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Calculating coniferous tree coverage using unmanned aerial vehicle photogrammetry

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Abstract

Unmanned aerial vehicles (UAVs) are a new and yet constantly developing part of forest inventory studies and vegetation-monitoring fields. Covering large areas, their extensive usage has saved time and money for researchers and conservationists to survey vegetation for various data analyses. Post-processing imaging software has improved the effectiveness of UAVs further by providing 3D models for accurate visualization of the data. We focus on determining the coniferous tree coverage to show the current advantages and disadvantages of the orthorectified 2D and 3D models obtained from the image photogrammetry software, Pix4Dmapper Pro—Non-Commercial. We also examine the methodology used for mapping the study site, additionally investigating the spread of coniferous trees. The collected images were transformed into 2D black and white binary pixel images to calculate the coverage area of coniferous trees in the study site using MATLAB. The research was able to conclude that the the 3D model was effective in perceiving the tree composition in the designated site, while the orthorectified 2D map is appropriate for the clear differentiation of coniferous and deciduous trees. In its conclusion, the paper will also be able to show how UAVs could be improved for future usability.

Keywords: Unmanned aerial vehicles, Pix4Dmapper, Vegetation, Forest, Phantom 2 Vision+, MATLAB

Introduction

The use of UAVs in ecological studies

Unmanned aerial vehicles (UAVs) or drones have evolved into one of the most promising tools in recent years owing to their accurate real-time data acquisition ability (Govorčin et al. 2014). Researchers have established an era of UAV-aided ecological studies considering their effectiveness and affordability. UAVs have long been applied in remote sensing applications, for mapping land coverage, monitoring deforestation and vegetation changes, approaching inaccessible areas, etc. The reason for UAV technology to gain momentum in forest conservation is due to the need for little hands on experience and safe remote operation. Commercially available UAVs can cover large areas and are compatible with post-processing software such as Pix4D. Thus, it has rooted its application in otherwise slow and labour-intensive processes.

Serge A. Wich and Lian Pin Koh, cofounders of the site ConservationDrones.org, were one of the first to monitor and protect the world's forest and wildlife using conservation drones (Koh 2013). We have discussed the UAVs' potential for data acquisition in ecology and conservation biology in our previous publication (Ivosević et al. 2015). Paneque-Gálvez et al. presented the feasibility and potential of small drones for community-based forest monitoring (Paneque-Gálvez et al. 2014). They identified the current constrains and challenges in usage of UAV technology for forest monitoring and implied that they will be surmounted with technological growth. Using high-resolution imagery and object-based image analysis, Getzin et al. (2012) have assessed the forest biodiversity with respect to gaps in canopy and soil composure variation.

The aerial photography techniques have bloomed in forest monitoring applications due to the availability of post-processing software which can compute 3D models from mere 2D images. Digital terrain modelling (DTM) and digital surface modelling (DSM) are used in order to make a 3D topography with the use of point cloud and triangle meshing techniques (Vallet et al. 2011; Küng

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Ivosevic et al. Journal of Ecology and Environment (2017) 41:10

Page 2 of 8

et al. 2011). Another conservation study based on UAV technology has indicated the linkage between disease transmission and environmental factors such as deforestation. The researchers have used Pix4D to map the area of deforestation and deterioration of species habitat (Forance et al. 2014). The quality of composed 3D structure depends on image overlapping, picture size and distinct visual content (Introduction Pix4D Webinar 1 2016). The accuracy of UAV photogrammetry is limited to the ability of the software to distinguish edges and texture (Küng et al. 2011; Introduction Pix4D Webinar 1 2016). While UAVs have been successfully used to list tree inventory and to measure their heights (Lisein et al. 2013), present-day image processing techniques are not applicable when millimetre scale accuracy is required.

The overall goal of the study was to determine whether it is possible to accurately detect coniferous species in the designated study site using the default Phantom 2 Vision+ platform and Pix4Dmapper Pro—-Non-Commercial and calculate the percentage of the area covered by conifers using MATLAB.

Phantom 2 Vision+

Phantom 2 Vision+ is simple to set up and an easy to fly unmanned aerial quadcopter developed by DJI, a Chinese company headquartered in Shenzhen, China (Fig. 1) (Dji.com 2016). The compact, highly integrated platform Phantom 2 Vision+ has an all-in-one system, with a three-axis stabilization gimbal holding, including a 14-MP HD camera, and 4 GB micro SD card for data storage. It also allows for tilting of the camera as you fly, creating unique angles, and gives the option of slow-motion shots and live view via a dedicated mobile application (Dji.com 2014).

Fig. 1 Phantom 2 Vision+ quadcopter starts the mission automatically using Pix4D capture mapper application

Pix4D software

Pix4D is an UAV, ground and aerial, image photogrammetry software. Founded by a Swiss company in 2011, Pix4D has become the main provider and industry standard for professional unmanned aerial vehicle (UAV) processing software (Pix4D 2016a). The Pix4D computing consists of three steps: initial processing, point cloud densification and DSM and orthomosaic generation, which are done automatically.

Pix4D software also provides the access of the support site and forum where the support team has put together, and is constantly updating, a wealth of information related to the Pix4D, academy video tutorials, webinars, example datasets and more (Pix4D 2016b).

Materials and methods
Study area
The study area was designated in Sobaeksan, Republic of Korea, more specifically Namcheon Valley, in Danyang. The location of the study site is given in Fig. 2, derived from the Pix4Dmapper Pro—Non-Commercial software. In 1987, Sobaeksan was designated as National Park No. 18. It covers an area of 320.50 km^2. Featuring beautiful valleys and ridgelines, Sobaeksan National Park is known for its abundant wildlife and breath-taking nature (English.visitkorea.or.kr 2016).

Two flights have been conducted at Sobaeksan, encompassing the small forest area (Table 1). The flights were set up to the automatic mode for flying linear transects with the dimensions of 70×70 m^2, altitude 70 m and 70×70 m^2, altitude 60 m, using the Pix4Dcapture mapper application (Fig. 3). These line transects are set by the software so as to obtain high image overlap which is needed for creating good 2D and 3D models. The surveyed area can be easily expended by either flying multiple missions or by increasing the altitude. Note that increasing the altitude will sacrifice image details. Thus, we cover our study site with low altitudes. The dominant tree species are *Pinus densiflora*, *Quercus mongolica*, *Quercus variabilis* and *Pinus koraiensis*. The best coverage of the chosen area was acquired when the images were taken from an altitude of 60 and 70 m, with the camera angle at 90°, facing the ground. This could be attributed to the possibility that the image overlapping was good for the post-processing of the image to form 3D maps. The data acquisition was done on 10 June 2015, and in total, 56 pictures were used to derive the results.

Data processing
Automatically taken images were synchronized with the SD card, from the UAV, to the Pix4D application and downloaded to the personal computer after each data collection. Data processing steps are given in Fig 4. The uploaded pictures were input to Pix4D to generate 2D and 3D maps. The copies of the individual pictures were used

Ivosevic *et al. Journal of Ecology and Environment* (2017) 41:10

Page 3 of 8
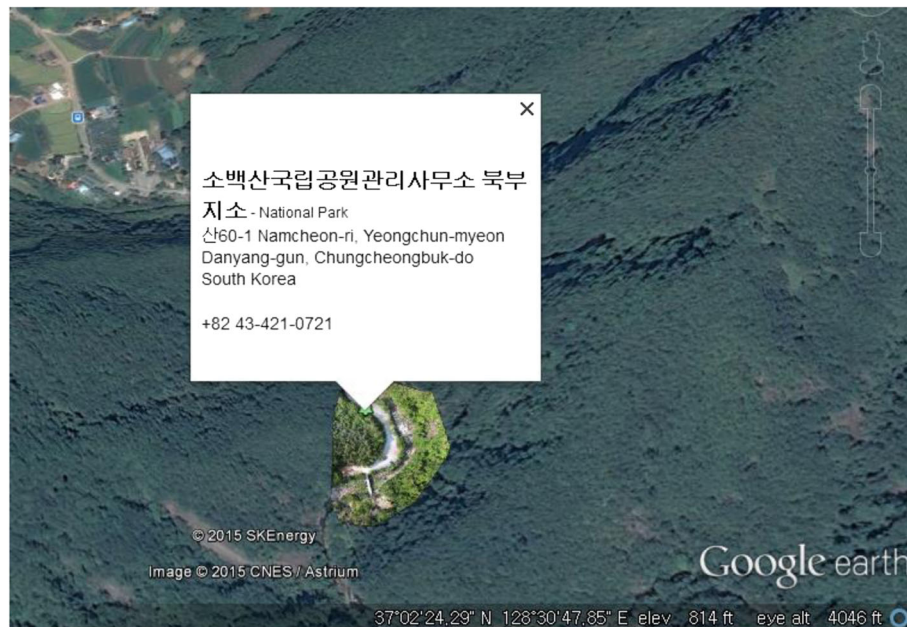
Fig. 2 Google earth representation of the study site generated using Pix4D software. The figure represents mapped area of the study site with the details of the exact location

to identify and colour the coniferous trees in red. Marking the coniferous trees was executed using Photoshop CS6 v13.0. The Color Replacement Tool was used to saturate the coniferous tree colour to red shades (foreground colour: R,G,B = 243,7,11). The different shades of red were a consequence of the tool used and does not denote any information. These modified pictures were processed using Pix4D to generate 2D and 3D maps with coniferous trees marked in red. These maps give an accurate visualization of the spread of conifers in the study site. Post-processing using MATLAB helped to calculate coverage area of the coniferous trees for the particular study site.

Results
Generated map output
Visual clues on coniferous tree coverage are obtained from 2D and 3D maps (Fig. 5a–d). Distance and area coverage can be extracted easily and more accurately from 2D maps while the depth perception can be

Table 1 Automatic flight details for image acquisition

Date	Time	Number of pictures	Dimensions of the terrain (m × m)	Altitude (m)	Camera angle (∠°)
10.06.2015	15:33–15:36	34	70 × 70	60	90
10.06.2015	15:46–15:48	22	70 × 70	70	90

Parameters such as altitude of the automatic mission, the area covered by the mission, camera angle and number of pictures taken per mission are mentioned in the table

obtained from 3D maps. They can be used as a first step in approaching any ecological survey. The later part of this article discusses how the coniferous tree coverage was estimated using a 2D map while its position was visualized using a 3D map.

Coniferous coverage area estimation
From the Pix4D quality report, it was evident that there was high image matching and the total covered area was 1820 m^2. Pix4D outputs the generated 2D map with a dimension of 1194 × 1807 pixels. The study site area in the 2D map image was made pure white and the remaining portion was made pure black using Photoshop (Fig. 6). The number of white pixels was found using MATLAB and area per pixel was calculated with the formula:

$$\text{Area per pixel} = \frac{\text{Total area of the study site}}{\text{Number of white pixels}}$$

The original 2D map was again taken, and the red-shaded parts were made true white while the remaining parts were made true black (Fig. 7). This highlights only the coniferous tree coverage area. The area covered by conifers is given by

$$\text{Area covered by coniferous trees} = \text{White pixels} * \text{Area per pixel}$$

$$\text{Percentage coverage}\,(\%) = \frac{\text{Area covered by coniferous trees}}{\text{Total area of the study site}} * 100$$

Workflow of the calculation is shown in Fig. 8. The coverage area of the coniferous trees in the study site
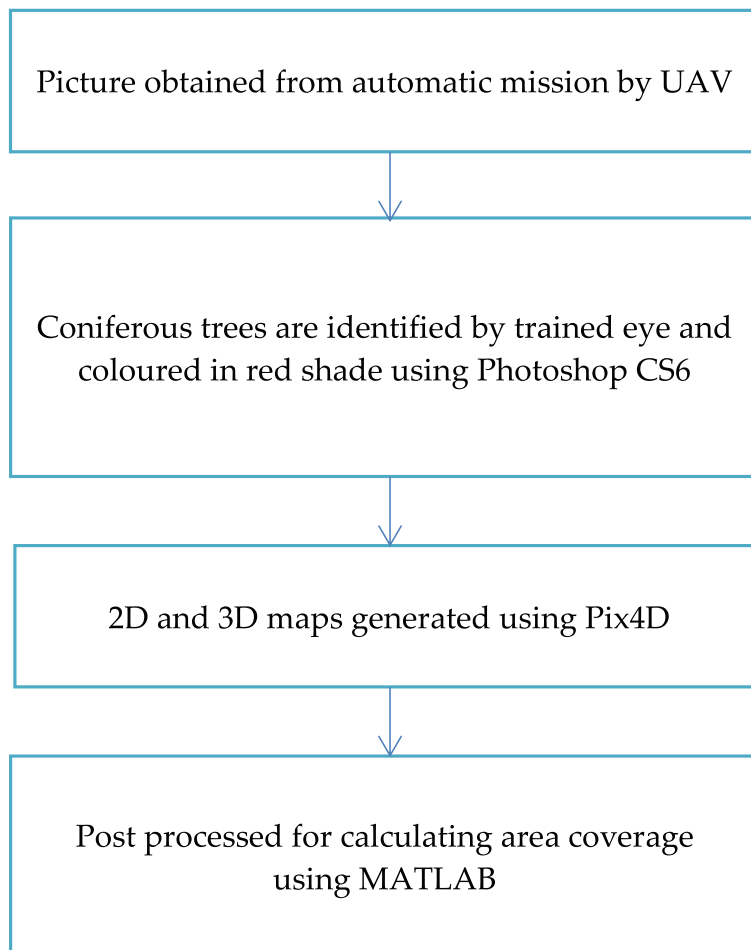
Ivosevic *et al. Journal of Ecology and Environment* (2017) 41:10

Page 4 of 8

Fig. 3 Automatic flight mission grid of the UAV. The UAV follows the grid lines automatically set by Pix4D capture mapper application

Picture obtained from automatic mission by UAV

Coniferous trees are identified by trained eye and coloured in red shade using Photoshop CS6

2D and 3D maps generated using Pix4D

Post processed for calculating area coverage using MATLAB

Fig. 4 Flowchart of data processing. Steps involved in making and calculating the coniferous tree coverage area

Ivosevic *et al. Journal of Ecology and Environment* (2017) 41:10

Page 5 of 8
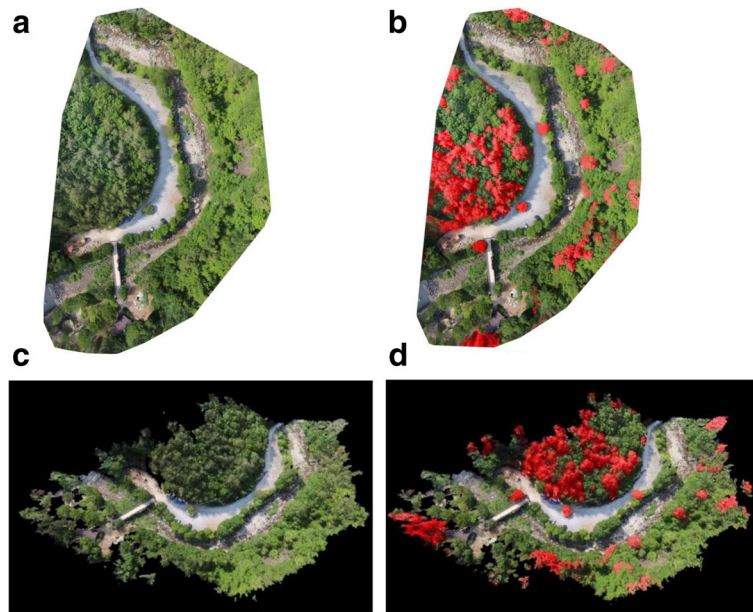
Fig. 5 2D and 3D map representation of the study site. **a** 2D and 3D maps generated from unmodified pictures using PixD software. **b** 2D and 3D maps generated from coloured pictures processed in Pix4D software. **c** 3D map generated from the unmodified pictures. **d** 3D map generated from coloured pictures

was calculated to be 291.5814 m^2. This, when compared to the total area of the study site of 1820 m^2, gives a conifer coverage percentage of 16.0209%.

The images which were made to true white and black colours using Photoshop were also transformed to binary black and white using *im2bw* command in MATLAB. This two-step image conversion was used as a simple process to avoid any chance of grayscales, other than black and white, from arising while using the *im2bw* command. Although López-Fernández et al. has used focal length and altitude of flight to measure the area coverage of solar panels in their study, the same method was not applicable
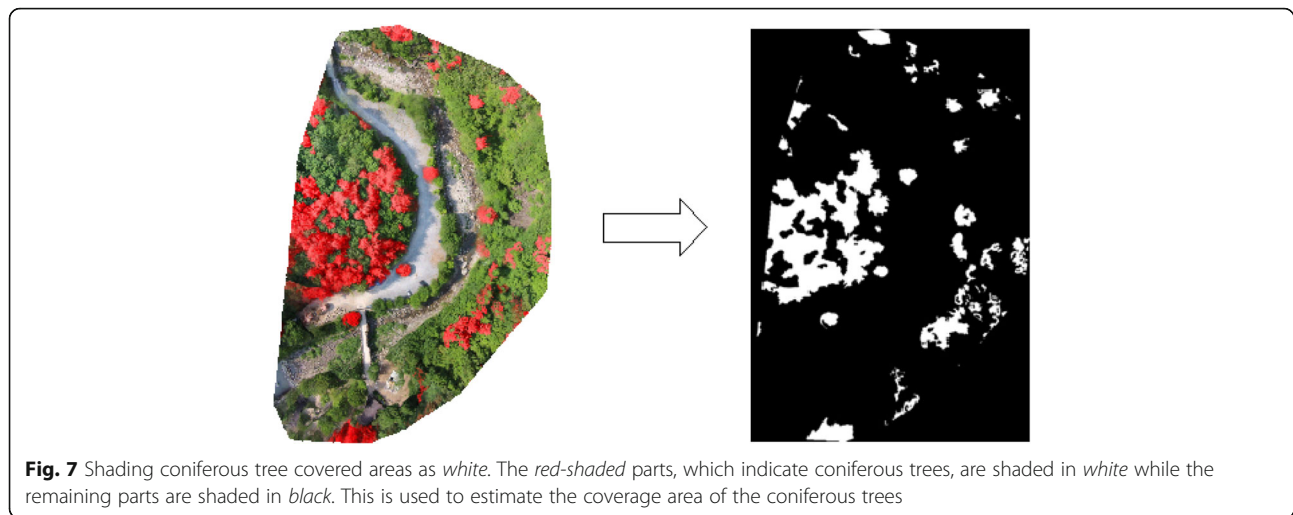
due to the subtle variation in altitude caused by wind (López-Fernández 2015). We therefore sort to a manual method of marking and calculating the coverage. Automatic detection of coniferous trees was not executed similar to the methods used by Dalponte et al. and Puerto et al. due to the unavailability of high-level image processing techniques (Dalponte et al. 2015, Puerto et al. 2015). Nevertheless, it shows promise for automation.

Utilities
The benefits of using UAV technology in ecological research applications are numerous. Phantom 2 Vision+ is
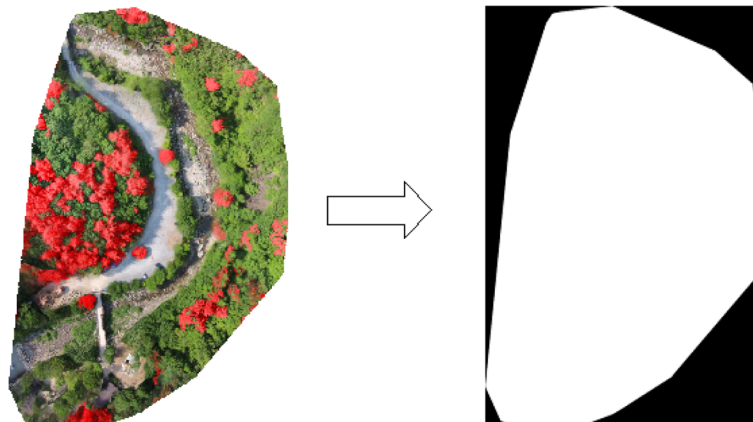
Fig. 6 Shading study site area with *white*. The study site area is shaded in *white* while the rest of the parts are made *black* using Photoshop in order to find the area per pixel using MATLAB

Ivosevic *et al. Journal of Ecology and Environment* (2017) 41:10

Page 6 of 8

Fig. 7 Shading coniferous tree covered areas as *white*. The *red-shaded* parts, which indicate coniferous trees, are shaded in *white* while the remaining parts are shaded in *black*. This is used to estimate the coverage area of the coniferous trees

a small sized, nimble and light UAV suitable for reaching the inaccessible areas for human foot. In addition, this particular UAV belongs to quadcopter UAVs whose advantage is the ability of vertical take-off and landing. Its capability to fly pre-programmed autonomous missions and acquire data on the go automatically sets it apart from the conventional methods of surveying. The bird's-eye view of the chosen study site provides a good coverage and insight of the spread of coniferous trees.
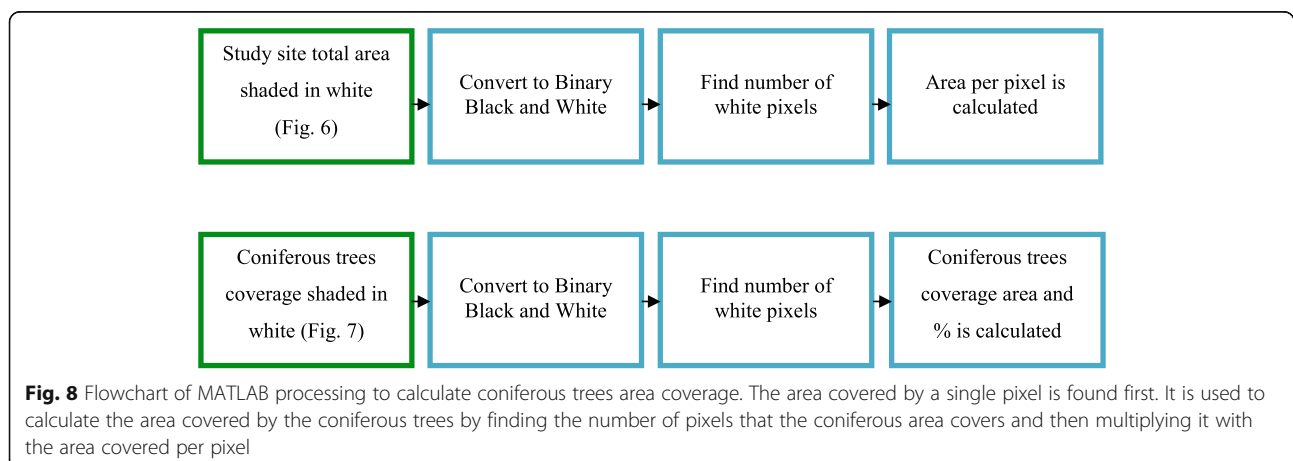
2D and 3D maps are generated from the Pix4D software automatically. They can be used to assess various terrain parameters when used in conjugation. While 2D map is preferably suitable for assessing area and distances, the 3D map gives a more realistic visual perspective. The inclusion of depth in 3D maps makes it applicable to express altitude variations within the target site. When used together, it can help to monitor changes in forest canopy and accurately position markers for applications like forest disease management, estimation of forest degradation, etc. As few as two missions could help to obtain comprehensive understanding of the

mapped area, as demonstrated in this article. Mapped area could be easily expanded by flying and connecting more missions together.

Constraints

There are several common technical issues of small UAVs such as short flight power duration, difficulties in maintaining the constant flight altitude, stability of the aircraft due to winds and turbulence and lack of GPS satellite connectivity in signal-shadowed regions leading to control loss. We were also taking into account the inaccessibility of the area due to the high density of trees, making sure to create the flight routes safe enough to mitigate the risk of possible hazards to the environment and people. Additionally, some countries require legalization and specific flight permission especially when the flight altitude and overall weight system increases (Cramer et al. 2013; Droneflight 2016). Flight missions were specially authorized by the government authorities of Korea.

One of the technological barriers for 3D map generating software at present is the quality with which it can

Fig. 8 Flowchart of MATLAB processing to calculate coniferous trees area coverage. The area covered by a single pixel is found first. It is used to calculate the area covered by the coniferous trees by finding the number of pixels that the coniferous area covers and then multiplying it with the area covered per pixel

Ivosevic et al. Journal of Ecology and Environment (2017) 41:10

Page 7 of 8

reproduce the images. The algorithms it uses average out minute details like shapes of the leaves, sand and snow (Introduction Pix4D Webinar 1 2016). A 2D map, although it has no depth perception, can retain most of the details from the images. In combination, 2D and 3D maps make up for their individual shortcomings.

Conclusions

The use of UAVs for modern photogrammetry applications has flourished over the last decade with various platforms being used to address the forest inventories (Puliti et al. 2015) and to create the forest canopy height models (Lisein et al. 2013). In this particular research, we aimed to test and analyse the automatic capabilities of Phantom 2 Vision+ with the aid of image processing and photogrammetric software.

In order to become one of the most reliable methods of data analysis both in the field of biology and those of other sciences, the UAV must satisfy certain primary criteria in order to complete its job properly, and most importantly, to be better than the currently available methods. This includes the size of its sensor, its accuracy, weight and flight duration, all of which will either enable it to stand out from other research methods, or will slow it down until a better solution is found.

Its potential to adjust its properties in data acquisition times and the affordability of image extraction could possibly result in the UAV industry surpassing the traditional aerial techniques (Zhang et al. 2012). Furthermore, UAVs could be one of the flexible tools to respond to immediate environmental data collection requirements. When it comes to area inaccessibility, as was the case in our study site, the UAV is hardly a replaceable device for obtaining the nadir picture perspective.

The UAV's potential as the next best tool in conservation biology also greatly depends on the interest of other researchers and their willingness to dedicate their time and effort into developing their own skills in using this tool for the benefit of all scientific research. Additionally, UAV developing companies also have a huge role to play if they would be willing to adapt their production plans to fit the various needs that other researchers require, instead of limiting UAVs to one particular type of flight usage. Understandably, this is something that will be developed as more interest rises in these flying machines.

In order to ensure that this message is delivered to a wider audience, mutual interaction and team work between researchers across the globe is needed so that true changes can be made to the conservation of some of the most valuable areas of our planet. The potential success of these developments has the certain ability to bring positive global changes and to enhance applications of technological advancements in ecology.

Authors' contributions
BI analysed and interpreted the image data of the coniferous tree and was a major contributor in writing the manuscript. YH mainly collected all the image data of coniferous tree with UAVs and processed the data using a 3D mapping software to analyse. OK mainly designed this work and revised the paper totally. All authors read and approved the final manuscript.

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Ivosevic *et al. Journal of Ecology and Environment* (2017) 41:10

Page 8 of 8

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