A Lightweight UAV-based Spectroscopic System for Water Quality Monitoring in Mining-Impacted Environments

Setup, Data Processing, and Validation

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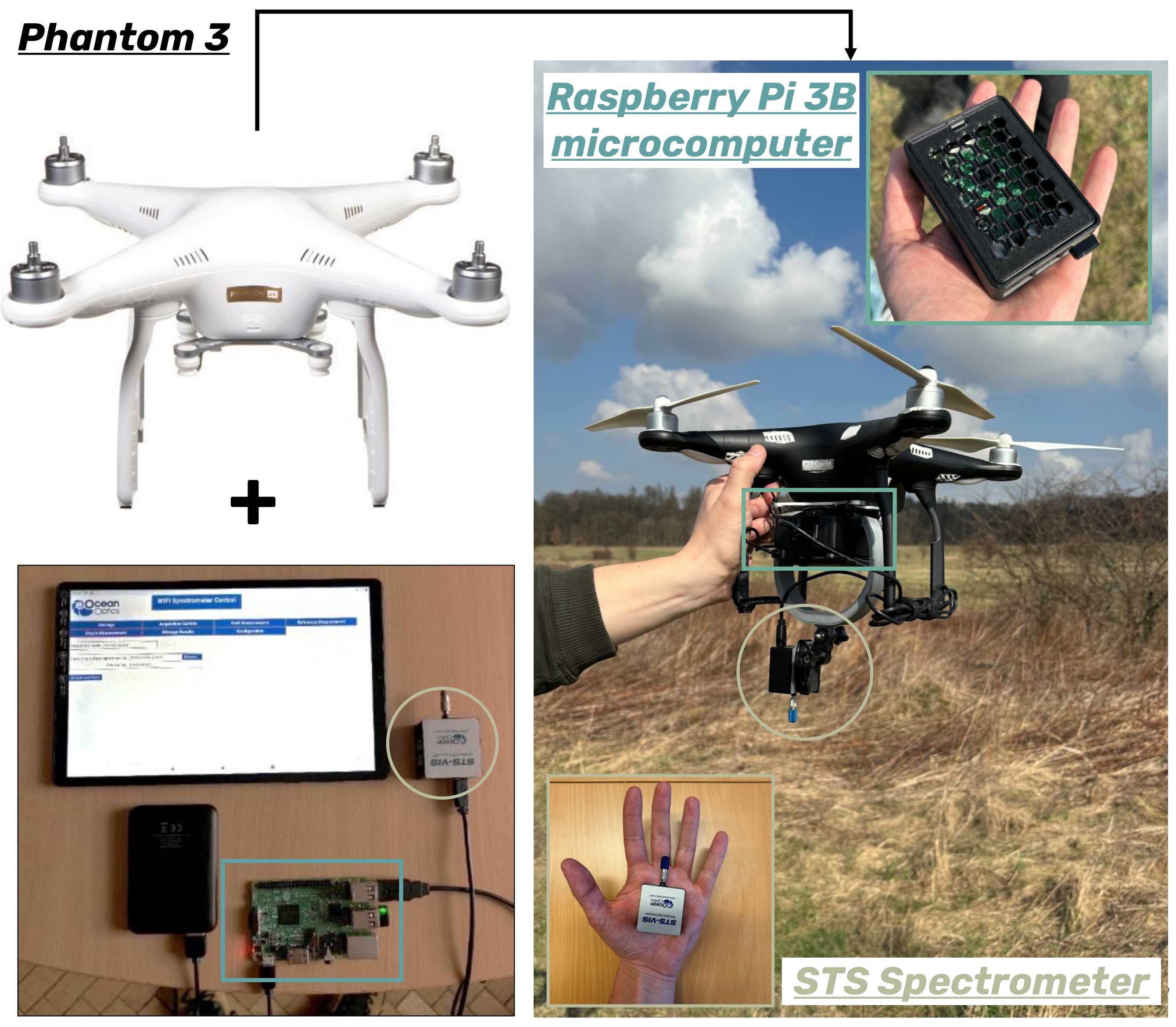
Abstract

Monitoring water quality in areas affected by mining activities requires high spatial and temporal resolution data, which remains a challenge for traditional methods. We present a novel, cost-effective instrumental setup using a small-scale lightweight Ocean Optics STS-VIS spectrometer mounted on a DJI Phantom 3 Advanced UAV via a custom 3D-printed holder. Tested across diverse mining regions in Greece and Spain, the system achieved a high spatial resolution of 1.2 m per measurement. Focusing on total suspended solids (TSS), our processing workflow integrated Savitzky-Golay filtering and Partial Least Squares Regression (PLSR). The results demonstrate that optimal data acquisition—specifically utilizing up-stream flight geometries—provides a robust, high precision alternative for monitoring TSS in mining impacted environments.

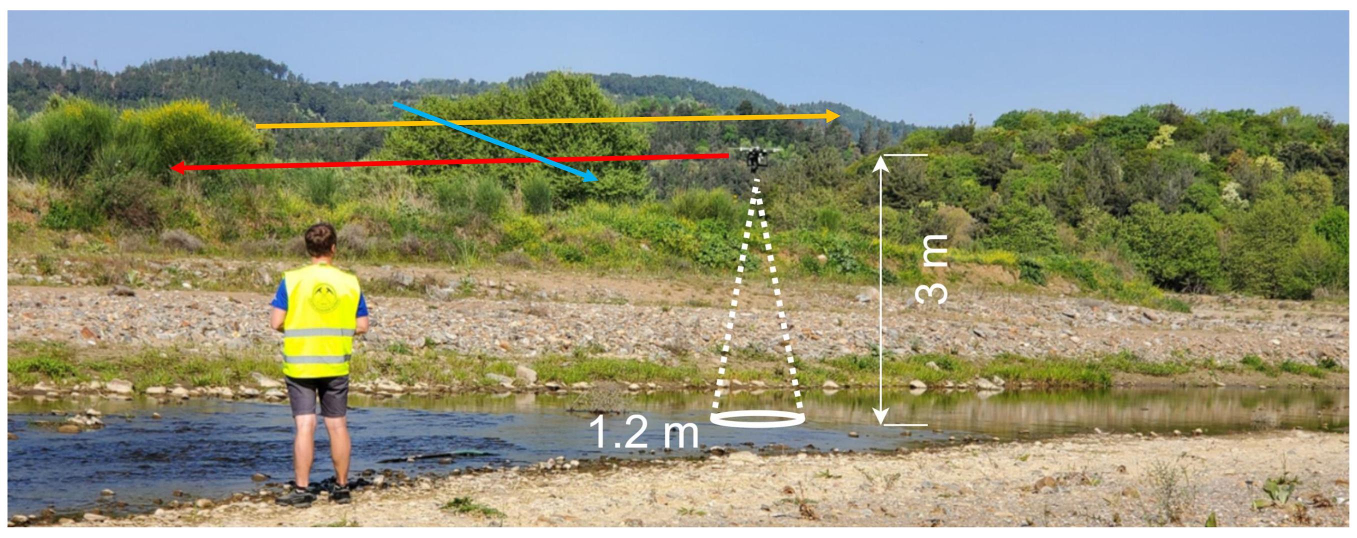
Key words: UAV, hyperspectral, field spectroscopy, surface water quality, mining, PLSR, Greece, Spain

Materials & Methods

- OceanOptics STS-VIS microspectrometer
- 40 x 42 x 24 mm • 337–823 nm • 1.2 nm spectral resolution
- controlled via a Raspberry Pi 3B microcomputer
- custom 3D-printed mount



- the altitude of 3 m • ground footprint of 1.2 m
- flights over flowing waters followed up-stream
- down-stream • diagonal transects



Conclusions

This research establishes a reproducible methodology for using low-cost, high-resolution UAV hyperspectral systems to monitor mining-impacted surface waters. The findings demonstrate that combining precise spectral smoothing (SGF window size 132) with targeted flight geometries—specifically, up-stream trajectories for TSS retrieval—is vital for mitigating inherently weak water signals and dynamic surface artifacts. This workflow transforms lightweight spectroscopic tools into reliable, high-precision instruments for tracking aquatic contaminants in logistically challenging environments .

Introduction

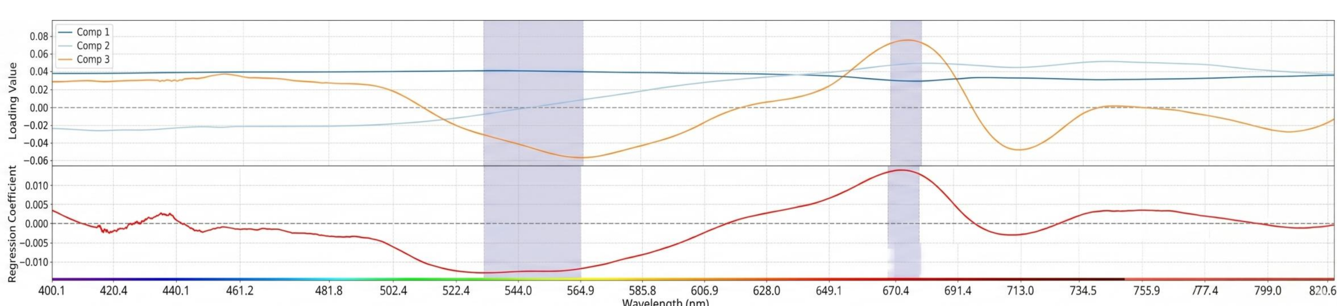
Monitoring the optical properties of surface waters is fundamental for assessing water quality and managing aquatic ecosystems, especially in regions heavily impacted by mining activities and acid mine drainage (AMD). Conventional sampling is often hazardous, and airborne or satellite systems remain constrained by relatively coarse spatial resolution. Hyperspectral imaging offers the continuous, narrow spectral bands required for precise quantification, but water leaving radiance is inherently weak, often contributing less than 10 % of the total radiance received at the sensor. This study validates a lightweight, UAV-based microspectrometer system designed to mitigate these challenges, allowing targeted data collection over narrow aquatic systems to quantitatively retrieve TSS.

Spectral Preprocessing and Modeling

Extracting accurate reflectance from a moving UAV platform is technically demanding due to high-frequency noise and electronic artifacts. To reveal diagnostically important features, raw spectral intensities were converted to reflectance and a Savitzky–Golay filter (SGF) was systematically tested. For TSS retrieval, a broad SGF window size of 132 with a 2nd-order polynomial was identified as optimal, effectively suppressing noise while preserving signal integrity. Following the removal of statistical outliers and non-water spectra, the relationship between the processed spectra and laboratory-analyzed water samples was modeled using Partial Least Squares Regression (PLSR) and validated via Leave-One-Out Cross-Validation (LOOCV) .

Results

The performance of the PLSR models demonstrated that acquisition geometry is a critical factor for accuracy. For TSS estimation, acquiring data along a single up-stream flight trajectory proved superior, generating a robust model with calibration and validation accuracies of R^2_{cal} = 0.782 and R^2_{val} = 0.634 . This up-stream orientation actively minimizes specular reflection (sun glint) and high-frequency surface turbulence. Spectral analysis via PLSR x-loading weights and regression coefficients revealed a pronounced negative correlation in the green region (540–590 nm), reflecting the suppression of the green reflectance peak as TSS increase. Conversely, a significant positive peak emerged in the red-edge region (670–680 nm), which aligns with the enhanced backscattering properties characteristic of high suspended particle loads.



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