FUAS LIDAR CROP LAI ESTIMATIONS FROM CANOPY DENSITY

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ABSTRACT

Unmanned Aircraft Systems (UAS), with the ability to fly close to the ground and under clouds, make it possible to collect data at unprecedented spatial and temporal resolutions. LiDAR systems are more commonly being used on UAS platforms as these sensors become smaller and more accessible. Within the field of precision farming, UAS LiDAR is often used for height calculations that takes advantage of its ability to penetrate through the canopy to the ground but the rate at which these signals pass through can provide important metrics on crop structure and (vegetation) density. These can be related to well known (or classically used) vegetation indices such as Leaf Area Index (LAI) which often plays a major contributor in monitoring plant health and predicting crop yield. This study exploits UAS LiDAR advantages and investigates its ability to estimate LAI for crops such as winter wheat. It was found that LiDAR LAI spatial patterns were consistent with other forms of data while providing estimates similar to ground measurements.

Index Terms— drone, LiDAR, LAI, biomass

1. INTRODUCTION

Precision farming relies on detailed and spatially complete information to make effective decisions in crop management such as with fertilizer and irrigation use. Unmanned Aircraft Systems (UAS) provide an avenue for increased resolution and data collection. Being that LiDAR is an active sensor and does not depend on solar reflectance and its corresponding zenith angle like commonly used passive optical sensors, it may further improve upon agricultural monitoring. Most frequently LiDAR is used to derive height estimations for crops [1]. Its signal's ability to penetrate through small gaps in the canopy allows it to gather underlying information about terrain elevations or about forest understories such as trunk diameters [2]. There are studies in forestry with manned airborne LiDAR systems (ALS) that have taken advantage of LiDAR's ability to penetrate vegetation canopies to derive LAI estimations based on the signals rate at which it passes through to the ground that is directly related to the vegetation structure and density [3–5]. The ratio between the signal returns among the above ground vegetation and those reaching the ground is referred to as gap fraction (GF). These studies have retrieved good results for example in both [3,5] a performance with a R^2 greater than 0.67 was exhibited. Apart from that, there is a lack of studies concerning this topic with UAS mounted LiDAR for crops. A possible explanation is that UAS passive optical sensors are more commonly chosen because they are more accessible and better supported with processing software. However, LiDAR is not affected by shading and may also deliver more detail in height metrics as photogrammetry with UAS passive optical sensors has a tendency to smooth out the data with current surface from motion (SfM) algorithms [6]. Proving accurate measurements of crop LAI might present additional ways to calculate biomass in combination with crop height in the future. As a result, this study investigates using UAS LiDAR GF methods to derive LAI from crops such as winter wheat.

2. METHODS

2.1. Study Area

In this study, a winter wheat field in Selhausen, Germany (50° 51′ 56″ N 6° 27′ 03″ E) that is approximately 10 ha in size was used to test the proposed method. The field is known to have features from variations in plant structure to appear in the field mid to late in the growing season. A past study proposes that this stems from differences in soil and response to water scarcity [7]. In Figure 1, the difference in the plant structure on the western side of the field as compared to the middle can be seen. These ground observations were taken just before harvest and after full senescence had taken place providing an example of the resulting heterogeneity that is possible after the growing season.

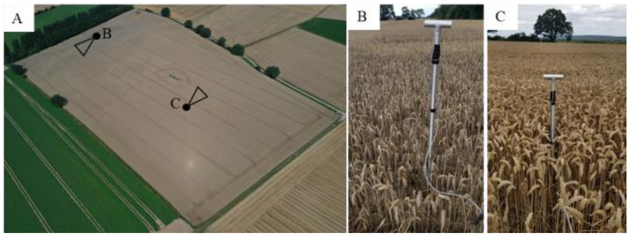

Figure 1. (A) Aerial image providing an overview of the winter wheat field used with (B) & (C) providing an example of the differences in crop structure and density on the ground with reference to a measuring stick that is approximately 1 m in height. Location and direction of the images are present in (A). These images were taken on the 28th of July 2020.

2.2. **LiDAR Data Acquisition & Processing**

The data collection took place on the 9th of June 2020. A DJI Matrice 600 (Figure 2) was attached with a mounted YellowScan Surveyor LiDAR system. The flights were flown at 50 meters above ground and at a speed of 5 m/s for the best balance in efficiency with point density and flight time. The LiDAR system consisted of a Dual Global Positioning System (DGPS), Inertial Measuring Units (IMU), onboard Computer Unit (CU), and a Velodyne LiDAR puck. The DGPS provides positioning and time synchronization, the IMU provides information on attitude, and the LiDAR puck emits and receives laser signals for ranging. The onboard CU combines the information received from these sensors and makes direct georeferencing possible. A Base Station (BS) was used to provide further precision in georeferencing by providing positioning corrections in reference to the UAS DGPS recording to provide a Smoothed Best Estimate of Trajectory (SBET) using Applanix's PosPac software.

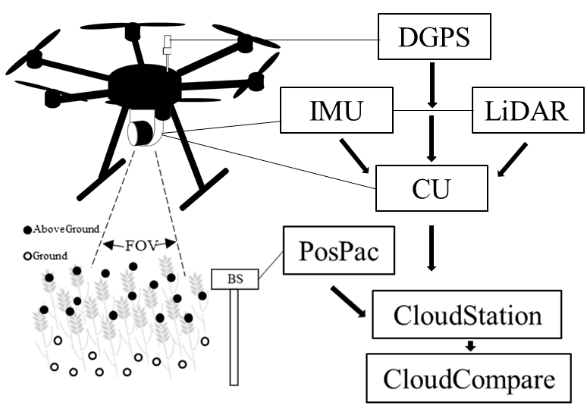

Figure 2. DJI Matrice 600 depicting a LiDAR scan over winter wheat with the workflow between the LiDAR system components and the software used to produce the resulting data.

YellowScan's CloudStation software was used to create a LAS (LASer) point cloud file from combining YellowScan's LiDAR CU output and the produced SBET with a user defined Field of View (FOV). The FOV applied was 70 degrees meaning points larger than 35 degrees from nadir on both sides of the UAS were omitted in the resulting LAS file. The CloudCompare module Cloth Simulation Filter (CSF) was implemented to take advantage of the LiDAR's ability to penetrate through the crop canopy by separating those points that reach the ground from the rest. The main approach bases on the modified Beer-Lambert light extinction model formula, as developed by [3],to link the canopies interception of the LiDAR signals to an estimation of LAI.

$$LiDAR\ LAI = -\frac{\cos(\bar{\theta})\ \ln(GF)}{k} \tag{1}$$

GF is a ratio of the ground points divided by the total points and with $\underline{\theta}$ representing the average can angle of all the points, and k being the extinction coefficient.

2.3. **Validation Data**

Additional data was collected to be used in comparison with the resulting LiDAR LAI estimations to validate the potential of the used method. Aerial (same day, 09.06.2020) and ground (02.06.2020) collections were used for this data. A Micasense RedEdge-M (five band) multispectral sensor was flown over the study area with a DJI Matrice 600. This data would be used to produce a NDVI and a LAI map from common and proven passive optical sensor methods to see the variation in plant health and structure. This provides more spatially complete data as opposed to the ground measurements so that similarities in spatial patterns can be compared. Additionally, the LiDAR data was able to provide an estimation of crop height by subtracting a Crop Simulation Surface (CSM) of the points on top of the canopy and a Digital Terrain Model (DTM) of the ground points.

Ground reference measurements were carried out with a linear ceptomer (SS1 SunScan Canopy Analysis System, Delta-T Devices Ltd, Campbridge, UK). In reference to Figure 3, the ceptometer system is optimized for measurements of Photosynthetically Active Radiation (PAR) about low regular canopies such as most agriculture crops. With the BF5 reference PAR sunshine sensor the system can be used in most weather conditions. With BF5 gathering information on the total PAR, the probe measures the fraction of light passing through the canopy that did not encounter foliage providing information about the crop density that is used to derive estimations of LAI.

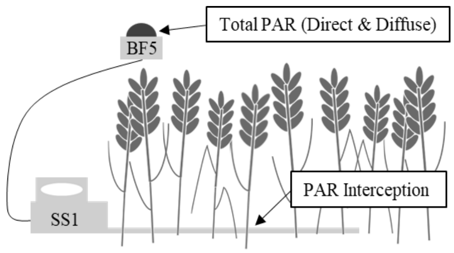

Figure 3. SunScan SS1 system with BF5 above canopy measures total Photosynthetically Active Radiation (PAR) from the sun directly and diffused. The probe is placed below the canopy to understand how PAR is intercepted by the canopy.

A total of 36 ceptometer measurements were taken and were distributed among four measurement area locations around the center of the field. The values were averaged to a single LAI value representative of the respective plots.

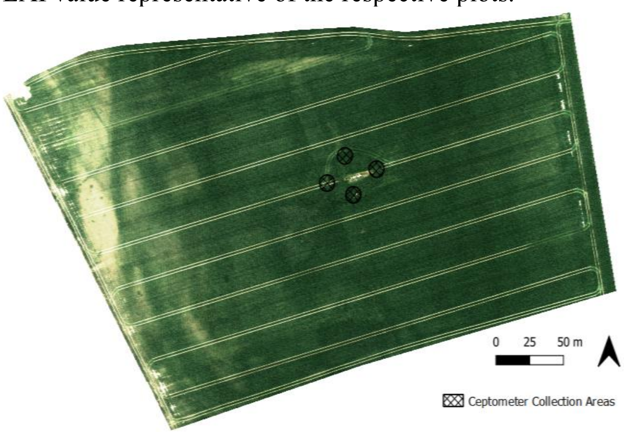

Figure 4. The location of the four ceptometer ground measurement areas marked with hatched circles near the center of the field.

3. RESULTS AND DISCUSSION

The results of the LiDAR LAI method used can be seen in Figure 5 with additional results in LiDAR height and multispectral LAI and NDVI for comparison. The spatial patterns in the LiDAR LAI closely resemble that appearing in the ancillary data. The canopy structure and LAI estimated using multispectral FC methods is similar to the LiDAR results. Also, with the NDVI results it can be seen that the health of the plants on the western side of the field is lower based on the chlorophyll presence being sensed with spectral reflectance.

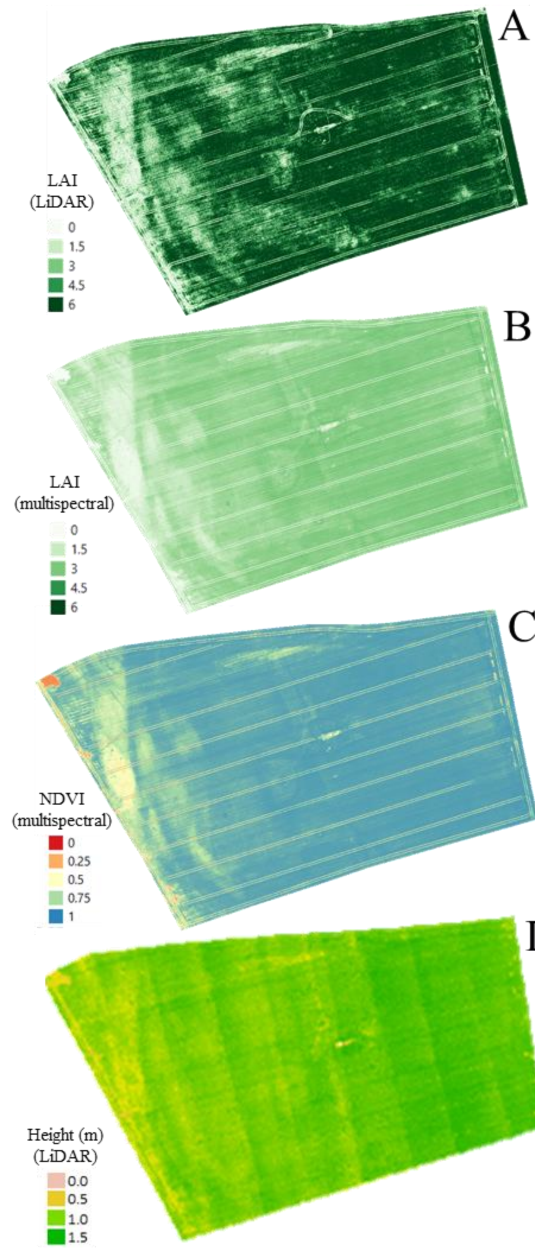

Figure 5. (A) LAI results with proposed LiDAR method, (B) LAI, (C) NDVI using a multispectral sensor, and (D) height data from the UAS LiDAR data.

For each of the designated ceptometer ground measurement areas, the pixels within the same areas of the resulting LiDAR LAI raster were extracted and averaged. The average was compared against the ceptometer averages as seen in Figure 6.

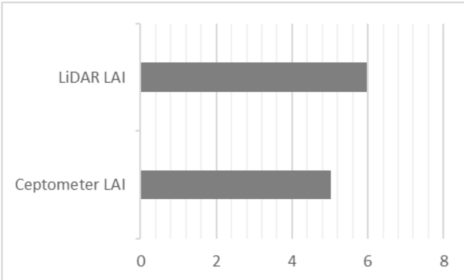

Figure 6. Averaged LAI values from the ceptometer ground testing areas in comparison with the average pixel values within those same areas in the LiDAR LAI raster.

The LiDAR method in the respective testing areas averaged a LAI value of 5.96 while the ceptometer averaged values of 5.01. This is an averaged estimation 18% greater than the ground method. It should be noted that the ceptometer measurements were taken seven days before the LiDAR flights. As winter wheat, a cereal crop, begins stages of senescence the ceptometer measurements become more similar to GAI while the LiDAR is more in line with PAI [8]. These both could be an explanation for the discrepancy that exists.

The results show that LiDAR has promise in estimating LAI based on canopy density and structure. Considering that LiDAR can provide accurate height information, these two metrics LAI (providing plant density horizontally per unit of ground) and height (providing the vertical extent of the crop) may be combined to estimate biomass. LiDAR is considered to provide better characterization of the crop canopy structure which could provide better estimations than previously seen with multispectral and photogrammetry methods [9].

This project provides one example of estimating crop density with LiDAR and relating it to LAI. LiDAR is already proven in providing accurate height information but with the potential of accurately estimating additional metrics based on crop density makes it more efficient to implement for farming practices. These methods and projects are rarely seen as LiDAR sensors are just recently becoming small and accessible enough to be used with UASs. LiDAR with UAS will become more common as this technology advances making these associated methods more relevant to precision farming.

4. CONCLUSION

A method to estimate LAI based on LiDAR's ability to sense crop canopy density structure with signal penetration was developed. It was shown that LAI with LiDAR can provide spatial patterns that are consistent with multispectral and LiDAR height data. The averaged values of LiDAR LAI were slightly higher (18% greater) than the values of the averaged ceptometer LAI values. The LiDAR method (using GF and active signal penetration) is not affected by changes in plant chlorophyll content or the effects of senescence like other methods explaining some differences. However, this also provides potential in providing better biomass estimation for cereal crops like winter wheat during presence of leaves experiencing senescence. The simple processes and benefits with UAS LiDAR exemplified in this project have the possibility to become more relevant in precision agriculture as this technology is continuing to become more accessible.

5. REFERENCES

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