Outlook for UAVs in monitoring forest structure, health and biodiversity – operational use in Finnish forestry

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Abstract

The utilization of unmanned aerial vehicles (UAVs) based remote sensing in environmental monitoring has gained a lot of attention during the last decade due to their flexibility the generally lower cost of data compared to other types of airborne remote sensing data. Scientists are also able to collect the data by themselves, which allows more flexible timing for data collection and enables multiple flights during a growing season. Forest managers and owners are also interested in utilizing UAVs but the application of the data somewhat differs from using e.g., more traditional aerial imagery due to the small areas that can be covered with UAVs. Thus, the application of UAVs in forest management has been concentrated to small-area surveys of special interest. These may be for instance forest inventories in urban areas or the monitoring of pest insect outbreaks. Here, we will give outlook of some studies in which UAVs have utilized in measuring and monitoring forest structure, health and biodiversity. Finally, the operational use of UAVs in Finnish Forestry is discussed.

Keywords: forest structure, forest health, biodiversity, UAV, drone, forest inventory, forest management, forest monitoring, point clouds, photogrammetry, laser scanning

FOREST STRUCTURE

Measuring forest structure is a relatively easy task for UAVs and wide-range of sensors can be used from laser scanning to low-cost digital cameras (Lin et al., 2011; Wallace et al., 2012). Point clouds generated from aerial imagery obtained with an UAV have enabled characterization of forest in hight resolution (Turner et al. 2012, Dandois & Ellis 2013). Dandois et al. (2015) concluded that for characterizing forest canopy forward overlap of images obtained with a commercial multirotor UAV is the most important feature in minimizing height error of a forest canopy. Wallace et al. (2016), on the other hand, examined properties of canopy cover and layer identified with photogrammetric point clouds obtained with an UAV. The study by Liang et al. (2019) assessed the performance UAV based LiDAR using of a Riegl RiCOPTER with VUX-1UAV and compared it to the terrestrial (TLS) and mobile (MLS) laser scanning in forest structural attribute measurements. The results showed that the UAV-based technique was comparable to terrestrial techniques in easy forest conditions, but in difficult forest the terrestrial techniques. UAV-based photogrammetric point clouds have also been applied in quantifying spatial canopy structure through canopy gaps (Getzin et al. 2014). In addition to photogrammetric points clouds, UAVs have been utilized for acquiring hyperspectral data from forest areas for identifying tree species (Nevalainen et al. 2017, Tuominen et al. 2018). Studies obtained the most reliable results when both spectral and structural features from both hyperspectral imagery and photogrammetric point clouds were included in the classification. Furthermore, Saarinen et al. (2018) utilized both photogrammetric point clouds and hyperspectral imagery in generating variety of structural attributes (e.g. standard deviation in diameter of breast height and tree height as well as basal-area weighted diameter at breast height) of boreal forests. They compared the results from individual tree crown approach (ITC) as well as approach of semi-individual tree crown (semi-ITC) and concluded that semi-ITC produced more reliable results. In addition to mature forests, photogrammetric point clouds and hyperspectral imagery have been applied in characterizing density and height of seedling plots (Imangholiloo et al. 2019). UAVs have been successfully used in estimating forest structural attributes with aerial imagery and photogrammetry even without a digital terrain model (Giannetti et al., 2018; Puliti et al., 2015) and a recent study has shown that in situ measurements are not always necessary if airborne laser scanning based models are available (Kotivuori et al., 2019).

FOREST HEALTH

The detection of changes in trees and forests caused by different stressors is a more challenging task than forest structure due to the need of accurate spectral information. Recent advancements in minituarized sensor technology have decreased the size of multi- and hyperspectral sensors allowing data collection from UAVs. Näsi et al. (2015) were the first to use UAV-based hyperspectral imaging in the detection of bark beetle damage at tree-level showing an overall accuracy of 76% in the classification of healthy, infested and dead trees. Similar results were also acquired later in an urban forest area (Näsi et al., 2018). Dash et al. (2017) simulated a disease outbreak by targeted application of herbicide and found that multispectral imagery collected from a UAV could detect tree stress symptoms already in the early stages.
Klouček et al. (2019) investigated the progress and detection of a bark beetle infestation by using a time-series of RGB and near-infrared (NIR) spectral information with a modified digital camera. They found the ratio of green and red bands to provide the highest classification accuracy of infested trees. Brovkina et al. (2018) investigated the detection of tree mechanical damage and resin exudation and found that a normalized difference vegetation index calculated from the red and NIR bands showed significant difference between the damaged and healthy trees. Lin et al. (2019) combined UAV-based lidar and hyperspectral imagery with radiative transfer modelling to detect various levels of Pine shoot beetle stress. They found that the most distinct differences in reflectance between healthy and infested trees were in the red edge (660 – 750 nm) and NIR spectral regions.
The studies presented show that UAVs have high potential in the mapping of tree and forest decline caused by a variety of different stressors. So far these studies have not been very successful in detecting tree stress in the early stages of tree decline, which is important information for forest managers. Active forest management can reduce the spread of pest insect infestations with for example tree removals but timely information on tree condition is essential. The recent development of minituarized hyperspectral sensors in the longer wavelengths (over 1200 nm) in will provide interesting prospects for the early detection of tree stress since these wavelengths have shown to be the first to be affected by a spruce bark beetle (Foster et al., 2017).

FOREST BIODIVERSITY

Forest biodiversity often refers to the variety of species in a forest area. Directly detecting individual species using remote sensing is often challenging and thus remote sensing based biodiversity monitoring mostly relies on detecting indirect indicators of biodiversity, such as dead wood (Mücke et al. 2013), canopy gaps (Vehmas et al. 2011) and aspens (Säynäjoki et al. 2008). Most remote sensing based biodiversity monitoring methods have been based on aerial images and laser scanning data acquired from airplanes, although some studies regarding biodiversity monitoring using data acquired with UAVs already exist (e.g. Getzin et al. 2012, Saarinen et al. 2018, Wallace et al. 2016).

UAVs enable the collection of more accurate and frequent data compared to the conventional remote sensing platforms, the airplane and helicopter, which require a higher flying altitude and are somewhat slow to mobilize. Thus, UAVs are suitable for small-scale tasks that require frequent data collection. Such tasks regarding biodiversity monitoring could include the mapping of an area to determine what kinds of restoration actions should be performed and where. Perhaps the most potential use of UAVs in biodiversity monitoring is, however, as a substitute for field measurements.

UAVs IN FINNISH FORESTRY

The first nationwide airborne laser scanning dataset in Finland was collected between the years 2010-2019. The second round of nationwide laser scanning and aerial imaging begins in 2020 and from now on, the scanning and imaging will be repeated every 3 to 6 years. One major use of the nationwide laser scanning dataset is deriving information about forest resources. The countrywide forest resource data are derived from laser scanning, aerial imaging and field reference datasets using area-based inventory approaches (Næsset 2002). Forest resource data of privately owned forests are openly available for everyone.

How could the current state of forest resource data collection be improved with UAV-based remote sensing? RGB, multi- and hyperspectral imagery as well as laser scanning data collected with UAVs have a higher spatial, spectral and temporal resolution compared to conventional airborne remote sensing data. Thus, UAV-based remote sensing enables monitoring and mapping forest structure, biodiversity and damages in more detail. Furthermore, mapping small areas using UAVs is relatively cheaper than using the more con-ventional remote sensing platforms, such as the airplane.

UAV-based remote sensing is used operationally in Finland in the following ways:

1) Forest planning and harvesting (Mosaicmill & Simosol, Silvere): Some Finnish consulting companies have begun developing forest planning and harvesting systems based on single-tree measurements from UAVs. Mosaicmill, the pioneer in this subject, reported 30 000 hectares of UAV-based forest planning in 2019.
2) Power line mapping (Sharper Shape): UAV-based mapping and monitoring of trees close to power lines has been done operationally for several years.
3) Many large forest owners have tested UAVs for monitoring forest damages and sapling growth. However, these uses of UAVs are not yet operational.
4) UAV-based urban forest monitoring has been experimented in some areas. However, UAVs are not yet widely used in urban forest monitoring.

CONCLUSION

Development of low cost UAVs and remote sensing technologies has been explosive in the past few years. Results of UAV based forest inventories have been highly promising, and several important applications can be identified to develop new more accurate, timely, and cost efficient forest inventory services. This development is extremely important also for the entire globe in the fight against to climate change; the UAV-technologies will offer crucial information for the development of nature based climate solutions. Also business ecosystems are developing around these themes.

However, in Finland, the accuracy and relatively low cost of conventional airplane-based remote sensing has hindered the development and use of UAV-based forestry applications. The high accuracy of UAV-based remote sensing would enable transitioning from an area-based inventory approach to the single-tree level. Single-tree level inventory, in turn, is the basis for utilizing precision forestry (Holopainen 2014) in the whole wood processing chain from raw wood to a finished wood product. Thus, UAV-based remote sensing could bring significant value to Finnish forestry. So far, the use of UAV-based remote sensing has been limited to small areas and research, but the use of UAVs in operational applications will likely increase in the future. A central challenge to the more widespread use of UAVs is legislation. In Finland, the legislation states that the operator must have a direct view to the UAV at all times and the airspace must be closed for other use. These requirements complicate the UAVs for mapping larger areas. Combining UAV-based remote sensing with, for example, a harvester would create many new uses of UAVs in the future.

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