DRONES IN HYDRAULICS

BY HAMISH BIGGS

The rise of drones in hydraulics reflects the demand for higher resolution data at lower cost. Drones are now affordable, reliable and easy to use, making them well suited for investigation of finer scale processes (mm to cm), compared to the landscape scales covered by aircraft and satellites. The rise of drones has also been paralleled by exponential improvements in lightweight sensor technology. For example, high resolution digital cameras (>50 MP), LiDAR units and hyperspectral cameras can now be carried by consumer grade drones with less than 5 kg of payload. This article provides an introduction to the use of drones in hydraulics and discusses an exciting future of drone based remote sensing.

Figure 1. Drones provide a cost-effective platform for aerial surveying of waterbodies. Photograph: Dave Allen, NIWA

Drone hardware

Unmanned Aerial Vehicles (UAVs), Unmanned Aerial Systems (UAS) and Remotely Piloted Aircraft Systems (RPAS) are some of the many synonyms for drones. Their forms are equally diverse, with fixed wing aircraft, miniature helicopters, balloons, blimps, kites and multirotor aircraft all used for environmental remote sensing [1]. The choice of appropriate drone hardware depends on the mission requirements (e.g. area covered, altitude, payload and flight time). The most commonly used drones for hydraulics applications are multirotor aircraft. Small multirotors (such as the DJI Phantom 4 Pro) are used for aerial imagery and general surveying, while larger units (such as the DJI Matrice 600 Pro) are suitable for LiDAR and other payloads up to 5 kg.

Aerial imagery and surveying

The most common application for drones in hydraulics is recording aerial imagery and surveying (Figure 1). The spatial resolution of aerial imagery is determined by drone altitude and camera specifications. For example, the DJI Phantom 4 Pro with 20 MP sensor and 24 mm equivalent focal length lens achieves pixel resolution of 5.5 mm at 20 m altitude and 27.5 mm at 100 m altitude. The spatial coverage of aerial imagery is determined by flight speed, altitude and image overlap. Camera settings, flight speed and lighting are critical to obtain good aerial imagery. Shutter priority mode is recommended, with 1/1000 shutter (or faster) to minimise image blur. Ground Control Points (GCP) are used to obtain georeferenced aerial images. GCPs can be either targets set out and surveyed, or identifiable features with known (surveyed) locations. The use of GCPs can sometimes be avoided if camera origin is known with RTK or PPK GPS precision. Aerial images can either be analysed individually or combined into a ‘georeferenced orthomosaic’ (basically a 2D photo map) for further analysis

Figure 2. Drone-based survey of aquatic vegetation (River Urie, UK)

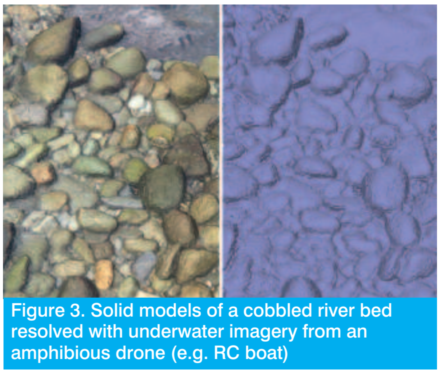

Figure 3. Solid models of a cobbled river bed resolved with underwater imagery from an amphibious drone (e.g. RC boat)

(Figure 2). Georeferenced orthomosaics can be easily generated with Structure from Motion (SfM) software such as Agisoft Photoscan or Pix4D. Imagery for this purpose should have 60-80% overlap on all sides and at least 8 GCPs distributed throughout the site. Further analysis of georeferenced orthomosaics often entails image segmentation into classes, then measurement of the total area of classes; or measurement of the number, area and dimensions of objects within a class [2]. Common applications in hydraulics are to delineate the boundaries of waterbodies, structures and biota (e.g. vegetation), then evaluate the total surface area and geometry of objects within each class.

Image analysis

Classification of aerial imagery can either be performed manually [2] or using automated techniques [3]. Which approach is appropriate depends on the survey frequency, input data type, classes to be resolved and required output accuracy. For one-off surveys with RGB imagery, manual image classification provides higher accuracy [3] and is usually faster than using automated techniques. For automated image classification significant time must be spent setting up and tuning the classification algorithms, then evaluating the accuracy of the automatic classifications against manual classifications or ground truth data. For research applications, this is often a diversion from the original purpose of the survey and results in studies devoted to the accuracy of the automatic classification rather than detailed analysis of the survey data. Automated techniques often struggle to separate the boundaries of overlapping or touching objects within a class. This is not a problem if only the total area of classes is required, however if the dimensions of individual objects within a class are required, then this is a big problem and manual image classification should be used. Where automated classification techniques excel is for routine monitoring of total class area over large spatial extents with multispectral or hyperspectral imagery [4]. Hyperspectral imagery has hundreds of narrow spectral bands (compared to the 3 lumped bands of RGB imagery). It is not easy to visualise, but is well suited for supervised image classification, object-based classification, or machine learning approaches [3, 4].

Digital Elevation Models (DEMs)

Accurate DEMs are critical for many hydraulic applications (e.g. erosion, hydraulic modelling, sediment transport and morphodynamics). High resolution DEMs can be obtained from drone-based aerial imagery or light weight terrestrial LiDAR units (such as those from LiDAR USA). DEMs from aerial imagery are obtained using Structure from Motion (SfM) image processing software (e.g. Agisoft Photoscan or Pix4D). For most terrain types the DEMs obtained using SfM have similar accuracy to LiDAR, but much lower equipment cost [5]. In terrain that is heavily vegetated or lacks distinct visual distinct features (e.g. uniform mud, sand, or snow) LiDAR provides more accurate and reliable data.

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Bathymetry

In the future bathymetric (green) LiDAR units may reach the price, performance and weight of terrestrial (infrared) LiDAR units. When this occurs drone-based bathymetric LiDAR surveys will become common practice. Until then, other means to determine bathymetry from remote sensing data can be used. For example, bathymetry from: underwater imagery (Figure 3), through water imagery corrected for surface refraction [6], spectral attenuation of light with depth, or turbulence metrics [7].

Underwater imagery

The SfM image processing techniques typically used for aerial drone surveying, can equally be applied to underwater camera imagery (Figure 3). For rivers that are sufficiently clear and deep, this enables Remote Control (RC) boat-based surveys to resolve bathymetry, grain size distributions and bed roughness. The bathymetry data or solid models can even be used as inputs for 2D or 3D hydraulic modelling.

Sediment size distributions

Imagery from drones or underwater cameras (Figure 3) can be used to obtain sediment size distributions [8, 9]. The smallest size fraction that these techniques are suitable for depends on the spatial resolution of the imagery. For braided gravel bed rivers with predominantly coarse sediment, low altitude drone-based surveying is a convenient way to map sediment size distributions over large spatial extents. This data has many applications, such as physical habitat mapping, roughness coefficients for hydraulic modelling, or inputs for sediment transport modelling.

Discharge gauging and Large Scale Particle Image Velocimetry (LSPIV)

Discharge gauging from imagery is useful for flow conditions where in-water measurement equipment cannot be deployed (e.g. flash floods and debris flows) or in remote locations without access to standard gauging equipment [10]. Imagery can be recorded from river banks or drones, then LSPIV techniques used to determine surface velocities. Discharge is estimated from surface velocities, bathymetry and a conversion from surface velocity to depth averaged velocity (such as the index velocity method). Bathymetry can be surveyed independently or estimated from imagery derived data (e.g. turbulence metrics) [7]. Imagery from drones has advantages over bank-based imagery in orthorectification and spatial coverage. For example, spatial distributions of surface velocities for physical habitat mapping, and discharge gauging in large rivers where bank-based imagery is not feasible. The 'Drone flow' project in New Zealand is currently developing a drone based LSPIV system featuring a stereoscopic camera system, high resolution IMU (for camera orientation) and RTK GPS (for camera origin) that will avoid the need for Ground Control Points (GCPs) and significantly improve drone based hydraulic measurements.

The future?

In such a diverse and rapidly evolving field, it is challenging to speculate about the future. However, there are a number of technologies and capabilities to watch. The first is the performance (and cost) of thermal infrared cameras. Rapid improvements in both spatial resolution (number of pixels) and thermal resolution (temperature graduation) will lead to many exciting applications in hydraulics. For example: studying turbulence and mixing processes at river confluences, identifying zones of ground water upwelling in rivers, studying the breakdown of thermal stratification in waterbodies as surface layers cool, studying mixing processes due to wind loading, using subtle water temperature differences as tracers for LSPIV, and discharge gauging at river confluences. The development of high performance aerial surveying systems (such as 'Drone flow') also promise an exciting future for drones in hydraulics by providing input data for hydraulic modeling, fish passage, discharge gauging and physical habitat assessments. ■

References

[1] Klemas, V. (2015). Coastal and environmental remote sensing from unmanned aerial vehicles: An overview. Journal of Coastal Research, 31(5), 1260-1267.

[2] Biggs, H., Nikora, V., Gibbins, C., Fraser, S., Papadopoulos, K., Green, D. & Hicks, D.M. (2018). Coupling Unmanned Aerial Vehicle (UAV) and hydraulic surveys to study the geometry and spatial distribution of aquatic macrophytes. Journal of Ecohydraulics, 3(1), 45-58.

[3] Husson, E., Ecke, F. & Reese, H. (2016). Comparison of manual mapping and automated object-based image analysis of non-submerged aquatic vegetation from very-high-resolution UAS images. Remote Sensing, 8(9), 724

[4] Parsons, M., Bratanov, D., Gaston, K. & Gonzalez, F. (2018). UAVs, Hyperspectral Remote Sensing, and Machine Learning Revolutionizing Reef Monitoring. Sensors, 18(7), 2026.

[5] Fonstad, M., Dietrich, J., Courville, B., Jensen, J. & Carbonneau, P. (2013). Topographic structure from motion: a new development in photogrammetric measurement. Earth Surface Processes and Landforms, 38(4), 421-430.

[6] Dietrich, J. (2017). Bathymetric Structure from Motion: extracting shallow stream bathymetry from multi view stereo photogrammetry. Earth Surface Processes and Landforms, 42(2), 355-364.

[7] Detert, M., Johnson, E. & Weitbrecht, V. (2017). Proof of concept for low cost and non contact synoptic airborne river flow measurements. International journal of remote sensing, 38(8-10), 2780-2807.

[8] Buscombe, D. (2013). Transferable wavelet method for grain size distribution from images of sediment surfaces and thin sections, and other natural granular patterns. Sedimentology, 60(7), 1709-1732.

[9] Detert, M. & Weitbrecht, V. (2013). User guide to gravelometric image analysis by BASEGRAIN. In: Advances in River Sediment Research, Proceedings of the 12th International Symposium on River Sedimentation ISRS 2013, (pp. 1789-1796). Kyoto, Japan. CRC Press.

[10] Le Coz, J., Jodeau, M., Hauet, A., Marchand, B. & Le Boursicaud, R. (2014). Image-based velocity and discharge measurements in field and laboratory river engineering studies using the free Fudaa-LSPIV software. In: Proceedings of the international conference on fluvial hydraulics, River Flow 2014 (pp. 1961–1967). Lausanne, Switzerland. CRC Press.

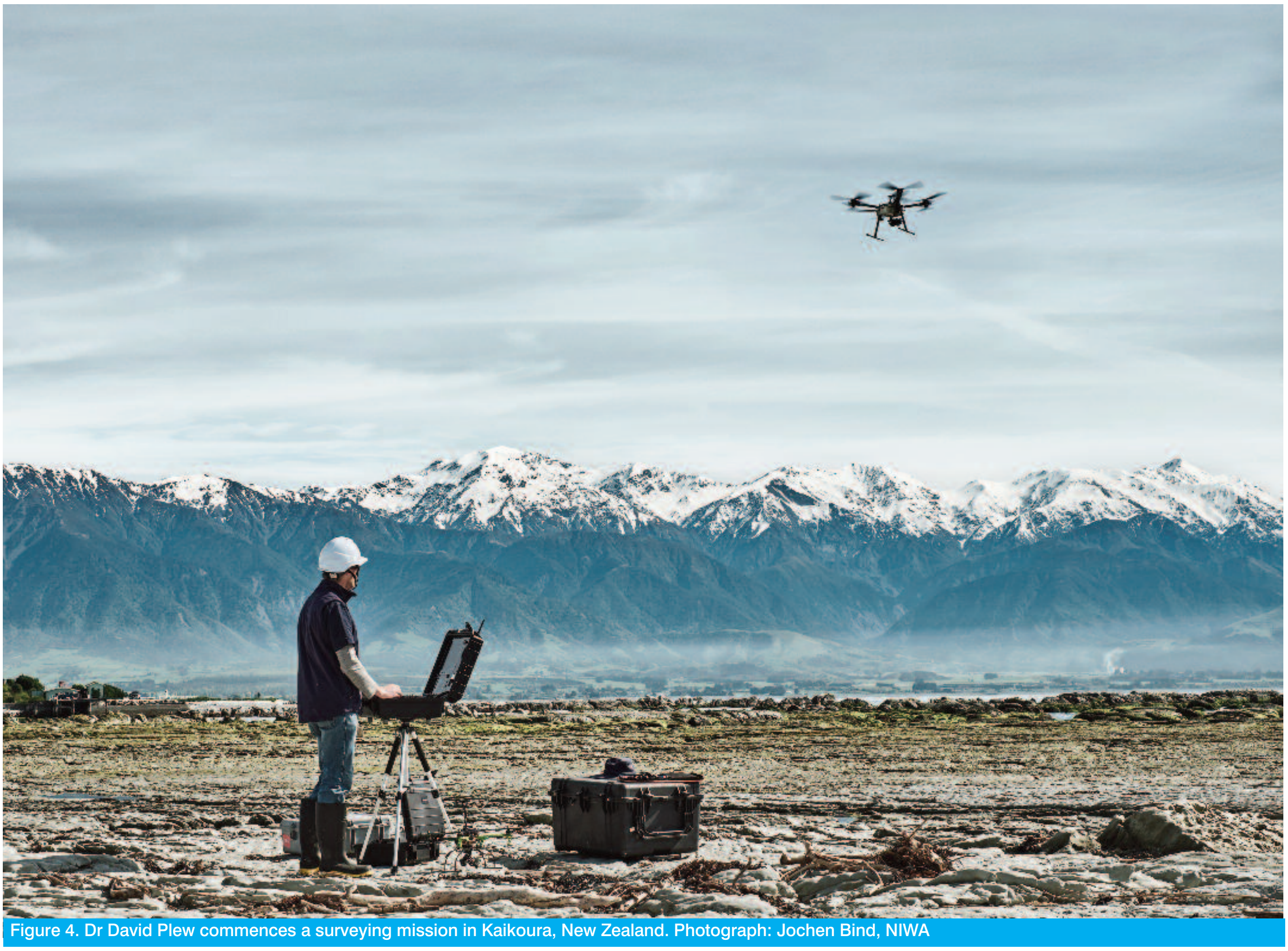

Figure 4. Dr David Plew commences a surveying mission in Kaikoura, New Zealand. Photograph: Jochen Bind, NIWA