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UAV IMAGERY TO SUPPORT INDIVIDUAL TREE MANAGEMENT AND MONITORING

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ABSTRACT

Unoccupied Aerial Vehicles (UAVs) have gained prominence in remote sensing applications, a.o. in individual tree detection (ITD) and management. This study explores the potential of UAV imagery in two key applications: assessing tree health using multispectral data on the one hand and evaluating the impact of different Structure-from-Motion (SfM) software packages on ITD on the other hand. In the first case study, multispectral UAV imagery was collected from an urban park in Belgium. Normalized Difference Red Edge Index (NDRE), oftenly used as a proxy of crop health, was found to be related to traditional visual tree assessments (VTAs), which highlights the potential of UAVs to complement ground surveys by offering a 'top view' perspective. While limitations exist in capturing within-canopy information, such as branch structure, multispectral UAV imagery can still be useful in detecting early signs of stress, presenting an objective supplement to subjective expert-driven VTAs. In the second case study, the impact of SfM software packages on ITD was investigated using existing imagery. Pix4DMapper, Agisoft Metashape and WebODM were employed to generate 3D point clouds for individual tree delineation. Pix4DMapper and Agisoft Metashape outperformed WebODM in terms of correctly classified trees, demonstrating higher recall, precision, and F-scores. WebODM exhibited a higher fraction of false negatives and false positives, and detected smaller trees on average. The findings emphasize the importance of SfM software selection in optimizing the accuracy of ITD from UAV-derived data. In conclusion, this research underscores the potential of UAVs in enhancing tree inventories, both in an urban or forest related context. The combination of multispectral imagery for tree health assessment and careful consideration of SfM software choices for ITD can contribute valuable insights to (urban) forestry management.

Index Terms— individual tree detection, urban forestry, tree health assessment, photogrammetry, multispectral

1. INTRODUCTION

Unoccupied aerial vehicles (UAVs) or drones are becoming an increasingly important research topic in various remote sensing applications. Recent technical and jurisdictional advances have brought them to the forefront of data-driven innovations in the domains of individual tree detection (ITD) and management [1]. UAVs equipped with a multispectral sensor can inform about the condition of the trees, whereas (a large number of) RGB images can provide information about the 3D-structure of trees through Structure-from-Motion (SfM) photogrammetry. In both cases, the process between image collection and processing requires (and strongly depends on) the setting of multiple flight planning parameters (such as flight altitude and image overlap) and processing parameters (such as raster smoothing intensity, point cloud thinning and ITD-algorithm) [2–4].

In this research, we focused on two applications of UAV imagery for updating tree inventories. The first case study aimed to explore the potential of multispectral UAV imagery for complementing traditional (visual) tree health assessments. The objective of the second case study was to quantify and assess the impact of using different structure-from-motion (SfM) photogrammetry software packages on the detection of individual taxus trees.

2. TREE HEALTH ASSESSMENTS USING MULTISPECTRAL UAV IMAGERY

In October 2021, multispectral UAV imagery (Micasense Altum) was collected from an urban park in the city of Hasselt, Belgium at a height of 40 m AGL and with 80 % image overlap. Image processing was carried out using Pix4DMapper (Ag Multispectral processing options template) and included radiometric calibration. Spectral indices such as the Normalized Difference Red Edge Index (NDRE, Formula 1) were computed in Pix4DMapper as well. This indicator is often used as a proxy of plant health as it reflects leaf chlorophyll content. In a final step, the mean NDRE values of each tree were compared with field observations of the tree condition. Here, the tree condition was estimated based on a traditional visual tree assessment (VTA). Conventional VTA incorporates both discoloration and defoliation of the entire tree canopy to establish an overall tree health score. Unlike ground-based VTA, UAVs capture information about the uppermost layer of the canopy. Consequently, the NDRE is heavily influenced by the conditions of the topmost leaves. Given that the initials signs of tree stress initiate in the top of the canopy, discoloration can be overestimated by UAV data. Extracting within-canopy information, like branch structure and foliar density, is challenging with multispectral drone data. This usually relies on techniques such as LiDAR (light detection and ranging) which can penetrate through the canopy. This inherent limitation of drone images can result in an underestimation of defoliation [5]. Conversely, UAV imagery can offer valuable indication of early leaf abscission, by revealing exposed branches at the top layer of the canopy, providing a distinct perspective compared to the VTA.

$$NDRE = \frac{(NIR - Red\,Edge)}{(NIR + Red\,Edge)} \qquad [1]$$

Figure 1 shows the resulting NDRE values and the tree condition as estimated using the field-based VTA. It can be seen that trees in a good condition typically have higher NDRE values. Similarly, trees with a medium or poor condition seem to coincide with lower NDRE values. This is also visible in the mean NDRE values per polygon representing a tree (Figure 1). The overestimation of discoloration and underestimation of defoliation can be attributable to the larger mean NDRE for poor VTA condition compared to those in medium VTA condition. The large variation in NDRE within the good condition class can be a result of the polygon shape used to calculate the mean NDRE per tree. For some trees background information from outside the canopy and information about neighboring trees was taken into the equation, reducing their mean NDRE.

In conclusion, these results indicate that NDRE can also be a useful indicator of tree condition. Dedicated, multi-sensor UAV missions have the potential to complement field surveys in updating urban tree inventories providing a supplementary "top view" perspective. The interpretation of zenithal UAV imagery regarding the overall tree condition should be carefully considered, but it shows great potential to capture early signs of stress. Furthermore, UAV imagery can act as a more objective indicator to support a subjective expert knowledge driven VTA.

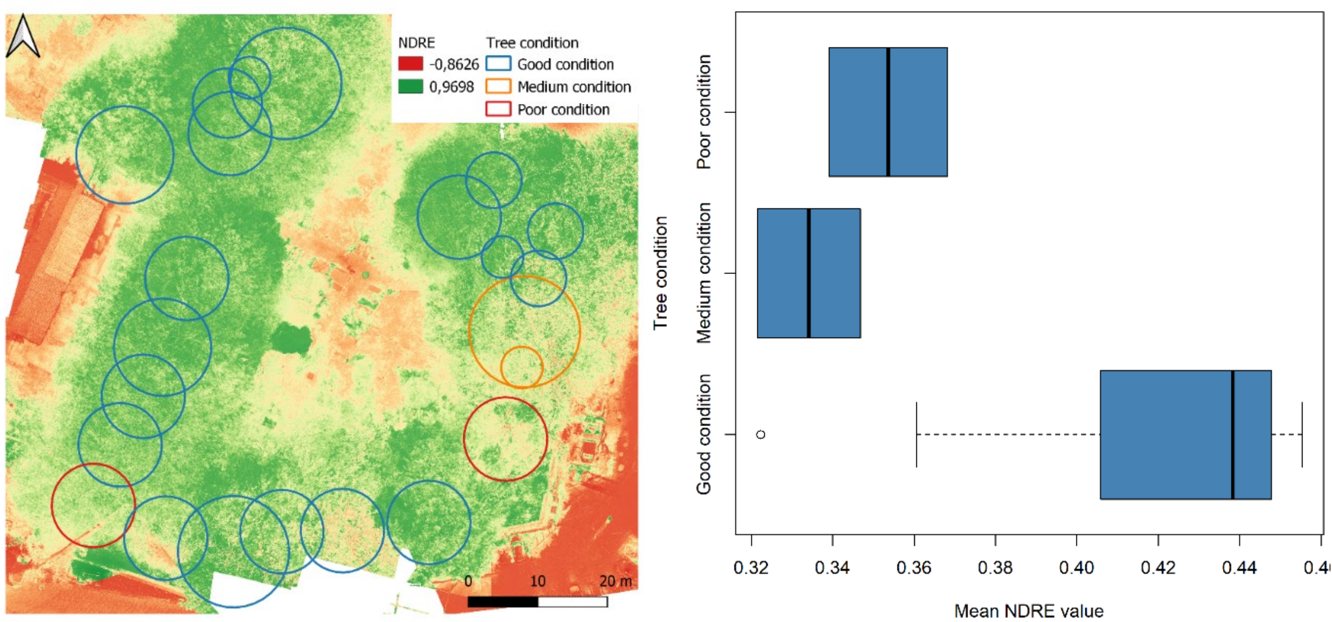

Figure 1. Geographical representation of the measured NDRE values and field-based tree health assessment

3. THE IMPACT OF SFM-SOFTWARE PACKAGES ON ITD

Making use of an existing image collection from November 2021 (flight altitude 40 m AGL, angle of 60°, and 80% image overlap, for more details we refer to [6]), we tested the effects of using three different SfM-software packages to generate 3D point clouds: two commercial (Pix4Dmapper and Agisoft Metashape) and one open-source (WebODM). In line with [7], default processing templates to generate point clouds were used when available. Based on the resulting point cloud, individual tree delineation was carried out in R-software following the procedure described in [6]. During this process, a smoothing window of 3 x 3 pixels was implemented on the resulting canopy height models (CHMs) and a watershed algorithm in combination with marked-controlled segmentation was applied. The performance of the tree delineation approaches was evaluated by computing the number of trees that were detected correctly (true positive, TP), omitted (false negative, FN) and committed (false positive, FP). Based on these metrics, recall (r, [2]), precision (p, [3]) and F-score (F, [4]) values were computed.

$$r = \frac{TP}{TP + FN} \qquad [2]$$

$$p = \frac{TP}{TP + FP} \qquad [3]$$

$$F = \frac{2 * r * p}{r + p} \qquad [4]$$

In general Pix4DMapper and Agisoft Metashape outperformed WebODM as is visible in the amount of trees classified correctly (TP) and corresponding recall, precision and F-scores. Remarkably, ITD using WebODM had a higher fraction of false negative (62) and false positive (18) trees. The default preprocessing workflow of WebODM resizes the raw orthophotos to a smaller resolution in order to improve computational efficiency and reduce data storage [7]. The loss of detail represents itself in a less crisp pointcloud. Trees in close proximity to each other can therefore be merged as one larger feature. Consequently, the tree detection algorithm fails to correctly measure the number of trees, resulting in a substantial false negative. In general, the detected trees were smaller (3.22 ± 0.99 m resp. 3.28 ± 0.93 m) based on WebODM resp. Agisoft Metashape than when computed using the point cloud derived by Pix4DMapper (3.43 ± 0.95 m).

The ITD methods used in this study, were purely based on structure parameters derived from a dense pointcloud generated by SfM-software. Recently, the use of Mask Region-based Convolutional Neural Networks (Mask R-CNN) are making their way into ITD, combining both spectral (RGB or MSP) and structural (CHM) data. These Mask R-CNN methods tend to yield higher accuracies compared to conventional ITD methods [8]. The data integration of machine learning methods might make ITD more robust against less accurate and sparse pointclouds. On the other hand, they require a lot of training data and computation power. The performance of ITD is largely related to the tree stand. In this study we focused on a taxus plantation, containing relatively ordered rows of circular shaped, pruned trees. As a result, the conventional ITD workflow with commercial SfM-software packages is able to yield very high recall, precision and F-scores. In dense forests, the ITD, even with deep learning approaches is substantially more difficult [9]. The impact of SfM-software packages will therefore become even more relevant to yield accurate CHMs and ITD results in dense forests.

Table 1. Overview of the results of the ITD approach using different SfM-software packages

	Pix4DMapper	WebODM	Agisoft Metashape
TTC	237	193	233
TP	235	175	230
FN	2	62	7
FP	2	18	3
r	0.99	0.74	0.97
p	0.99	0.91	0.99
F	0.99	0.81	0.98
TH (m, mean ± SD)	3.43 ± 0.95	3.22 ± 0.99	3.28 ± 0.93
CA (m^2, mean ± SD)	1.79 ± 1.01	1.56 ± 1.08	1.30 ± 0.79

TTC: total tree count, TP: true positive, FN: false negative, FP: false positive, r: recall, p: precision, F: F-score, TH: tree height, CA: crown area.

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