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Comparison of Seedling Detection and Height Measurement Using 3D Point Cloud Models from Three Software Tools: Applications in Forest Restoration

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Abstract

A challenge for forest restoration is the monitoring of success, particularly of seedling survivorship. The 3D-point-cloud models, generated from aerial images taken from unmanned aerial vehicles (UAVs), are useful in monitoring vegetation recovery. However, the use of aerial images is challenging due to small seedling size. Many photogrammetry software tools are available for creating 3D-models, but they differ in their performance. This research aims to compare ease of use, seedling detection and the accuracy of seedling height measurement using 3D-point-cloud models from the free versions of three tools: Pix4Dmapper, DroneDeploy, and WebODM. The studied site was at a forest restoration plot of the Siam Cement Group (SCG) Public Company Limited, Lampang, Thailand. The height of 178 planted seedlings was measured manually and used as ground-truth data. On the same day, a UAV was used to automatically capture RGB images of the area, which were processed using the three software tools using their default settings. The percent detection, and the accuracy of height measurements were compared. This study found that DroneDeploy correctly detected 42% of the seedlings, followed by Pix4Dmapper (29%) and WebODM (16%). DroneDeploy and Pix4Dmapper had higher commission error (3%: detection of seedlings that were not there) than WebODM (1%). The differences in seedling detection may arise from differences in algorithms and the default settings used by the software. The accuracy of seedling height measurement was assessed using linear regression against the ground truth data and found that the three software tools performed well (R-squared > 85%). Finally, the pros and cons of each software and their future applications were discussed.

Keywords: UAV; Photogrammetric software; Seedling monitoring; Seedling height

1. Introduction

A point-cloud is a three-dimensional dataset generated from many georeferenced points produced by photogrammetry software (Lindberg and Holmgren, 2017). The raw data used in generating 3D point clouds can include remote sensing imagery such as aerial images taken from unmanned aerial vehicles (UAVs) (Yang *et al.,* 2017) represented as a collection of two-dimensional (2D) images, via estimation of motion of the camera, which is corresponding to the overlapping images. Overlapping aerial image sequences are analyzed based on a photogrammetric technique (Lindberg and Holmgren, 2017) (via Structure from Motion: estimation of motion of the camera, which corresponding to images), resulting in a 3D point cloud model (Özyeşil *et al.,* 2017). There are many photogrammetric software tools that allow the usage of overlapping images via a variety of platforms (Talib *et al.,* 2021), including open-source and non-open-source software with a limited trial period. However, the 3D point cloud model outputs can vary (Westoby *et al.,* 2012) depending on the photogrammetric software used. Therefore, it is a primary step to select software appropriate to the types of data being collected for forest restoration assessment.

Remote sensing has been applied for ecological restoration monitoring in a variety of situations (Buters *et al.,* 2019). For forest restoration, monitoring the performance of planted seedlings has been a crucial step in determining the progress of a restoration project (Dash *et al.,* 2017). Traditionally, monitoring seedling performance, usually assessed by measuring seedling is done by hand in ground surveys. The use of 3D point cloud models generated from UAV aerial images has the potential to monitor these seedling growth parameters instead of traditional ground surveys. Three dimensional point cloud models can speed up the monitoring process and lower the total cost of implementation (Itkin *et al.,* 2016). For trees, several recommended photogrammetric software tools for generating 3D point cloud models (e.g. 3DSurvey, Agisoft Photoscan, Pix4Dmapper Pro, SURE, and Autodesk 123D, etc.), are available and accurate in acquiring tree parameters (e.g. height, circumference, crown area, etc.) (Lindberg and Holmgren, 2017). For seedlings, monitoring seedling performance with a 3D point cloud model is still challenging due to the small size of the seedlings (Buters *et al.,* 2019). The question remains whether those recommended software tools can be applied and used to derive accurate assessments of seedling parameters. As we were interested in keeping the photogrammetry process affordable for forest restoration practitioners, we focus on testing freeware versions of the photogrammetric software. This research study aims to compare ease of use, seedling detection and the accuracy of seedling height measurement using 3D point cloud models from free versions of three currently available photogrammetric software programs: Pix4D mapper, Dronedeploy, and WebODM.

2. Materials and Methods

2.1 Study area

The study site is located at a restoration plot in the Semi-Open Cut Mining of the Siam Cement Group (SCG) Public Company Limited, Chae Hom district, Lampang Province, Thailand (18°32’41.7”N 99°34’11.4”E; elevation 423 m). The restoration plot is in a rock quarry with a thin layer of topsoil. Native tree seedlings (n =178) were planted in August 2020 according to the Framework Tree Species method (Elliott *et al.,* 2021). At the time of this study, the seedlings were 9 months old.

2.2 Field data collection

For the ground measurement, the height of the stem of each seedling was measured from the soil surface to the shoot meristem (Wangpakapattanawong and Elliott, 2008). These height data from ground-based measurement were used as ground truth data for measurement accuracy comparison with the three selected software programs.

On the same day, aerial-based images were taken using a UAV (Phantom 4 UAV Pro V2 drone-DJI), equipped with a RBG camera (FC6310S_8.8). The Litchi flight planner (v. 4.18.0-g) was used to create the flight mission and control the UAV to fly autonomously and capture the images at 10 meters above the study area. The images (5,472 x 3,078 pixels) had more than 70% overlap as required for creation of the 3D point cloud model.

2.3 Point cloud generation and predicted height assessment

A total of 333 aerial images were used to generate the point cloud models in three photogrammetric software tools, including (1) the non-commercial version of Pix4D mapper, (2) the 14-day trial version of Dronedeploy, and (3) the free open-source WebODM software. For each software, we used the default settings and followed steps taken from tutorials as follows.

1. Open Pix4D mapper software → click *New Project* → type *Project Name* → click *Add Images* → let *Image Properties* as default → let *Auto Detected: WGS 84/UTM zone 47N* as default → select *3D Models* in the *Standard of the Processing Options Template* → wait for processing,
2. Open Dronedeploy software browser → click *+Project* → click *Upload* → type *Map Name* and *click Select Photos* → click *Upload Images* → wait for processing
3. Open WebODM software manager → open software browser → log in account → click A*dd Project* → type *Project Name* → click S*elect Images and GCP* → let *Additional Options* as default → click *Review and Start Processing* → wait for processing

The 3D point cloud outputs of each software were used to detect individual seedlings manually and measuring their height. For seedling height, the outputs from WebODM and Dronedeploy were exported, and the height was measured in Cloudcompare, an open-source software for point cloud processing. For the Pix4D Mapper, the height measurement was done by calculating the distance between the tip point and the seedling's basal point directly in the Pix4D Mapper's software interface.

2.4 Outputs comparison and accuracy assessment

The properties of the 3D point cloud model outputs were recorded. In addition, the ease of use was evaluated based on installation, pre-processing procedures, processing time and time spent on height measurement after obtaining the 3D point clouds. In terms of seedling detection, the total number of correctly detected seedlings (out of 178 seedlings on the ground) from each software was counted and the percentage of correctly identified seedlings was calculated. The percentage of seedlings that failed to be detected was reported as an omission error (%). The percentage of seedlings wrongly detected was also calculated as commission error (%). Simple linear regression was then used to test the relationship between the height measurements derived from the ground-truth data (x-axis) and the point-cloud models (y-axis).

3. Results and Discussion

3.1 Software outputs and ease of use of each software

Dronedeploy and WebODM allow users to export PDF reports summarizing software performance and outputs, however Pix4D-mapper does not allow exporting and only provide the reports on a pop-up window. Although Pix4D-mapper provided useful information in its reports, the convenience of being able to export the reports from Dronedeploy and WebODM is significant. A comparison of the information relating to 3D point cloud model properties produced for each of the three software programs are listed in Table 1.

Table 1. Information reported about the 3D point clouds from each software. Check marks (✓) indicate "reported" while blank cells indicate "not reported" from the software

Reported information	Pix4D-mapper	Dronedeploy	WebODM
Average ground sampling distance (GSP)	✓	✓	✓
Area coverage		✓	✓
Image quality	✓	✓	
Matching quality	✓		
Tie points quality	✓		
Georeferencing quality	✓	✓	✓
Camera position and orientation uncertainties	✓	✓	✓
RMS error	✓	✓	✓
Rolling shutter statistics	✓	✓	✓
Point cloud densification details	✓	✓	✓
Result preview	✓	✓	✓
Reporting unit within output	meter	feet	meter

In addition, the ease of use of the three software were evaluated using four criteria (Table 2). The Dronedeploy was ranked highest, followed by Pix4D-mapper, and then WebODM. In addition, Dronedeploy took the least time and computer storage during the installation and processing.

3.2 Seedling detection percentage

Dronedeploy correctly detected the greatest number of seedlings with the smallest omission error, in comparison to Pix4D-mapper, and WebODM (Table 3). The omission errors (failures to detect seedlings when they are present) may arise from the size and health of the seedlings e.g., crown not fully projected or where seedlings have lost their leaves (Dash *et al.,* 2017).

3.3 Accuracy of height measurement

Simple linear regression was used to test the relationship of height measurement from the point cloud models from each of the three software and the ground truth data. Due to the difference of the number of seedlings detected by each model, the number of data points in each regression analysis was different: Pix4D-mapper (n = 51) Dronedeploy (n = 75) WebODM (n = 29). The regressions were statistically significant (Figure 1) and there was a strong linear relationship between the height measurements from the ground survey and from the point cloud models from all three software (Pix4D-mapper, $R^2 = 0.90$, $p < 0.001$; Dronedeploy, $R^2 = 0.98$, $p < 0.001$; WebODM, $R^2 = 0.88$, $p < 0.001$).

Table 2. The criteria indicating the ease of use of the three selected software.

Comparison criteria	Pix4D-mapper	Dronedeploy	WebODM
Complexity of software installation	simple	none (online browser)	complicated*
Complexity of steps before processing	moderate	simple	moderate
Processing time	1 hr 33 mins	32 mins	47 mins
Time spent on height measurement	1 hr 9 mins	1 hr 3 mins	19 mins

*complicated = requires installing docker, to run the software (without docker it would not be possible to run WebODM, but it also used up internal storage).

Table 3. Percentage of seedlings detected by each software.

Percentage of detection	Pix4D-mapper	Dronedeploy	WebODM
Correctly identified	29	42	16
Omission error	71	58	84
Commission error	3	3	1

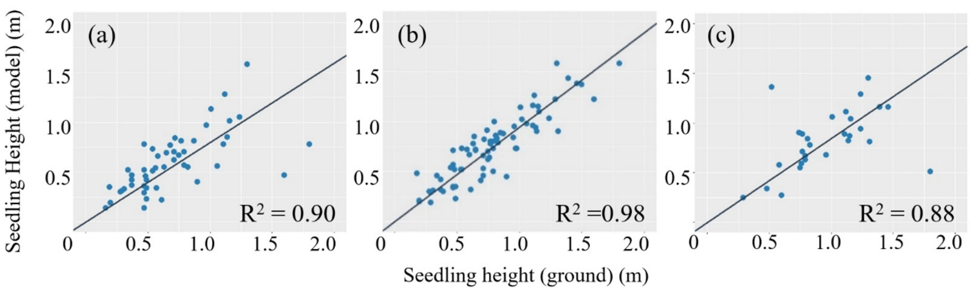

Figure 1. Linear regression between the measured height from 3D model and ground truth data: correctly detected seedlings height from Pix4D mapper (n = 51) (a), Dronedeploy (n = 75) (b), WebODM (n = 29) (c).

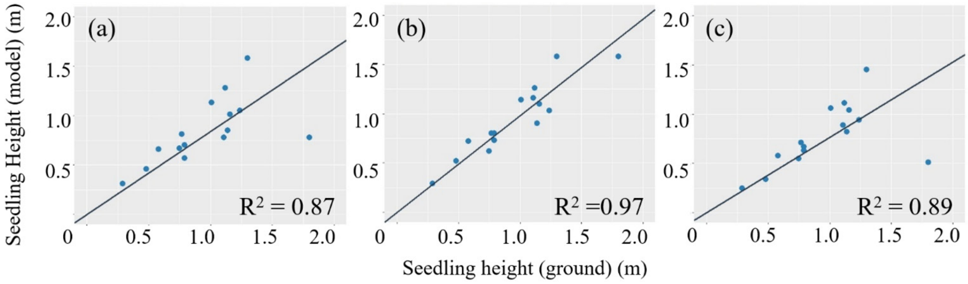

Figure 2 Linear regression between the measured height from 3D model and ground truth data: overlapping detected seedlings among three software (n = 15) from Pix4D mapper (a), Dronedeploy (b), WebODM (c).

In addition, the linear relationship between the height data from the point cloud models and the ground truth data for those seedlings were correctly detected by all three software tools (n =15). The relationship between height measurements from the point-cloud models and the ground-truth data was statistically significant (Pix4D-mapper, R2 = 0.87, $p < 0.001$; Dronedeploy, R2 = 0.97, $p < 0.001$; WebODM, R2 = 0.89, $p < 0.001$;) (Figure 2).

All software tools generated point cloud models that allowed height measurements were strongly related to the ground truth data. However, there were still some errors in height measurements from the point cloud models. The free version of the software tools may have limited features which affect the accuracy of the height measurement. This study concern that there are commercial versions of these software tools which provide more features. Users should investigate what features are available in each software products to choose the appropriate software for a given task.

Since the accuracy of height measurement was high for all software, the software that correctly detected the highest number of seedlings gave more useful data on seedling height. Differences in ease of use also set the software apart. In this study, Dronedeploy worked well in detecting seedlings using aerial images and was relatively simple to use.

For monitoring seedlings in forest restoration studies, this study showed that the use of UAV aerial images has the potential to replace ground surveys. However, further work is needed. Better seedling detection may come from the combination of using UAVs with more powerful cameras, developing different flight plans for different stages of restoration, investigating further into image preprocessing steps before generating point cloud models, and applying other advanced remote sensing equipment e.g., lidar, etc.

4. Conclusion

Among the free versions of the three software tools tested, Dronedeploy performed best at generating 3D point cloud models, and at acquiring seedling height data. This study can be used as a preliminary guideline for environmental researchers to choose suitable software for seedling measurement. This study does not rule out the potential use of other software tools and suggests the need for further investigation.

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