UAV-based Technologies for Remote Sensing in Environmental Monitoring and Physical Resilience Assessment

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Abstract: Multispectral sensors have been shown to be effective in the identification of different components of the environment, showcasing opportunities for their use in the maintenance and improvement of the ecosystem services' quality and the sustainable use of natural resources. Moreover, main current outcomes include: 1) Integration of the *eALERT* platform for real-time environmental monitoring and instant warning, and LiDAR technology into a complex, advanced monitoring and surveillance platform; 2) Development of physical technologies with the unmanned aerial vehicles (UAV) application in monitoring and precise quantitative analysis of critical infrastructures. Software application is used in connection with the UAV-based measuring station for computational modeling of environmental factors, which facilitates the analysis and interpretation of the monitoring results.

Keywords: UAV; natural and artificial ecosystems; critical infrastructure; fluorescence analysis; sensors.

1 Introduction

Currently, modern technologies witness a vertiginous expansion, being widely used in various human activities by providing a solid support in decision-making for monitoring and evaluating the state of natural and artificial ecosystems (Sandbrook 2015, Yang et al. 2017). In this context, our systemic approach is inspired by the interdisciplinary applications, computational modeling of environmental factors, UAV-based 3D mapping through Pix4Dmapper photogrammetry, etc. The application of modern intelligent technologies allows for the first time the implementation of a national complex system of exact monitoring of environmental factors with the application of UAVs through modern optical methods and different types of real-time sensors. The obtained results facilitate formulation of scientifically based recommendations regarding the adjustment of technological processes with the aim of reducing the effects of atmospheric pollution, soil surface degradation and the instability of urban and natural ecosystems (Sprincean et al. 2023). Also, the monitoring of some natural and artificial ecosystems in the Orheiul Vechi Natural-Cutural Reserve protected area aims at providing data for the analysis of biological variables with a decisive role in ensuring the sustainability of ecosystems (Birsan et al. 2023).

2 Materials and methods

An integrated UAV-based system composed of a drone, measuring station and a dedicated software application was developed and used for exact monitoring and computational modeling of environmental factors, such as PM-pollution, organic compounds, formaldehyde, hydrogen chloride, hydrogen cyanide etc. DYS D800 X-8 professional multi-rotor aerial photography and heavy lift platform comes prebuilt from high quality metal and carbon fiber components simply (Figure 1). Flight controller and cameras package are added

to make up professional standard aerial monitoring platform. As shown in Figure 1, HD camera (1) to control the flight and visualization of the objects under study, the Survey3 multispectral camera (2) and laser emitter (3) are installed on the DYS D800 X-8 drone platform. The drone

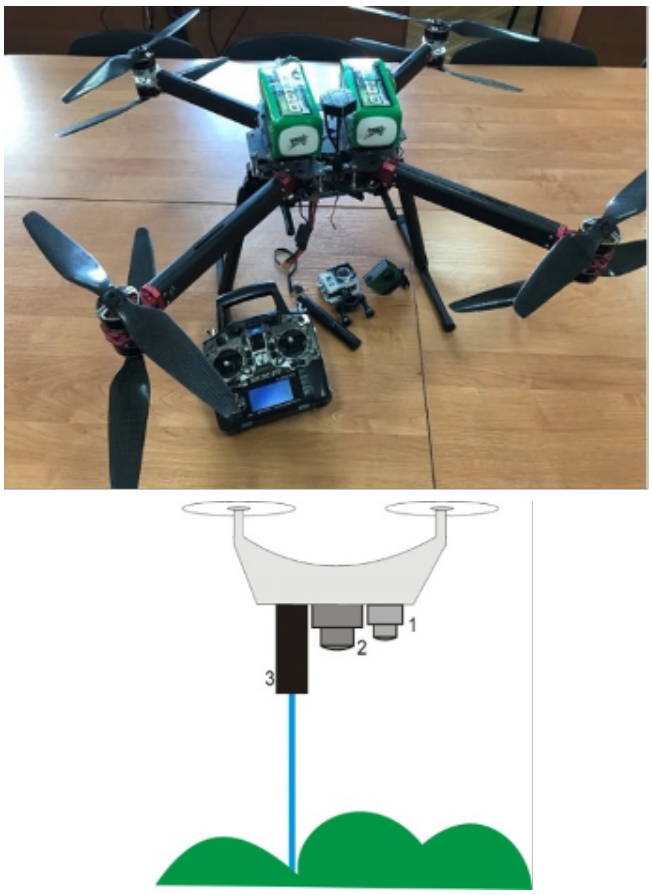

Figure 1. Drone-based technique used to record the fluorescence of plants under the remote laser excitation.

flies above the crowns of trees and with the help of camera (1) the object is selected for research, after which the multispectral camera (2) is switched on and the beam of laser (3) is pointed in direction of the object under study.

Also, the additional system functionality consists of air quality monitoring with dust and gas sensors, measurement of environmental conditions, real-time data recording in the cloud and measuring station, data recording in the form of HD movie with measurement parameters streamed online, measurement data streamed to a computer by using remote multi-channel communication Wi-Fi or GSM, and data from any period with measured parameters saved on the station and cloud service. The choice of vegetation index for plant monitoring depends on the biological peculiarities of the species, as well as on the developmental stage of the plants. Software application for computational modeling of environmental factors in connection with this measuring station, which facilitates the analysis and interpretation of the monitoring results, has been developed as an integrated mobile system for exact monitoring and computational modeling of environmental factors. Figure 2 shows an example of the performed 3D mapping and the monitoring data processing.

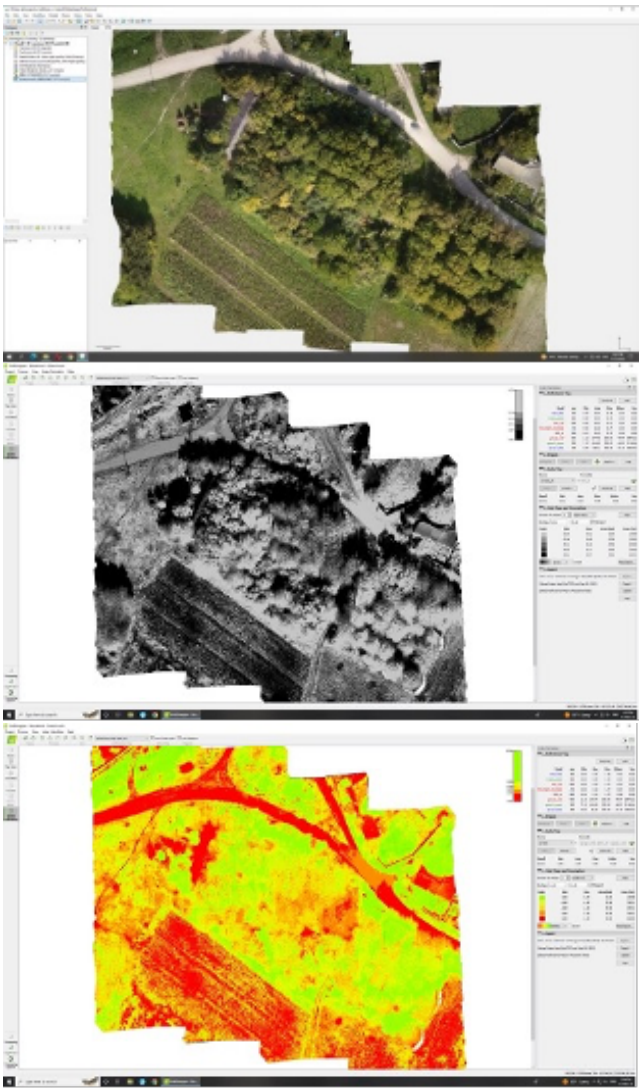

Figure 2. Digital 3D mapping and data processing.

Monitoring of the cultural-natural heritage is the basic condition for the conservation of the Orheiul Vechi reserve ecosystem. For this reason, the identification of ways to monitor the protected area with the help of advanced technologies, based on UAV, represents another innovative approach. Multispectral indices to monitor vegetation, such as Normalized Difference Vegetation Index (NDVI), are applied. The research regarding the analysis of the spectral features of the vegetation in the Orheiul Vechi protected area was carried out at the stage of senescence. So, the phenology of plants varies significantly due to the coloring of foliage, the differences being more pronounced, which allows the differentiation of plant categories and their health.

3 Results

The drone-based technique was used to record the fluorescence of plants under remote laser excitation (Figure 3). The study of fluorescence spectra of plants makes it possible to assess their condition based on the chlorophyll content in plant tissues (Wang et al. 2017). Laser radiation sources with wavelengths of 405 nm and 450 nm are applied. Changing the spectral dependence of fluorescence makes it possible to detect plant diseases at early stages. Photoluminescence spectra for the leaf samples of peach, apple, plum and grapevine have also been excited with ultraviolet (UV) radiation of wavelength 337.4 nm and violet radiation of wavelength λ=405 nm. The edge of the absorption band is approximated with the limiting wavelength of the diffuse reflection coefficient $R_d(\lambda)$ from which R_d reaches the saturation threshold. Photoluminescence spectra were recorded with spectrophotometric equipment with a high optical power monochromator of type MOR-2. Also, diffuse reflection and photoluminescence spectra are investigated for soil and leaf samples collected at different stages of development.

Figure 3. Laser radiation images with wavelengths of 405 nm (left) and 450 nm (right).

Apart from highlighting the presence and state of vegetation, the multispectral data obtained in the near infrared region provided the possibility of identifying the main elements of the studied area: roads, houses etc., and allowed their classification into four main classes of land use/coverage: 1) land covered with spontaneous vegetation (grasses, shrubs, and trees); 2) cultivated agricultural land; 3) land devoid of vegetation; 4) land with constructions. The remote sensing method allowed for the highlighting of the areas covered with vegetation not only in the populated area, but also in the areas covered by spontaneous vegetation, as well as on agricultural land.

Biophysical, biological and structural parameters of the vegetation can be extracted from the remote sensing data. Thus, based on the degree of reflection of the electromagnetic radiation, the comparison of images shown in Figure 4 denotes the presence of plants with different degrees of vitality. The shades of light gray to white, in the right image, attest the existence of plant species with a well-developed crown, an abundant biomass and increased chlorophyll content. We would also like to mention that the information obtained with the help of remote sensing regarding the floristic structure and composition is extremely valuable for the inventory of protected areas, the interaction of biotic and abiotic components largely resulting in many other characteristics of ecosystems.

Figure 4. The health status of plants is assessed using the multispectral device. Images are taken with the RGB and NIR camera, respectively.

4 Discussion

The proposed technique is combined with the *eALERT* platform for real-time environmental monitoring (https://ealert.md) and the UAV-based collection of airborne pollutants followed by their fluorescence spectral measurements. This has been proved to be useful in studying air pollution due to the small size and weight of our pollutants collection device. The use of drones allows particle collection at various altitudes and over extended areas, which may be difficult when applying other methods (Shi et al. 2015). Collection time is subject to the drone flight time and does not depend on the air flow rates. Automated flight paths combined with LiDAR and other sensors provide a faster, safer, more accurate, and cost-effective solution. Moreover, the remote sensing technique can be extended to the physical security and critical infrastructure protection, in particular to the protection of critical infrastructure elements with a focus on energy, transport and ICT. Moreover, the security threats can be mitigated by applying an integrated approach including organizational aspects, training, technologies for monitoring, modeling, and UAV-based surveillance to enhance the capacity for physical resilience in critical entities (Zhang and Zhu 2023).

UAVs have already become an affordable and cost-efficient tool to quickly map a targeted area for many emerging applications in the arena of ecological monitoring, biodiversity conservation, and agriculture (Díaz-Delgado and Mücher 2019, Victor et al. 2024). The development of the UAV-based methods used for vegetation monitoring is fascinating (Wallace et al. 2012, Yang et al. 2020, Hassan et al. 2021). The vegetation stage of the leaves and their type can be determined both by the edge of the diffuse reflection band and the numerical value of the diffuse reflection coefficient in the slope region of the dependence $R_d(\lambda)$. When the leaves are excited with the UV radiation, the samples emit photoluminescence bands with intensity maxima at certain wavelengths characteristic of their vegetation type and stage. One can also mention that some indices, being used independently, provide sufficient information for plant monitoring during most of the growing season. However, since the life cycle of plants includes several distinct stages, to be more informative, the indices used in monitoring plants at different stages of development require adjustments or can be used in combination with other variables. From the multitude of biological variables, the chlorophyll content represents the most important parameter in the evaluation of the physiological states of plants. Assessment of plant photosynthetic performance based on the reflectance measurements with high spectral resolution has shown a strong ability to detect fine variations in spectral absorption features related to the chlorophyll changes.

5 Conclusions

The advanced technologies of remote sensing, together with the traditional methods and procedures of data collection evaluated by direct observation and analysis, are of real help for solving the problems of natural and artificial ecosystems related to the environmental protection and biodiversity conservation. The use of drones in ecosystem monitoring offers numerous benefits, contributing to the efficient management of ecosystem resources, the timely identification and management of environmental problems, the sustainable agricultural development as a result of monitoring plant health etc.

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