Potential of Unmanned Aerial Vehicle Based Photogrammetric Point Clouds for Automatic Single Tree Detection

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The measurement of geometric tree attributes is a major part of forest inventories. In practice respective attributes are mostly measured by terrestrial surveys, less often by laser scanning. These methods are relatively time consuming or costly. The presented study was conducted in order to evaluate photogrammetric point clouds, based on Unmanned Aerial Vehicles (UAV) photo flights, as a cost effective and fast additional instrument for single tree detection and tree height measurements within forest stands. A coniferous and a deciduous forest site near Freiburg im Breisgau, Germany were surveyed during the leaf-on state. For each site point clouds were generated photogrammetrically from UAV-based aerial photographs. The point clouds were processed with software developed for analyzing Light Detection And Ranging (LiDAR) data for forestry applications, to generate virtual tree models. Multiple models were calculated, by varying processing parameters, and analyzed for their accuracy by comparing the models to reference data acquired by Terrestrial Laser Scanning (TLS). Through evaluating the models by their number of detected trees and height accuracy, conclusions could be drawn for the various software parameters' impact on the results.

1 Introduction

The measurement of geometric stand and tree attributes is a major part of forest inventories. Recently, Unmanned Aerial Vehicles (UAV) have been proven to be valuable platforms for mounting cameras to create photogrammetric point clouds through the structure from motion technique (WESTOBY ET AL., 2012; FRITZ ET AL., 2013), and, on larger UAVs, laser scanning devices (WALLACE ET AL., 2012). The resulting point clouds have been studied for applications such as precision farming (REIDELSTUERZ ET AL., 2007) and vegetation monitoring (HERWITZ ET AL., 2004) in agriculture, archeology (EISENBEISS AND ZHANG, 2006), forest fire monitoring (MERINO ET AL., 2012) or the calculation of Digital Elevation Models (DEM)(EISENBEISS AND ZHANG, 2006).

The objectives of this study were the following:

- Testing the capability of LiDAR data processing software for the use with UAV based photogrammetric point clouds
- Evaluating the potential of UAV based photogrammetric point clouds for single tree detection and three height measurements

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2 Study sites and methods

2.1 Study sites

A coniferous and a broadleaved forest stand were compared in this study. Both study sites are located near Freiburg im Breisgau, Germany. The coniferous forest site is a densely growing pure stand of Douglas fir (*Pseudotsuga menziesii*), with moderate understory growth and a size of 1.11ha. The deciduous forest is 1.28ha sized section of an oak (*Quercus robur*) dominated open forest stand, with little undergrowth.

2.2 Methods

2.2.1 Reference Data

The reference data for both sites was acquired by Terrestrial Laser Scanning (TLS). After tie point based co-referencing the TLS and UAV point clouds, the tree positions were extracted from the TLS data, by cutting out 20cm thick horizontal slices from the LiDAR point cloud, and selecting a minimum of 5 points of round shapes, resembling the tree stems. A circle was fitted to the selected points, using the least squares method. The circle center coordinates were listed in a table, to which the height information was added, by visually interpreting the registered UAV point cloud, selecting the highest point from the corresponding tree crowns above the extracted tree positions.

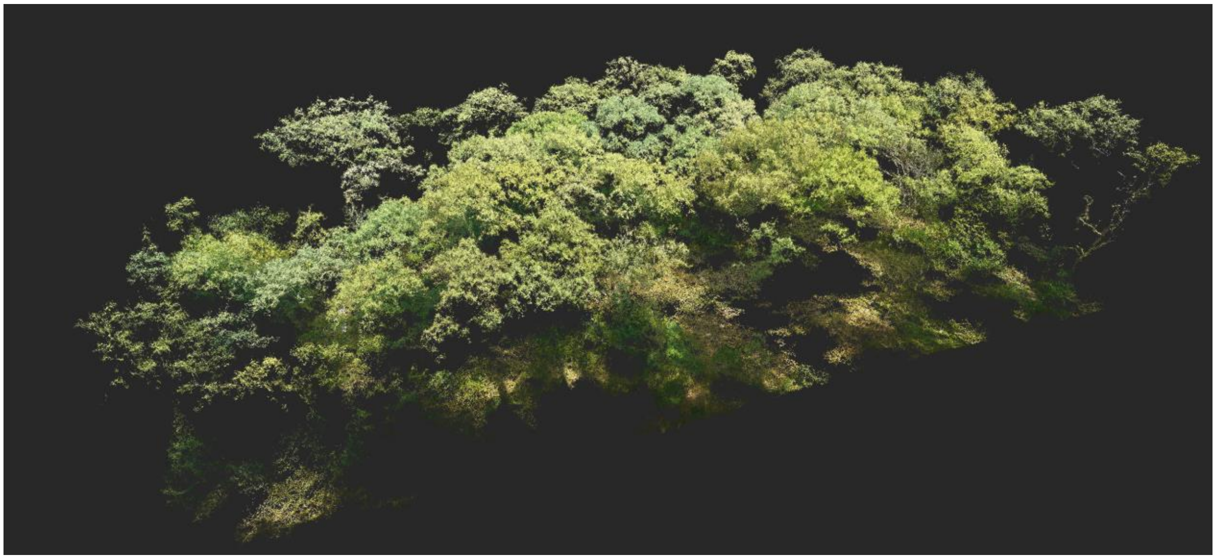

Fig. 1: 3img point cloud of deciduous forest site

2.2.2 UAV scan and point cloud reconstruction

The UAV chosen for this study was a MK Okto2 (Highsystems GmbH) octocopter. The sensor mounted to the UAV was a standard consumer camera (Panasonic Lumix G3), with a 20mm lens. With a flying altitude of 100m the resulting pixel size resembled 1,9cm^2 on the ground. To capture the tree crown cover comprehensively and also record as many ground points as possible, for later Digital Terrain Model (DTM) calculations, the camera was tilted 90°, facing the nadir direction. At a pulse rate of 1.4Hz, 458 photos were taken of the deciduous forest site, and 432 of the coniferous forest site. The resulting forward overlap was approximately 95% for both study sites and the sidelap was 75% for the deciduous forest site or respectively 70% for the coniferous forest site. The flight patterns were programmed pre-flight, by setting GPS way points, which the UAV followed consecutively.

After sorting out blurred and overexposed images, two point clouds for each study site were calculated for comparison, one requiring a minimum of three (further referred to as 3img), and one of four images (further referred to as 4img), displaying the same point for its 3D reconstruction, the difference lying in the point accuracy and point cloud density. The resulting average point densities for the coniferous forest site were 2901m^{-2} for the 3img and 2411m^{-2} for the 4img point cloud, and respectively 2233m^{-2} and 1990m^{-2} for the deciduous forest site. As a visual example, figure 1 shows the 3img point cloud calculated for the deciduous forest site.

2.2.3 Digital elevation models and pouring algorithm

The software TreesVis, developed by WEINACKER ET AL. (2004), was used to calculate the DTM and Digital Surface Models (DSM), as well as perform the pouring algorithm for single tree detection based on the calculated DEM. The software was developed for airborne and terrestrial LiDAR data, with the focus on forestry applications.

One terrain model for each study site was created from the 3img UAV point clouds, since more ground points were calculated for the 3img point clouds than for the 4img point clouds. The settings for the DTM calculations were chosen iteratively by applying various parameter combinations, and comparing the resulting DTM to a DTM calculated from the TLS data.

14 DSM with altered processing parameter combinations were calculated from both the 3img and the 4img UAV point clouds. For each DSM the pouring algorithm, in order to delineate single trees, was executed six times with altering parameters. Thus in total 168 tree models were calculated for each study site. Figure 2 displays a tree model for the deciduous forest site.

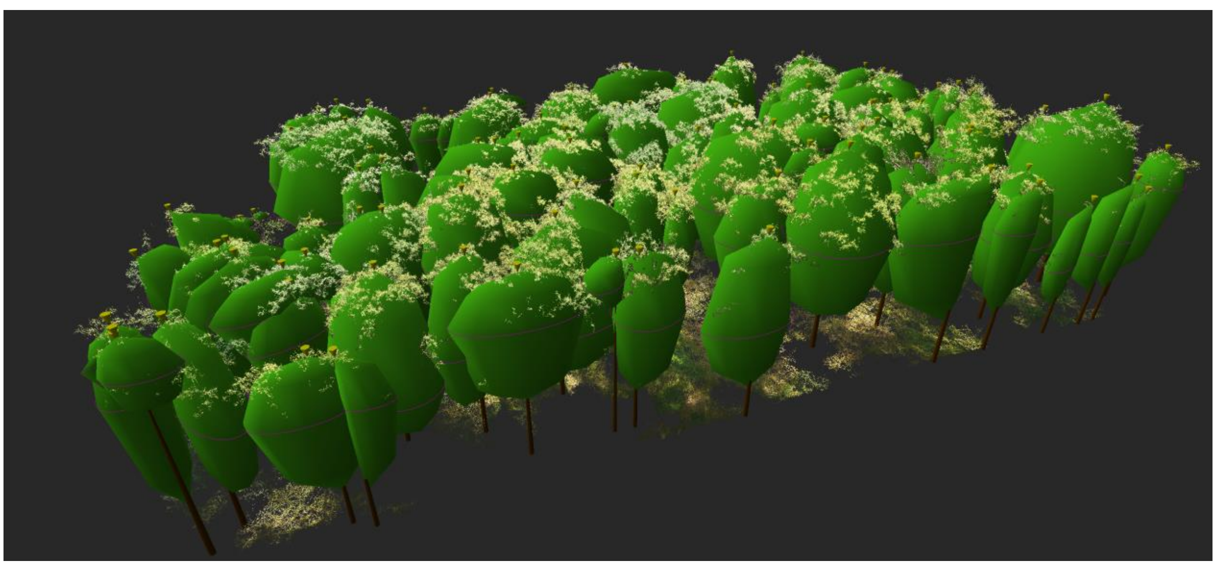

Fig. 2: Modeled trees for 3img point cloud of deciduous forest site

2.2.4 Model and reference data comparison

A process chain was set up to extract modeled trees, located within a set radius of the reference tree positions and write them to a table including both the model and the reference tree data. The process chain was executed twice for both study sites. In one case the search radius was set to 1m, in the other to 2m. Higher search radii would have been impractical, due to the reference tree density. The 336 resulting tables, for each study site, were subsequently analyzed in R as follows.

2.2.5 Statistical analysis

After a first inspection, the data bases, containing information on all calculated tree models, were reduced, to contain only models, where the number of modeled trees were within a certain percentage range (± 30 trees at maximum) of the number of reference trees, to exclude high tree detection numbers, only based overestimated tree density. The tables were then further reduced, to comprise not more than 10 models with the highest detected tree numbers.

For visual interpretation of the deviations' constancy, the density of height difference, deviation distances and angels were plotted for the remaining models. A relatively higher density and steeper local slopes were interpreted as a statement of a model's better fit to the reference data. Furthermore the following attributes compared for a linear relationship, were: reference and model tree height, height difference, tree center distance, reference tree density, azimuth angle and the height difference between the TLS and UAV DTM.

3 Results

3.1 Deciduous forest site

The models selected for final evaluation featured 16 detected trees, of the 120 reference trees, for the 1 m search radius and 36 for the 2m search radius. The median of the height difference between the reference and modeled trees was -0.19m, or respectively -0.11m. The models for both search radii results showed a strong relationship between the model and reference tree heights. Also the 1m search radius model showed a strong relationship between the reference tree density and the near distance, indicating that with a higher tree density the near distance increased. Comparing the detected trees with the reference trees positions and height, indicated, that the detected modeled trees corresponded to the highest reference trees. Also fewer trees were detected in areas of densely standing trees.

3.2 Coniferous forest site

The 1 m search radius detected 192 of 219 trees; the 2m search radius detected 198 trees. The median of the height difference was 0.44m for the 1m search radius and 0.52m for the 2m search radius. The medians for the near distance resulted in 0.44m and 0.42m. Besides the strong correlation detected for the modeled and reference tree heights, both search radius results showed a strong correlation between the model and reference tree height difference and the DTM height difference of the TLS and UAV DTM. The detected tree model positions also indicate, that the detection probability depends on tree height and density.

4 Discussion

4.1 Deciduous forest site

For the selected model of the deciduous forest study site, only 13.33% of the reference trees could be counted as an accurate resemblance of the reference tree positions. By extending the search radius to 2m, detection rate was increased to 30%. However, deviations in position accuracy of up to 2m were not considered accurate enough, since the increased search radius also led to an increase of wrongly associated trees. This decision is supported by a weaker relationship between the model and reference tree heights.

The results further clearly show, that tree detection accuracy depended on both the reference tree height and the tree density. The dependency on tree height can be explained through the occlusion caused by higher tree crowns. The impact of the reference tree's density on the number of detected trees and resulting tree center distance can possibly be explained by irregularities in the tree crown formations, caused by the competition for light between close standing trees. Thus the range of reference tree heights from 8.79m to 31.02m, with a mean of 22.79m, thereby indicating a highly diverse forest structure, can be seen as the main reason for the low tree detection rate.

4.2 Coniferous forest site

The percentages of detected trees for the coniferous forest were 87.68% by the 1m search radius and 90.41% by the 2m search radius. Since the r^2-values for the correlation between the tree heights decreased with the higher search radius, it is likely, that some of the few more detected trees were associated to wrong reference trees. The results of the correlation tests not only show that the modeled tree heights fit the reference tree heights well, but also that the height difference depends strongly on the difference in DTM height. In order to model tree heights as accurate as possible, future calculations would have to be based on highly accurate DTM. Then again the inter-quartile range of the DTM height differences of approximately 1m and a mean of -0.08m already show a fair accuracy for the UAV DTM. As with the deciduous forest site, the tree heights were an important factor for single tree detection. The reference tree heights ranged from 23.92m to 35.73m, plus one outlier of 6.66m, and a mean of 32.15m. This relatively small range, with a tendency towards high trees, in combination with the Douglas fir's straight growth and pointy tree crown, probably led to the high detection rates. This already shows potential for the presented method being applied for homogenous coniferous or plantation forests.

4.3 Further research

The results can only be seen as significant for coniferous or deciduous forests on even ground. For further evaluation, similar studies have to be conducted for forests on uneven terrain, mixed forests and broadleaved forest during leaf off state.

Through optimizing the process, e.g. by splitting the point cloud into multiple point clouds, according to tree height groups, or tree species, based on the RGB-information, more accurate results are likely. Also, different pouring algorithms could be implemented and tested.

On the basis of the presented method, further research possibilities would be, to use tree allometry data in order to derive the trees' DBH, and further calculate meaningful estimates of parameters like timber volume or biomass. With the pouring algorithm also calculating the tree crown's border, this method's potential for canopy density and closure measurements could be evaluated.

5 Conclusion

This study presented a possible procedure for UAV photography based single tree detection and tree height measurement, using point clouds as a basis. With a maximum detection rate of

87.68% within a search radius of 1 m and a mean height accuracy of 0.5 m, the described procedure shows promising results for UAV based photogrammetry as a new instrument for forest mensuration. The accuracy as well as spatial extent reached by this method can be classed between TLS and ALS, confirming UAV based photogrammetry to be an adequate addition to laser scanning for measuring forest attributes.
As indicated by the recommendations for further research, the procedure shows a high potential for further enhancements.
Not only are UAV becoming more affordable for the public, but also, considering the operational aspect, the resulting labor costs, necessary for applying the described method, can be reduced to a minimum, due to automation of many involved procedures. The manpower involved in an analysis of a 10 ha area was estimated as less than 2 hours.
With further studies confirming the application potential for forestry use, as well as considering the low operating costs, UAV based photogrammetry has a high potential of evolving to a valuable, widely used instrument for forest inventories.

A rendered visualization of the methodology and the results is available at http://goo.gl/KlFlsZ

6 References

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