant height. Results showed that flight speed and altitude, which impact point density, affected how well the UAV LIDAR point clouds could be related to manual height measurements. Despite lower correlation at higher speeds and altitudes, the study found that plant height could still be accurately measured with increased efficiency at higher speeds and altitudes. A non-nadir look angle was found to have a higher correlation than a nadir look angle. However, further research is needed to understand better the relationship between UAV LiDAR flight parameters with plant height and other crop traits such as biomass and nitrogen uptake.

1 Introduction

Integrating miniaturized laser scanning (LiDAR) systems on unmanned aerial vehicles (UAV), also known as UAV LiDAR systems, has opened up new possibilities for monitoring in various fields, including agriculture (e.g., SHENDRYK et al. 2020). Effective monitoring is crucial in agriculture due to global food shortages and the impacts of climate change (WEISS et al. 2020). However, the use of UAV LiDAR systems in agriculture is limited, partly due to a lack of understanding of flight parameters and their effect on the quality of the derived geospatial information.

In UAV LiDAR remote sensing, there is a trade-off between resolution and coverage. High-resolution, e.g., a dense point cloud, is limited in coverage, while lower-resolution data allows for more extensive coverage but may degrade information quality. Improving flight characteristics knowledge could enable improved planning for optimizing the monitoring of larger areas using UAV LiDAR remote sensing for agricultural monitoring.

Therefore, I conducted a UAV LiDAR experiment over a winter wheat field trial in Germany to study the relationship between flight parameters and plant height, a critical factor in precision agriculture applications.

2 Study Site and Field measurements

2.1 Study Site

The study took place at the Campus Klein-Altendorf (CKA), located about 20 km from Bonn. The study site was a winter wheat field trial managed with 120 plots, each 7m × 1.5m, arranged in 5 rows with three different nitrogen treatments (0, 120, 240 kg/ha) and six different winter wheat

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varieties. The study site is equivalent to the studies done by JENAL et al. 2021 and HÜTT et al. 2022, where the field trial setup is described in more detail.

2.2 Manual Height Measurement of the Winter Wheat Plants

Figure 1 (left) shows where winter wheat plants were manually measured. The positions of the height measurements of winter wheat plants were measured using an RTK GPS Topcon GR-5 system in a Base Rover configuration. It provides sub-5 cm accuracy in the X, Y, and Z positions (TOPCON, 2023), and I used the same base station to correct the UAV LiDAR trajectory (section 2.4). A round plastic disc with a diameter of 30 cm was attached to the pole of the RTK GPS device. This plate was adjustable vertically along the pole and was positioned as high as the two highest wheat plants at each measurement location. The distance from the plate to a laser distance measurement device (Leica Disto) was then measured by this device and recorded using a smartphone. Subtracting the laser distance device's height from the measured distance between the plastic plate and the distance measurer allowed calculating the wheat plant heights. A photo of the device is shown in Fig.2 (right).

Fig. 1: Left: RGB orthoimage acquired with a DJI Phantom 4 UAV of the study site with the locations of the manual plant height measurements. Right: RTK GPS Laser Distance Winter Wheat Plant Height Measurer

2.3 UAV LiDAR Campaign

On June 23, 2021, the UAV LiDAR experiment was conducted with a Riegl Mini-VUX-1 mounted on a DJI Matrice 600 pro. The 360° rotating mirror of the LiDAR scanner reflects the beams around the UAV, perpendicular to its flight direction, providing up to 100,000 measurements per second (RIEGL, 2023). As a result, the area below the UAV is scanned in a line scanner pattern. UgCS was used to preplan and automate the flight. The aim was to achieve uniform point spacing in both range and azimuth directions by adjusting the flight height (to control range distance between points) and speed (to control azimuth distance between points). At first, the UAV was flown lower (Fig 2, middle) and slower (Fig.2 left) to achieve a denser point cloud. Later, faster and higher overflights of the field were carried out.

Furthermore, the faster and higher the UAV was planned to fly, the more space was given, before and after the field, to allow the UAV to have a constant speed over the field trial (Fig.2 right). To also examine the effect of the look angle, the field was overflown directly above it and with an offset, so the field trial is viewed approximately with an off-nadir angle of 45°. Table 1 lists the flight characteristics, an estimation of point spacing, and potential area coverage per minute. The area coverage calculation assumes that only points at an angle up to 45° off-nadir are used and assumes a straight flight path without turns, thus overestimating the actual coverage.

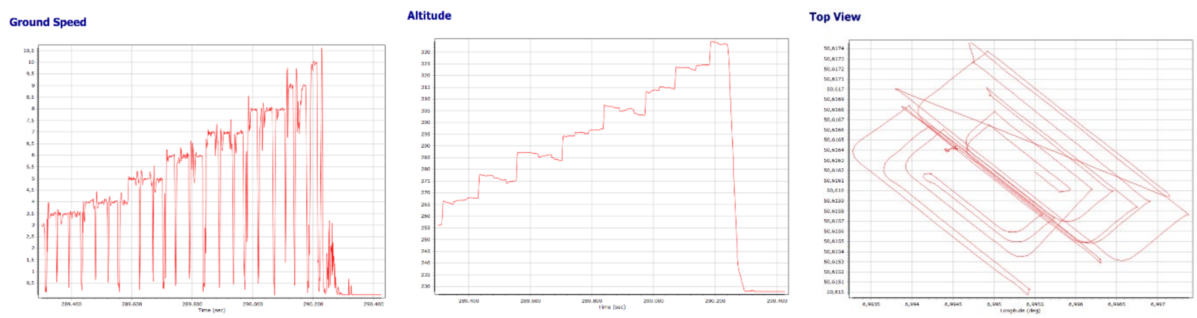

Fig. 2: Plots of the trajectory: left: increasing ground speed, middle: increasing flight height, right: Top View of the trajectory

Tab. 1: Flight Plan Characteristics, * at 110 m, there was no off-nadir flight

Height above ground (m)	Ground Speed (m/s)	approx. Dist. between Points (m)	Swath Width (+/- 40°) (m)	potential Area Coverage/Minute (ha)
30	2	0.07	50.3	0.6
40	3	0.08	67.1	1.2
50	4	0.12	83.9	2.0
60	5	0.14	100.7	3.0
70	6	0.16	117.5	4.2
80	7	0.19	134.3	5.6
90	8	0.21	151.0	7.2
100	9	0.23	167.8	9.1
110*	10	0.26	184.6	11.1

2.4 Generating and processing UAV LiDAR point clouds

The Applanix IMU APX-15 captured the trajectory and orientation of the UAV LiDAR system, and GPS correction data was obtained via the Topcon GNSS GR-5 standing next to the field. During post-processing, these datasets were integrated to approximate the system's location during the flight with high precision (0.02 - 0.05m) (APPLANIX 2023). Subsequently, a preliminary version of the LiDAR point cloud was generated in RiProcess based on the corrected trajectory. The accuracy of the point cloud was then enhanced further by incorporating ground targets into the analysis in RiPrecision. Finally, each overflight was separated and subjected to individual analysis.

2.5 Processing of the UAV LiDAR point clouds and Statistical analysis

The analysis of the individual point cloud strips was conducted in LASTools as follows:

1. Outlier points were removed if there were fewer than 4 points per square meter.
2. The height was normalized using a ground model from the same year (February 3) to obtain the relative height above ground instead of absolute heights.
3. A 15 cm buffer was created in a GIS environment around the manual height measurements, which had the same extent as the manual measurement plate.
4. The maximum height of points was calculated using the LAScanopy function of LASTools for each measurement area, with all points falling into the buffer.

As a final step, linear regressions were established between the maximum LiDAR height and the manually measured plant height for each overflight. Fig. 3 shows three normalized points from different height and speed combinations.

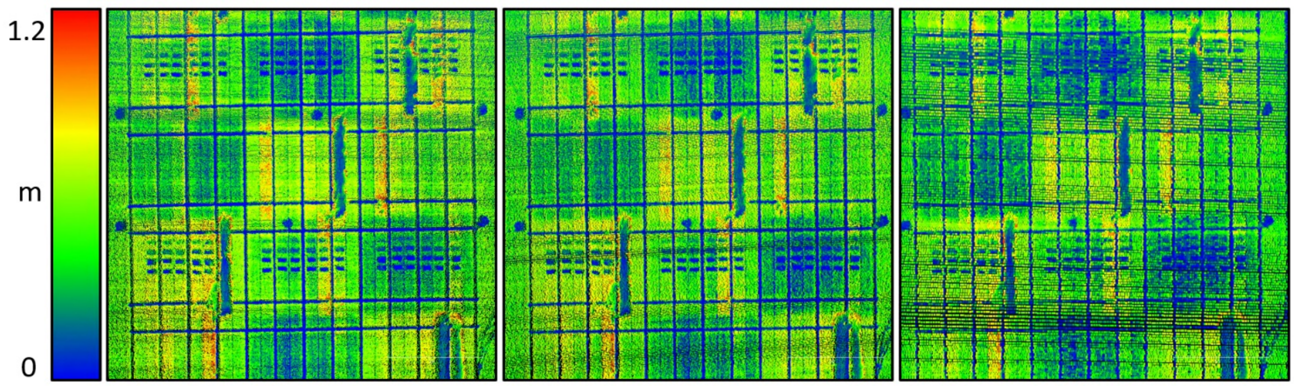

Fig. 3: Normalized point clouds from 3 different heights (all nadir), coloured by height above ground: left: 30m - 2m/s, middle: 60m – 5 m/s, right: 100 m – 9 m/s right

3 Results

The results show that, in general, higher flight heights with higher flight speeds and hence lower point densities result in a lower correlation with the manual height measurements (Tab.2). Interestingly, the average R^2 from the off-nadir data is 0.035 higher than the R^2 using data from the nadir overflights. The decrease of R^2 from 30 m height and 2 m/s to 100 m and 9 m/s is about 0.05 on average, and the same for off-nadir and nadir look (Fig. 4). The highest correlation between manually measured plant height and maximum LiDAR height was obtained for the 50 m flight at 4m/s with a non-nadir look angle. Noteworthy are the intercepts of the linear regressions. In the nadir case, their average is 0.52 m, with an increasing tendency towards higher altitudes. For the off-nadir scenario, it is 0.4 m on average, without a clear trend.

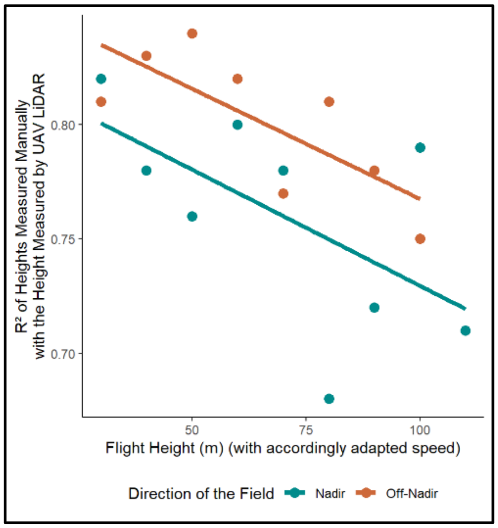

Fig. 4: The R^2 values for 17 combinations of UAV flight height and speed for both nadir and off-nadir viewing angles

Tab. 2: Correlation Coefficients of the maximum point height above ground of the different height and speed combinations and the manual measurements

	Nadir		45° Off-Nadir	
Flight height	**R^2**	**Linear Regression**	**R^2**	**Linear Regression**
30	0.82	0.46 + 0.91x	0.81	0.42 + 0.90x
40	0.77	0.50 + 0.86x	0.83	0.41 + 0.90x
50	0.78	0.49 + 0.88x	0.83	0.38 + 0.94x
60	0.79	0.50 + 0.89x	0.82	0.41 + 0.91x
70	0.78	0.54 + 0.88x	0.77	0.38 + 0.94x
80	0.69	0.59 + 0.80x	0.81	0.38 + 0.99x
90	0.73	0.56 + 0.86x	0.78	0.44 + 0.95x
100	0.79	0.56 + 0.89x	0.75	0.43 + 0.88x
110	0.71	0.61 + 0.81x		

4 Discussion

The study showed that it is possible to measure winter wheat plant height using UAV LiDAR accurately. This conclusion agrees with previous studies on the topic (TEN HARKEL et al. 2019; BATES et al. 2021; HÜTT et al. 2022). However, when UAV LiDAR is used at higher flying speeds and altitudes, the point density of the point clouds decreases, negatively impacting the correlation with manual measurements. Despite this, even with a coarser point cloud obtained from a 100 m altitude at 9m/s flying speed, the results are still considered acceptable, with R^2 values of 0.79 for nadir measurements and 0.75 for off-nadir measurements.

The difference in correlation between nadir and off-nadir measurements is noteworthy and could be because, in a nadir look, it is more likely that the highest plants were missed, as winter wheat plants grow vertically. In this study, the manual measurements focused on the highest plants in a

circle with a 30 cm diameter. Further investigation into how different UAV LiDAR metrics (HÜTT et al. 2022) respond to the difference in look angle and point density would be valuable.
Additionally, repeating the experiment at different stages in the growing period would be interesting. Also, different UAV LiDAR systems, such as Riegl's VUX, which has a higher sampling rate and provides the full waveform of each LiDAR return, would be a great addition. Such research would allow for a more detailed and comprehensive analysis of the data and a deeper understanding of the relationship between UAV LiDAR and winter wheat plant height.

5 Conclusion and Outlook

The study shows that it is generally possible to use UAV LiDAR to monitor winter wheat plant heights with high accuracy and precision. The results indicate that flight speed and altitude, which influence the point density, negatively impacted the accuracy of the correlation with manual height measurements. However, if maximizing accuracy is not a primary concern, plant height can still be accurately determined at higher speeds and altitudes, resulting in increased efficiency. Further research is needed to consolidate the study's findings and how the different flight parameters influence the estimation of crop traits such as plant height, biomass, or nitrogen uptake. A refinement of future crop trait retrieval algorithms could be in considering the angle under which the agricultural area is viewed.

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