

A Review of Unmanned Aerial Vehicles Usage as an Environmental Survey Tool within Tidal Stream Environments

James Slingsby ¹, Beth E. Scott ², Louise Kregting ^{3,*}, Jason McIlvenny ¹, Jared Wilson ⁴ and Benjamin J. Williamson ¹

¹ Environmental Research Institute, University of the Highlands and Islands, Thurso KW14 7EE, UK; james.slingsby@uhi.ac.uk (J.S.); jason.mcilvenny@uhi.ac.uk (J.M.); benjamin.williamson@uhi.ac.uk (B.J.W.)

² School of Biological Sciences, University of Aberdeen, Aberdeen AB24 2TZ, UK; b.e.scott@abdn.ac.uk

³ Plant & Food Research, Mt Albert Research Centre, Auckland 1025, New Zealand

⁴ Marine Scotland Science, Marine Laboratory, Aberdeen AB11 9DB, UK; jared.wilson@gov.scot

* Correspondence: louise.kregting@plantandfood.co.nz

Supplementary Table S2. Literature examined, in relation to UAV usage within tidal stream environments, detailing origin, purpose, UAV specifications and methodology, image processing techniques and summary of work.

Main Author and Date	Citation Number	Title	Origin	Purpose	UAV Specifications and Methodology	Image Processing Techniques	Summary
Lieber et al., 2019	[19]	Localised anthropogenic wake generates a predictable foraging hotspot for top predators	Northern Ireland, UK	To investigate whether a localised (< 1 km) anthropogenicall y generated wake can present a reliable foraging location for surface-feeding seabirds (<i>Sternidae</i>), comparable to those at adjacent natural wake features.	DJI Mavic Pro quadcopter Transects across the survey site at 120 m altitude collecting video footage.	Pre-processing: Video footage was converted to imagery. Machine learning approaches were used to identify, count and track terns over wakes. Processing: Moving objects were detected using frame-to-frame differencing, segmentation then filtering to remove glare. “Bag of features” classifier was used to compile tracks of targets identified as terns.	Findings demonstrate that wake features, predictable in time and space, persistently attract top predators at highly localised scales. Findings provided the first empirical evidence that localised hydrodynamic forcing can present a mechanism to promote a foraging hotspot, where predator aggregations exceed those at adjacent natural wake features.
Lieber et al., 2021	[23]	A bird’s eye view on turbulence: Seabird foraging associations with evolving surface flow features	Northern Ireland, UK	To map foraging tern’s trajectories and underlying surface velocity field in synchrony across the wake of a monopile structure	DJI Phantom 3 quadcopter Stationary hovers ranging between 68 and 153 s in duration, during the flood wake, at 100 m altitude.	Pre-processing: Conversion of video into images. Segmentation and filtering applied to remove sun-glint and large foam patches. Processing:	Methodological approach identified correlations between tern behavioural modes and environmental cues at previously unobtainable scales.

Main Author and Date	Citation Number	Title	Origin	Purpose	UAV Specifications and Methodology	Image Processing Techniques	Summary
McIlvenny et al., 2022	[91]	Comparison of dense optical flow and PIV techniques for mapping surface current flow in tidal stream energy sites	Wales and Scotland, UK	To compare field measurements of flow speeds in tidally energetic channels between large-scale particle image velocimetry (LSPIV) utilising PIVlab and dense optical flow techniques using the Gunnar-Farneback algorithm.	DJI Phantom 4 Pro 2.0 Video recording in parallel to current flow direction at 120 m altitude.	<p>Images passed through a trained “Bag of Features” classifier before using Kalman filters to compile tracks of targets identified as terns only. Water surface velocity fields were extracted every 0.25 s from video using particle image velocimetry (PIV) techniques.</p> <p>Pre-processing: Video was converted to image stills and then to greyscale. Contrast Limited Adaptive Histogram Equalisation (CLAHE) and then MATLAB imadjust functions were then applied to define new pixel intensity values.</p> <p>Processing: PIVlab software was used to compute temporal mean flow vectors for all video footage. Using MATLAB software dense optical flow was performed to calculate temporal mean optical flow vectors for each pixel within the entirety of the video footage. An image complexity metric was used to show the difference in image complexity and structures between the Inner Sound and Ramsey Sound.</p>	<p>Both PIVlab and dense optical flow methods provided similar results (~20-30% error). However, PIVlab processing methods were recommended for processing velocity data at tidal energy sites as a bias (underprediction) in optical flow for higher velocities (>1 m/s) was found.</p> <p>Overall, UAVs provide a method to rapidly investigate detailed flow conditions in tidal streams over a large spatial scale.</p>

Main Author and Date	Citation Number	Title	Origin	Purpose	UAV Specifications and Methodology	Image Processing Techniques	Summary
Fairley et al., 2022	[93]	Drone-based large-scale particle image velocimetry applied to tidal stream energy resource assessment	Wales and Scotland, UK	To demonstrate the application of large-scale particle image velocimetry (LSPIV) to drone-collected video data of unseeded flows for the measurement of surface currents at tidal sites.	DJI M210 v2 RTK drone and DJI Phantom 4 Pro 2.0 Video recording in parallel to current flow direction at 120 m altitude	Pre-processing: Video converted to image still and then to greyscale. Contrast limited adaptive histogram equalisation (CLAHE) was applied to enhance image pixel values. Processing: PIVlab software was used to conduct analysis.	Drone video derived surface velocities were found to be suitably accurate for “first-order” tidal resource assessments under favourable environmental conditions. The tested approach is complementary to existing ADCP techniques in terms of coverage, resolution, and accuracy.
Slingsby et al., 2021	[94]	Surface Characterisation of Kolk-Boils within Tidal Stream Environments Using UAV Imagery	Scotland, UK	To characterise the spatial distribution of kolk-boils within a tidal stream environment, and to understand the drivers and predictability of these features.	DJI Phantom 4 Advanced V2.0 Images taken, from 70 m altitude, across 10-30 min long transects going against the prevailing current direction.	Pre-processing: Images registered in space and time using UAV telemetry data. Processing: Relevant objects of interest, and measurements, were taken from images with the use of a manual graphical user interface (GUI).	The technique can be used to inform turbine development, micro-siting and provide better understanding of environmental implications of turbine operation. It highlights the suitability of UAVs for capturing rapid fine-scale hydrodynamic data in the absence of in situ measurements.
Slingsby et al., 2022	[95]	Using Unmanned Aerial Vehicle (UAV) Imagery to Characterise Pursuit-Diving Seabird Association with Tidal Stream Hydrodynamic Habitat Features	Scotland, UK	To demonstrate the ability of UAV imagery to quantify auk orientation relative to the flow, in relation to hydrodynamic variables (current velocity and tidal phase). To demonstrate the ability of UAV imagery to quantify relationships between auks and individual turbulent features.	DJI Phantom 4 Advanced V2.0 Images taken, from 70 m altitude, across 10-30 min long transects going against the prevailing current direction.	Pre-processing: Georectification of all images to allow for conversion of image units (pixels to metres). Processing: Auk species detected and measurements taken manually using a GUI.	The study further demonstrated the ability of UAVs as a survey platform within tidal streams and highlighted new insights into seabird behaviour in relation to flow conditions and usage of turbulent features.