

APPLICATION OF MULTISPECTRAL SENSOR AND SMALL UNMANNED AERIAL SYSTEMS FOR EARLY DETECTION OF STRESS IN FOREST STANDS OF WESTERN SERBIA

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Abstract

The main goal in the sustainable forestry is to achieve healthy forest stands which will be passed on to the next generations. Healthy ecosystems and economies rely on high-quality forests. Massive forest decline has occurred in many countries in the last several decades caused by high-number of pest infestation induced by draught and climate change. After the trees have been already physiologically stressed, pests come as the secondary infestation. Many forest pests are capable of devastating the entire forests. In the forest health protection, the key of success is to prevent major pests to breed in high number, as well as early detection of symptoms invisible to the naked eye. The object of study chosen for the application of the multispectral sensor mounted on unmanned aerial system (UAS), were coniferous forest stands, located at Mt. Kopaonik, W Serbia. Utilization of the multispectral imagery have provided us with sufficient information on the forest health and vigor. This was the first application of 5-sensor high-resolution multispectral imagery for the identification of stress of forests in Serbia. Through applications of algorithms and vegetation indices, it was possible to identify not only the dead trees in the remote and hard-to-reach areas, but also the trees which were still physiologically active, but possibly threatened by pests, although without any visible signs of health problems. The results of the study proved that the use of the multispectral sensor and small UAV has in early detection of stress for purpose of improving the health of forest ecosystems were justified.

Keywords: *Remote sensing, Forest protection, Early detection, Forest pests, Multispectral camera.*

Introduction

Due to the climate changes, extreme climate conditions, and extended periods of drought, many forest stands have been diagnosed with a decline of health and productivity. As a modern phenomenon, desiccation of mainly autochthonous spruce stands is present in most countries of Central and Southeastern Europe (Tabaković-Tošić, Milosavljević, 2018). Classified as a national park, Mt. Kopaonik, with over 1600 plant species and its valuable coniferous forest was of special interest. It is situated in western Serbia, with the highest peak of 2017 meters above sea level, and the total area of the national park of 121.06 km². Mt. Kopaonik has a subarctic climate, with snow season lasting from November to May. In spite of abundant amounts of snow, the latest observations showed many issues with mortality of large areas of native woodland. The physiological stress caused by drought made individual conifer trees and entire areas suitable for pest infestation which furthermore caused devastation of wide areas. Many of those areas on Mt. Kopaonik suffered from both drought and secondary pest infestations.

During 2018. salvage logging was done in the areas identified with total loss of vitality of groups of trees, and in areas infested with two species of bark beetle - *Pityogenes chalcographus* L. and *Ips typographus* L. In total 11,330 m³ of wood was removed.

Another important effect bark-beetle infestation is the production of fuel for wildfires. The changes in foliage chemistry and reduction of moisture increase flammability of the tree and reduces heat requirements for ignition (Jolly *et al.*, 2012).

Use of modern technology would allow precise identification of areas not only already infested, but also the areas prone to the infestation. This information would increase the effectiveness of prevention measures. Two study areas were chosen for this research.

The purpose of the study was testing the combination of small Unmanned Aerial Systems (sUAS) and ground-truthing for early detection and identification of apparently healthy, and physiologically active trees, that may be prone to the secondary infestation. This was the first application of sUAS in combination with 5-band multispectral imagery in forestry in Serbia.

Materials and Methods

Remote sensing approach chosen for study areas consisted of multispectral and RGB sensors mounted on small Unmanned Aerial Systems. The multispectral sensor was MicaSense RedEdge M. This multispectral sensor consists of 5 individual sensors, each capable of taking images in a single discreet narrow band. Medium wavelengths for sensors are: Blue (475nm), Green (560 nm), Red (668), Red Edge (717nm), Near Infrared (840nm). The resolution of each sensor is 1.2 Mpix. The multispectral sensor is also equipped with its own GPS and magnetometer module, and Downward Light Sensor for correction of sensor exposure during the flight. Before and after each flight, the calibration images were taken by a multispectral sensor. Images of calibration panel with predefined spectral values are used during the processing of the images so that sensitivity to different light conditions of reflectance values in the resulting orthomosaics are minimal. All images used from the multispectral sensor were in 16-bit TIFF format. RGB sensor has a standard Bayer pattern sensor for taking images in the visible part of the electromagnetic spectrum. It has a resolution of 20 Mpix, and the sensor was mounted on 3-axis gimbal. Small UAS used as a carrier platform for both sensors was quadcopter DJI Phantom 4 Pro. Both sensors were mounted simultaneously while sUAS was airborne. Flight altitude of first flights was 100m above ground level (AGL), above the point of take-off, while the second area was imaged from 80m AGL. The altitude remained constant throughout the flight – aircraft did not follow terrain change. The first study area was mapped in automatic flight mode via 3rd party professional UAS surveying app Datufly, while the second flight was flown manually, due to the combination of environmental factors – flight altitude, the height of trees, high wind velocity, and area of coverage.

Imaging was done in the middle of the April, and there were patches of snow still present on the ground but canopies were 100% clear and visible. Processing of the images was done in professional photogrammetry software Agisoft Metashape

Rationale

Multispectral imaging has been in use for over 60 years in agriculture and precision agriculture. Reflectance values have been related to vegetation characteristics such as plant biomass or fraction of intercepted photosynthetically active radiation (Barnes, Clarke, Richards, 2000). With recent improvement and development of technologies, the sensors became more compact, and in combination with small UAS, it provided the opportunity to transfer knowledge and technology into other industries. In forest inventory mapping high-resolution multispectral imagery became an essential, and an often critical tool for effective forest management (Moskal *et al.*, 2002). Many technologies and innovation transcended from agriculture to forestry. The same vegetation indices, developed for estimation and quantitative evaluation of crop health, are also used in forestry.

Since bark beetles can affect large spots in hard to reach areas, remote sensing is the most promising way to cover large areas, identify the potential infestation, measure it and provide information for future decision making (Stoyanova *et al.*, 2018).

Vegetation indices (VI) are a mathematical algorithm based on digital brightness (spectral) values. Those values are added, subtracted, divided and multiplied to yield a single value that indicates the amount of vigor of vegetation in pixel. High values of VI corresponds with the areas covered by a substantial amount of healthy vegetation (Cambell, Wynne, 2011).

High-resolution multispectral imaging is the latest tool used in forestry to prevent wide area pest infestation and devastation. Five narrow band individual sensors allowed the application of multiple vegetation indices:

- NDVI – Normalized Difference Vegetation Index
- NDRE – Normalized Difference Red Edge

NDVI is the most widely used VI. It represents the band ratio of two spectral behaviors with inverse relationship – absorption of Red light by chlorophyll, and strong reflectance of Near-Infrared light by mesophyll tissue. Physiologically active and growing plants have high values of NDVI, whereas bare lands, water, snow, man-made objects, and dry vegetation have low index values (Cambell, Wynne, 2011).

NDVI values are calculated through formula:

$$\frac{R_{NIR} - R}{R_{NIR} + R}$$

R_{NIR} – Reflectance values in Near Infrared band

R_{RED} – Reflectance values in Red band

NDRE is the modification of the NDVI which uses Red Edge portion of the electromagnetic spectrum instead of RED light. Due to the longer wavelength, it is capable of penetrating deeper in the canopy, thus providing more relevant information on the health status of a plant, and it is more sensitive to the chlorophyll status than indices relying on RED. Using the information from Red Edge part of the spectrum has the potential to significantly improve forest stress monitoring (Eitel *et al.*, 2011) and NDRE is potentially the best index for forest stand assessment since it is less sensitive to the changes in different study area parameters (Modzelewska *et al.*, 2017)

NDRE values are calculated through formula:

$$\frac{R_{NIR} - R_{EDGE}}{R_{NIR} + R_{EDGE}}$$

R_{NIR} – Reflectance values in Near Infrared band

$R_{RED\ EDGE}$ – Reflectance values in Red Edge band

Both indices have a range of values from -1 to +1. Vegetation index values are represented through color-coded thematic maps for easy visualization. To increase visibility HEAT palette was used with high levels of the index in red color, while low levels were in blue.

Study areas

For this research two study areas were chosen. Before the application of sUAS, both areas were surveyed by personnel of the Institute of forestry, and health status of each area was diagnosed by routing and random sampling methods.

The first study area (management unit Samokovska Reka, forest compartment 114/d) had a total area of approximately 35 ha. It consists of tall spruce trees of various ages. Maximum terrain altitude was 1530 m a.s.l., while the minimum was 1440 meters. The forest was predominantly coniferous, with no, or very little signs of desiccation. Majority of forests were situated in the lower parts of the study area. There was no predefined area of interest, the entire area was imaged with both sensors and multiple vegetation indices we applied.

The second area (management unit Samokovska Reka, forest compartment 95/b) had a total area of approximately 2.3 ha, and altitudes form 1540 – 1570m a.s.l. This area was heavily affected with infestation with a lot of dry and fallen trees, surrounded by apparently healthy vegetation.

Imaging of both study areas took approximately 30 minutes in total.

Results and Discussion

The products of the imaging and processing were dense point cloud, digital elevation model (DEM), and ortho-mosaics. We have produced both RGB (Figure 1) and vegetation indices (Figure 2 and Figure 4) orthomosaics. High resolution of the images provided orthomosaics with a resolution of approx. 3.4 cm/pixel for RGB and 8 cm/pixel for multispectral. This allowed the application of indices not only on tree level but also on parts of the trees.

Mapping of both study areas showed several areas with daed trees which are easily visible even in the RGB orthomosaic. However, the purpose of this research was not the identification of already dead trees, but the identification of the areas that will present the future potential of infestation. Also, the areas of dry trees provided a good starting point for ground-truthing. Especially interesting were areas in the vicinity of dry trees with individuals and groups of trees with medium to low VI values.



Figure 1. Study area 1 – RGB orthomosaic

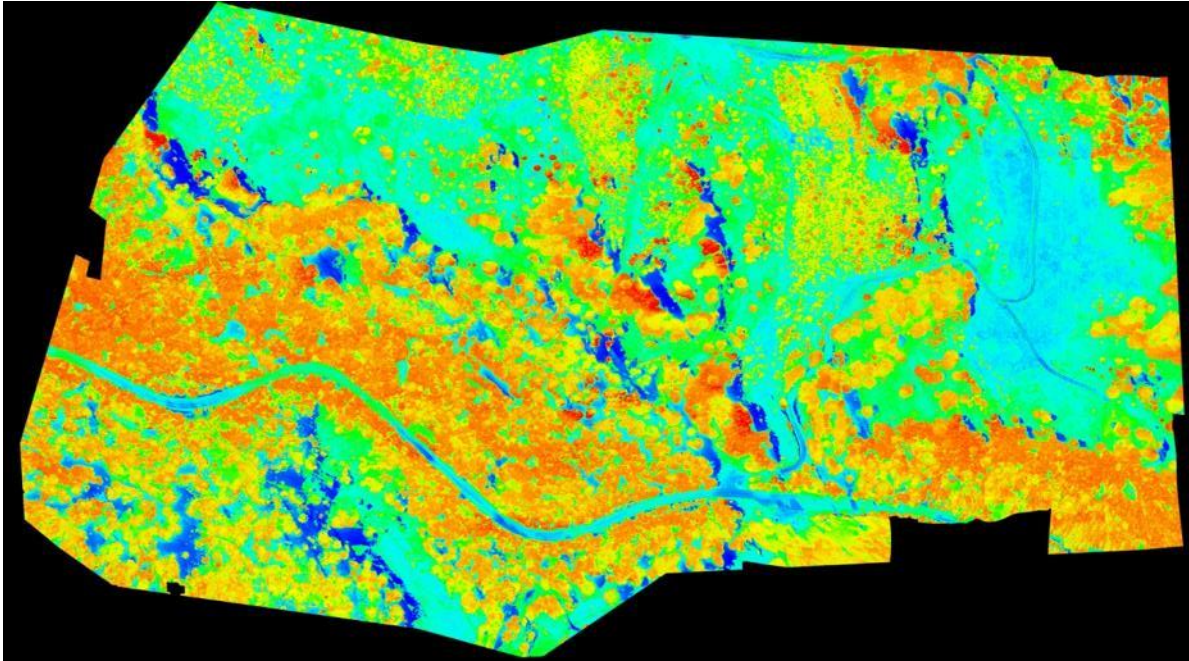


Figure 2. Sturdy area 1 – NDVI index

Application of the NDVI vegetation indices showed several areas with lower index values that in the RGB orthomosaic looked healthy and physiologically active (Figure 3). Aerial imaging also showed exact locations of dead and fallen trees, which have remained in the forest. Terrestrial (*in-situ*) observations confirmed the poor state of the stand with a high number of dying trees, with the presence of fungi, and old entering and exiting holes of bark beetle. To the poor health of the forest has also contributed poor extraction of the dead and fallen trees which could serve for development and rapid multiplication of highly aggressive xylophagous insect pests (Dimitrov *et al.*, 2019).

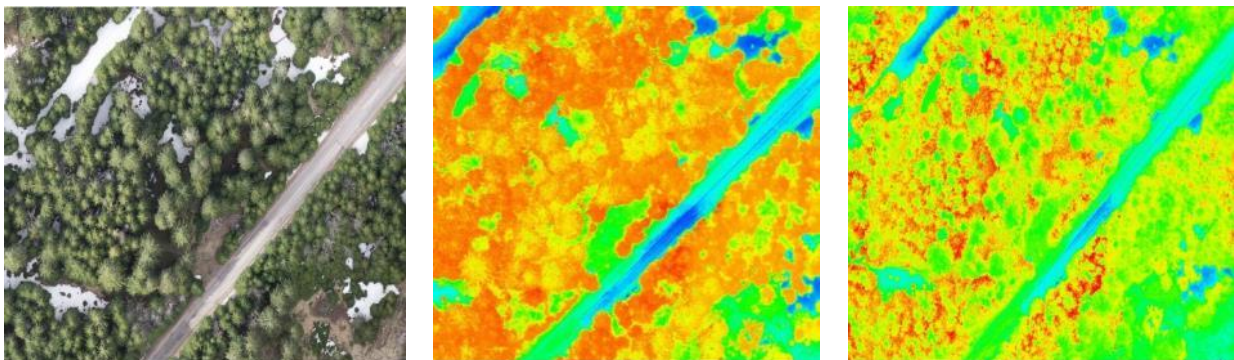


Figure 3. Study area 1 – comparison of same area in RGB, NDVI, and NDRE maps

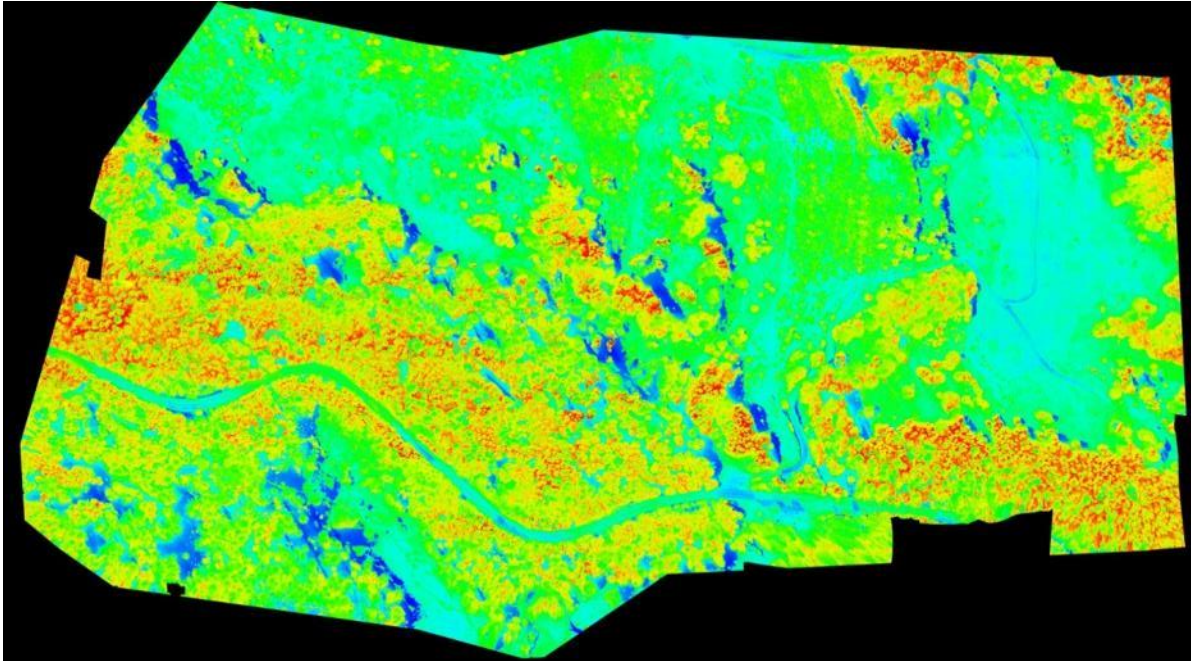


Figure 4. Study area 1 – NDRE index

Application of NDRE vegetation index confirmed NDVI map, but it also showed more dramatic status with more pronounced low levels of the physiological activity of vegetation as shown in Figure 5. Since this was the first imaging early in the spring, another imaging in the summer should add more data to this first map. It should also provide more information on the physiological activity of the trees. NDRE showed many areas and trees with low index values. Regular imaging and application of NDRE index have the potential for providing relevant information on the health status of the forest throughout the year. Especially since indices relying on NIR and RED tends to saturate at medium to fully developed canopies (Xie Q *et al.*, 2018).

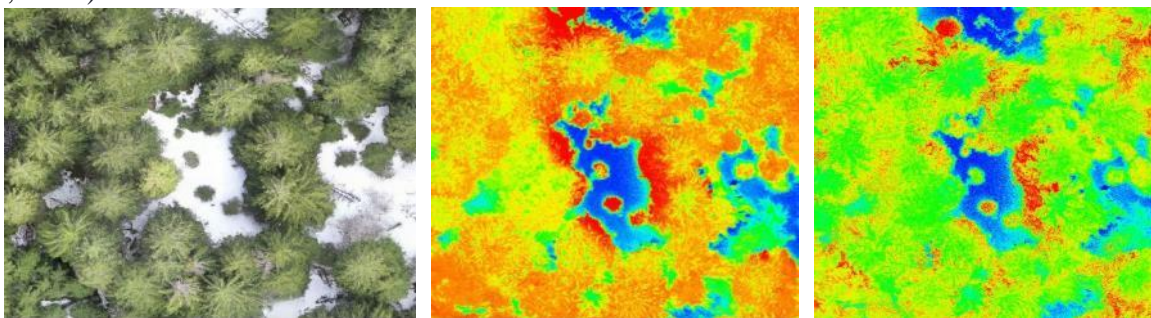


Figure 5. Part of study area 2 – from left to right - RGB, NDVI, NDRE

Conclusion

Use of small unmanned aerial vehicles equipped with RGB and multispectral sensors are a fast and easy tool for acquiring the high amount of precise information which can be used for assessment of health status of vegetation, identification, and geolocation of the problematic areas. This kind of imaging can be used as a foundation for further land cover classification for field-work and forest care planning. This kind of high-resolution imaging provided high levels of details, in 2D and 3D color-coded multispectral vegetation indices. All processing and assessment were performed on a pixel level. Future exploration of this technology would require a comparison of these results with object-based classification, alongside further and continuous ground-truthing to provide the most reliable information.

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