DEPLOYMENT OF UAVs WITH SPECTRAL SENSORS FOR REAL-TIME COASTAL MONITORING

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ABSTRACT

The complex coastal environment poses many logistical challenges for the deployment of Unmanned Aerial Vehicles (UAV) for real-time monitoring of marine operations, such as land reclamation. One of the challenges is the difficulty during calibration in synchronizing the images acquired by UAV spectral sensors and ground-truth measurements due to a time delay factor. In particular, these discrepancies generate significant outliers in the correlation between water leaving reflectance and turbidity, resulting in inaccuracies in model prediction of turbidity distribution (Kieu et al., 2023). This study focuses on streamlining the logistics during calibration to minimize this time delay factor, thereby enhancing data calibration accuracy.

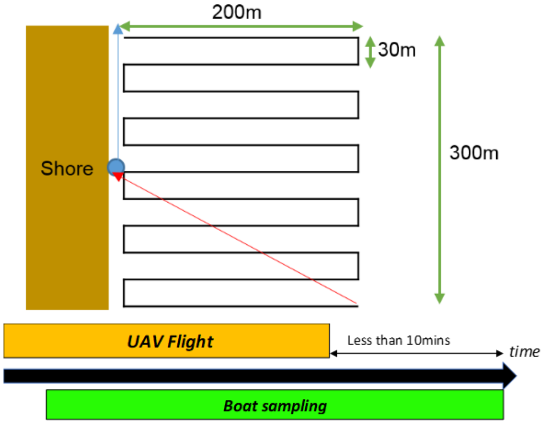


Figure 1: (a) UAV flight pattern and (b) operation protocol adopted in the coastal environment.

A framework for coastal field deployment of UAVs which includes permits and licenses acquisition, weather monitoring, contingency planning, field coordination during the UAV surveys as well as data transfer and processing after the surveys (Trinh et al., 2022), was adopted. During field operations, a total of 21 surveys comprising 62 intensive flights were carried out to establish an optimized protocol aimed at minimizing the time interval between UAV-borne spectral imaging and ground-truth data acquired by the sampling vessel (Figure 1). An in-situ turbidity sensor was mounted on the sampling vessel at a strategic placement for continuous turbidity recording in addition to grab sampling. This addition significantly enhanced the effectiveness of data acquisition, enabling the generation of extensive datasets containing thousands of data points. The methodology was applied to turbidity monitoring for Environmental Monitoring and Management Plans (EMMPs) in the coastal waters off South-West Singapore as shown in Figure 2.

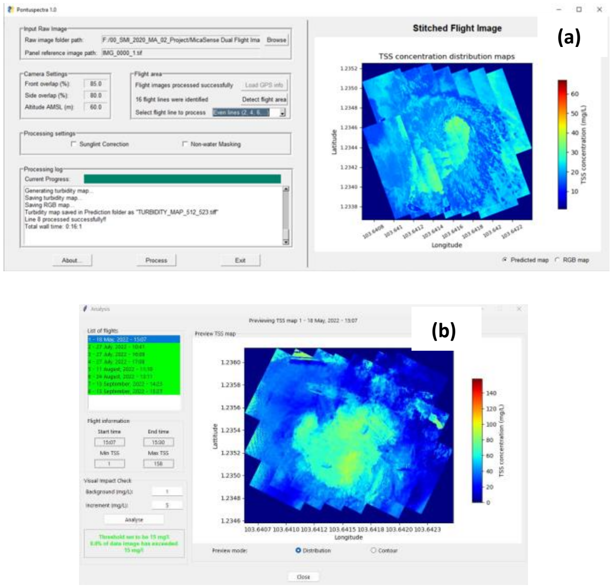
Figure 2: UAV operations for EMMP works in Singapore.

A comparative analysis in a pilot field trial was conducted between two multirotor UAV configurations: the DJI M600 Pro with a hyperspectral camera and the DJI M300 RTK with a multispectral camera, as specified in Table 1. Compared to UAV-borne multispectral sensors, UAV-borne hyperspectral systems capture a much wider frequency range with a broader range of wavelengths, yielding spectral bands with fine resolutions for image processing. However, this system is costly and heavy, thus requires larger UAVs, which can be prohibitive for frequent usage in the industry. To achieve high accuracy for remote sensing with multispectral sensors, spectral analysis was performed to identify the optimal spectral bands for remote sensing of turbidity (Kieu et al., 2023). We managed to distinguish turbidity signals from background noise in coastal areas and capture the nonlinear spectral responses arising from exceptionally high concentrations of suspended sediments generated during land reclamation. From these optimal bands, a suitable multispectral camera for frequent UAV deployment in coastal waters was chosen. The DJI M300 RTK, equipped with the selected multispectral camera, offers superior cost-effectiveness, faster setup, extended endurance, and sufficiently high image quality, and is thus a compelling choice for widespread industry adoption.

Table 1: UAV and sensor parameters of two UAVs platform operated at 58-meter AMSL height to cover 4-hectare area

Parameter	DJI M600 Pro & Hyperspectral Imager	DJI M300 RTK & Multispectral Imager
Flight Duration	10 - 12 mins	15 - 20 mins
Max endurance	18 mins	35 mins
Max payload	5.5 kgs	2kgs
Flight Velocity	5 m/s	4-5 m/s
Wind resistivity	9 m/s	12 m/s
Side overlap	~1 line/10 m of lateral dimension	~1 line/15 m of lateral dimension
Set-up time	~1 hr	10 - 15 mins
Spectral bands	61 bands	10 bands
Resolution	2 cm/pixel	4 cm/pixel
Processing time	60 - 80 mins	35 - 45 mins
Sensitivity to noise	Low	Moderate

Subsequently, two innovative software solutions for EMMP turbidity monitoring in coastal waters using UAV-multispectral imagers are established: Pontuspectra and PontusDash. Pontuspectra software (Figure 3a) provides a fully automated process to generate turbidity distribution maps from images of coastal waters taken from a UAV-borne multispectral imager. It also has user-friendly features such as auto detection of the flight area, image alignment correction, automated sun glint correction and masking of non-water objects. A companion dashboard software, PontusDash, (Figure 3b) was also developed with Pontuspectra to aid decision making for the transboundary concerns of non-compliances to the environmental quality objectives (EQOs). By adopting this technology, we have significantly reduced processing time and have enabled field-based data analysis in real time.



Raw image folder path: F:/00_SMI_2020_MA_02_Project/MicaSense Dual Flight Ima

Panel reference image path: IMG_0000_1.tif

Front overlap (%): 85.0

Side overlap (%): 80.0

Altitude AMSL (m): 60.0

Flight images processed successfully

16 flight lines were identified

Select flight line to process: Even lines (2, 4, 6, ...)

```
Generating turbidity map...
Saving turbidity map...
Saving RGB map...
Turbidity map saved in Prediction folder as "TURBIDITY_MAP_512_523.tif"
Line 8 processed successfully!!
Total wall time: 0:16:1
```

Previewing TSS map 1 - 18 May, 2022 - 15:07

1 - 18 May, 2022 - 15:07

Start time: 15:07

End time: 15:30

Min TSS: 1

Max TSS: 158

Background (mg/L): 1

Increment (mg/L): 5

Figure 3: User interface of (a) Pontuspectra software and (b) PontushDash softward

Finally, this study also extends beyond the development of technological solutions with UAVs and towards their real-time deployment for coastal monitoring. The presentation will discuss how the approach can support Coastal engineers and EMMP practitioners who need to implement EMMP and monitoring of turbidities in waters around the site areas. A workflow example is shown in Figure 4. More importantly, methodologies have been established to integrate on-demand UAV deployments with the automated software, which can respond to ever-changing situations during land reclamation. This covers larger coastal areas more efficiently while minimizing disruptions, ultimately benefitting logistics planning for environmental monitoring and marine operations enabling land reclamation to be carried out more sustainably. It can also deliver cost savings from reducing the need to purchase monthly satellite images and manpower for manual processing of UAV images while optimizing reclamation productivity. This approach is especially critical for developmental works with tight timelines and near sensitive receptors where highly visible water discoloration events need to be avoided such as near recreational beaches, waterways, natural coastal habitats as well as sensitive industrial and domestic receptors with water intake points. The use of UAVs with spectral sensors can be adapted easily to other marine applications such as the monitoring of dredging works and even be extended beyond coastal EMMP. Similar deep-learning models can be trained and cross-deployed for air pollution control to identify black smoke emissions exceeding allowable EQOs.

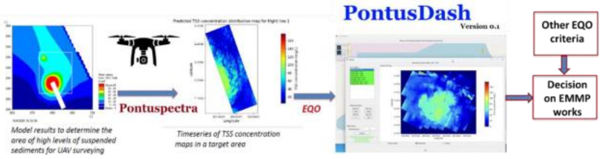


Figure 4: Decision support workflow for EMMP works.

KEYWORDS: Unmanned Aerial Vehicle (UAV), coastal monitoring, logistics planning, time delay reduction, comparative analysis.

REFERENCES

Kieu, H. T., Pak, H.Y., Trinh, H.L., Pang, D.S.C., Khoo, E., and Law, A.W.K., (2023): UAV-based remote sensing of turbidity in coastal environment for engineering assessment, Marine Pollution Bulletin, ELSEVIER, vol. 196, pp. 115482-115494.

Trinh, H.L., Kieu, H.T., Pak, H.Y., Pang, D.S.C., Cokro, A.A. and Law, A.W.K., (2022): A framework for survey planning using portable Unmanned Aerial Vehicles (pUAVs) in coastal hydro-environment, Remote Sensing, MDPI, vol. 14, pp. 2283-2305.

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