Possibilities of the Utilization of UAS (Unmanned Aerial Systems) in the Preparation of Forest Management Plans for Private Forests

Konrad Kiš[1,], Ema Svirčević[1]*

[1] DVOKUT-ECRO Ltd., Zagreb, Croatia, konrad.kis@dvokut-ecro.hr, ema.svircevic@dvokut-ecro.hr
* corresponding author
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Abstract: The management of private forests in Croatia differs from the management of state forests due to a variety of reasons. State forests have been managed for centuries and the current methodology for the preparation of management plans stipulated by the Ordinance on Forest Management mostly meets all the criteria for successful management. One of the crucial sources when drafting management plans is random samples, i.e. a certain percentage of forest surface which, regarding the forest type, varies between 2 and 7%, and based on which the parameters for forest stand are calculated. This methodology works fine in state forests of homogenous structure but is not applicable in private forests with a substantial number of owners with an average size of forest holding less than 1 hectare where a sampling intensity of 2% certainly does not reflect the true situation. Using advanced technologies like UAS with multispectral cameras and LiDAR, a new methodology for performing forest inventory in private forests could be developed, eliminating the sampling errors, and enabling insight into the factual situation, since such a survey would cover the entire forest area. Designing a reliable method for private forests using close-range remote sensing provides precise insight into real situations in private forests and enhances their management because, among other things, silvicultural measures could be prescribed for the specific area and not at the forest section level as is now the case. Also, the analysis of multispectral images provides an overview of the health state of forests.

Keywords: private forests; close-range remote sensing; forest inventory; multispectral images; LiDAR.

1 Introduction

This paper highlights the ongoing problem of regulating private forests and suggests that close-range remote sensing methods can help address it. While numerous studies exist on this topic (Goodbody et al. 2017, Dash et al. 2018, Liang et al. 2019, Ecke et al. 2022, Massey University 2022, Tomljanović et al. 2022), no universally accepted methodology has been established. Examples of successful utilization of Unmanned Aerial Systems (UAS) in forest inventory include disaster response and fire detection in Turkey (Abdurrahim and Eker 2019) and Finland (Forest.fi 2022). Another research by Gomes and Maillard (2016) shows that various hybrid algorithms using pattern recognition on very high-resolution images with an "ordinary" RGB camera can detect individual tree crowns in a forest. Despite ongoing research, no widely accepted method for conducting forest inventory using close-range remote sensing techniques has been developed. Traditional field methods are effective for state-owned forests but provide limited insights for private forests.

2 Materials and methods

To illustrate the need for new methods in preparing forest management plans for private forests, a recent forest inventory for the "Zagreb – Medvednica" management unit will be used. The inventory highlights the discontinuity (Figure 1) and variability (Figure 2) of private forests, which are often composed of small estates. This variability emphasizes the need for more accurate methods, as traditional sampling intensities may not reflect the true situation. According to Božić et al. (2022), the majority, i.e. 85.15% of private forest owners' estates are less than 20 hectares in size, assuming of course that forest management "styles" greatly differ, which even more emphasizes the variability of private forests in Croatia. In such a situation, and this pertains to the most of private forests' management units due to the composition of private forest owners' estate size, the prescribed sampling intensity of 2% does not reflect the true situation.

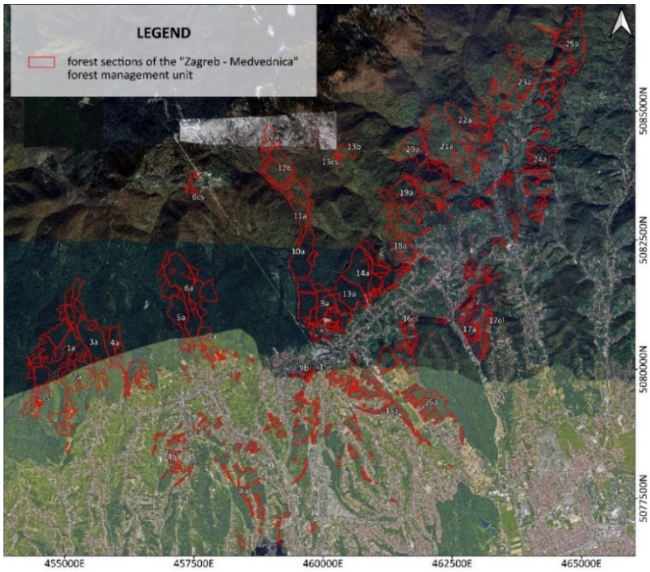

Figure 1. Private forests management unit "Zagreb – Medvednica" which depicts the discontinuity of forest sections in the observed area.

Furthermore, in situations like this where the area of interest (AOI) is utterly disjoined and scattered, it is almost impossible to apply the free-sampling method which should eliminate any researcher's bias. Often, sample points had to be offset from the original grid to fit into the AOI, which certainly increases the bias.

Figure 2. Part of forest section 17a depicts the colossal heterogeneity of private forests.

Having in mind all the facts, the conclusion is that current methods for performing the forest inventory in private forests are inadequate. The proposed methodology would comprise three major aspects:

- Scanning of the whole forest area with an airborne or terrestrial LiDAR, or both,
- Recording of the whole forest area with an RGB and a multispectral (if not even hyperspectral) camera,
- Complementary field research to determine the so-called "ground truth", i.e. confirmation of the close-range remote sensing findings.

3 Results

The major data that must be derived from the research are quantitative parameters such as tree diameter, tree height (from which volume can be determined), exact position of each tree in a stand (for future measurements, i.e. determining of increment), tree species, health status of forest and forest stand, digital elevation model (DEM) and the amount of deadwood within a stand.

When it comes to quantitative parameters, LiDAR tools are beyond doubting the best way to achieve them (Figure 3 and Figure 4). An airborne laser scanner (ALS) system is the most common type of LiDAR sensor and is the most suitable for application in forestry when compared to terrestrial and spaceborne scanners (Balenović et al. 2013). In combination with a terrestrial LiDAR which could be used for precise measurement of tree diameters, a model could be developed for the determination of a stand's quantitative parameters, although the same will require lots of machine learning and ground-truth determination.

A multispectral camera-equipped UAV can identify tree species and vegetation health within a stand. Developing a model for tree species identification via multispectral cameras requires extensive machine learning and ground-truth data across seasons. This involves significant field and desktop work but can ultimately produce an accurate model for determining stand biological features. The stand age for even-aged forests must be, though, acquired from historical data, although recent research combines LiDAR and historical data in the preparation of the stand age model (Maltamo et al. 2020). A detailed description of the habitat and stand's health should be, however, complemented via field research.

This article aims to highlight the importance and necessity of using close-range remote sensing techniques for forest inventory, particularly in private forests. As it does not pertain to a specific project or field research, it does not generate results but rather raises awareness about the potential of these methods for private forests, even in their early stages. The use of UAV-generated images (RGB, multispectral, or hyperspectral) and LiDAR (terrestrial or airborne) for forest inventory has been addressed in recent research (Lin et al. 2022, Vivar-Vivar et al. 2022, Xiong et al. 2024, Ziegelmaier et al. 2024), emphasizing the significance of these techniques and technologies in this field.

4 Discussion

Although a comprehensive methodology for forest inventory in private forests using close-range remote sensing has not yet been developed, there are compelling reasons to do so. Private forests are becoming increasingly important in Croatia due to the restitution process (Ostoić et al. 2015), which has led to a significant increase in privately owned forests (Croatian Forests Ltd. 2017). This shift highlights the need for advanced technology to streamline forest inventory processes, reducing time consumption and costs. While field observations are still necessary, the use of close-range remote sensing can greatly reduce the time and effort required, increasing overall efficiency.

Close-range remote sensing methodologies offer several benefits in private forest management:

- Eliminate sampling errors by accurately assessing the entire forest area,
- Precisely prescribe silvicultural measures for specific areas,
- Reduce costs and time consumption compared to traditional methods,
- Increase competitiveness in the market through reduced costs and improved efficiency.

It is important, however, to state the disadvantages of this method at this point – the equipment for this methodology is rather costly, and it requires significant hardware resources to process a large amount of data. This can, however, be resolved by renting external hardware resources (cloud) where data can be easily and effectively processed, saving valuable time. Also, substantial time and financial resources will be required for the training of the staff.

5 Conclusions

Numerous studies and research have been and are still being conducted regarding the use of UASs equipped with LiDAR, multispectral, or hyperspectral cameras (Lin et al. 2022, Fassnacht et al. 2024, Xiong et al. 2024, Ziegelmaier et al. 2024), however there is still no holistic, comprehensive methodology for fully performing a forest

Figure 3. 3D model of an old oak stand taken by a DJI R300 drone equipped with an airborne LiDAR head, generated from point cloud (courtesy of "Croatian Forests" Ltd.).

Figure 4. 3D model of an old oak stand taken by a DJI R300 drone equipped with an airborne LiDAR head, generated from a point cloud with a graduated symbology of the height above sea level (courtesy of "Croatian Forests" Ltd.).

inventory. To develop one, future studies should be aimed at developing the methodology for deriving the wood volume of each tree from the LiDAR point cloud and determining tree species from multispectral and hyperspectral imagery, thus providing most relevant data for performing the forest inventory and preparation of the forest management plan.

Cutting-edge technology is particularly useful in private forest management units due to its ability to eliminate sampling errors, reduce costs, and increase efficiency. It allows for precise silvicultural measures and enhances competitiveness in the market. Although a comprehensive methodology for private forests does not yet exist, the benefits are too compelling to ignore, and it is only a matter of time before it is developed.

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