Quantifying Fluvial Topography using UAS Imagery and SfM-Photogrammetry

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1. Background & Context

The quantitative measurement and monitoring of fluvial topography at high spatial and temporal resolutions is in increasing demand for a range of river science and management applications, including geomorphic change detection, hydraulic modelling, habitat assessments, river restorations and sediment budgeting[1,2].

Traditionally, fluvial topography is quantified using cross sections where point measurements are taken at regular intervals. This typically involves the use of surveyor's levels, mapping- or survey-grade GPS devices (Figure 1) or total station surveys. Such approaches are time consuming, labour intensive and provide limited spatial coverage[3,4].

Figure 1. Surveying fluvial topography using a dGPS

Existing remote sensing approaches (e.g. terrestrial laser scanning[5], optical depth mapping[6]) are yet to provide a single technique for surveying fluvial topography in both exposed and submerged areas, with high spatial resolution, reach-scale coverage, high accuracy and reasonable cost.

2. Aims of this Research

In this paper, we explore the potential of using high resolution imagery acquired from a small unmanned aerial system (UAS) and processed using Structure-from-Motion (SfM) photogrammetry for quantifying fluvial topography. Our focus is on the 'mesoscale', which we define as river reaches from ten's to hundred's of metres in length, surveyed with centimetre level spatial resolution. This work forms part of a wider PhD study assessing a UAS-SfM approach for quantifying a variety of physical river habitat parameters.

Figure 2. The Draganflyer X6 – an unmanned aerial system

Research Questions

1) How accurate, precise & replicable are the topographic datasets generated using UAS-SfM?
2) Does the accuracy/precision vary between different river systems?
3) Does the accuracy/precision vary between exposed & submerged areas?
4) Does the application of a simple refraction correction procedure improve the results?

3. Study Sites

1) San Pedro River, Valdivia, Chile - Large, bedrock channel with patches of gravel, cobbles & boulders.
2) River Arrow, Warwickshire, UK - Small, lowland, meandering pool-riffle system with cobble bed.
3) Coledale Beck, Cumbria, UK – Small upland, pool-riffle system.

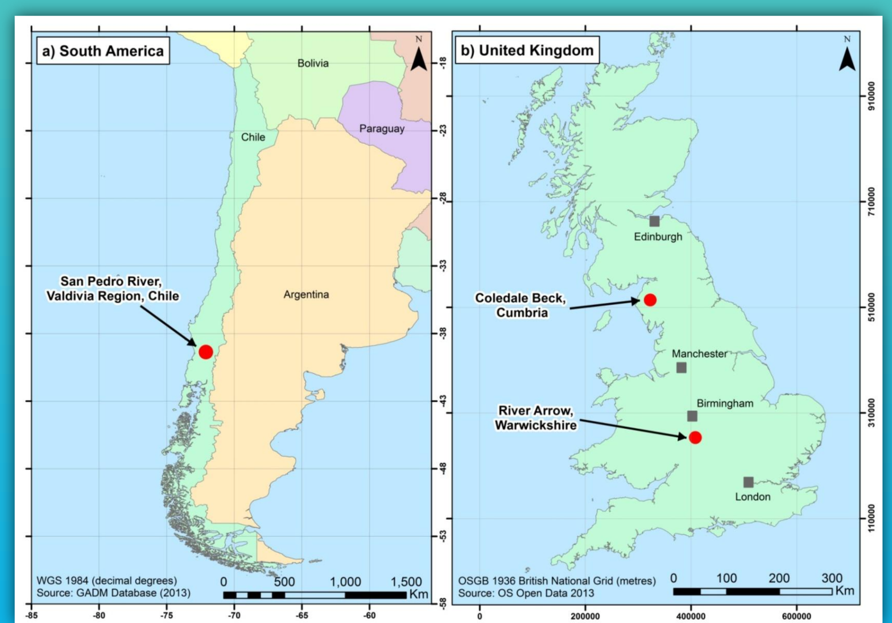

Figure 3. Study site locations

4. Data Collection

Image Acquisition

Imagery was collected at all sites using a consumer-grade 10.1 MP digital camera attached to a small, lightweight, rotary-winged UAS known as the Draganflyer X6 (Figure 2).

The Draganflyer was flown at 25-30m above ground level to give c. 1cm resolution imagery, as determined by prior calibration tests. Images were collected with a high level of overlap (c. 80%) to allow subsequent SfM processing.

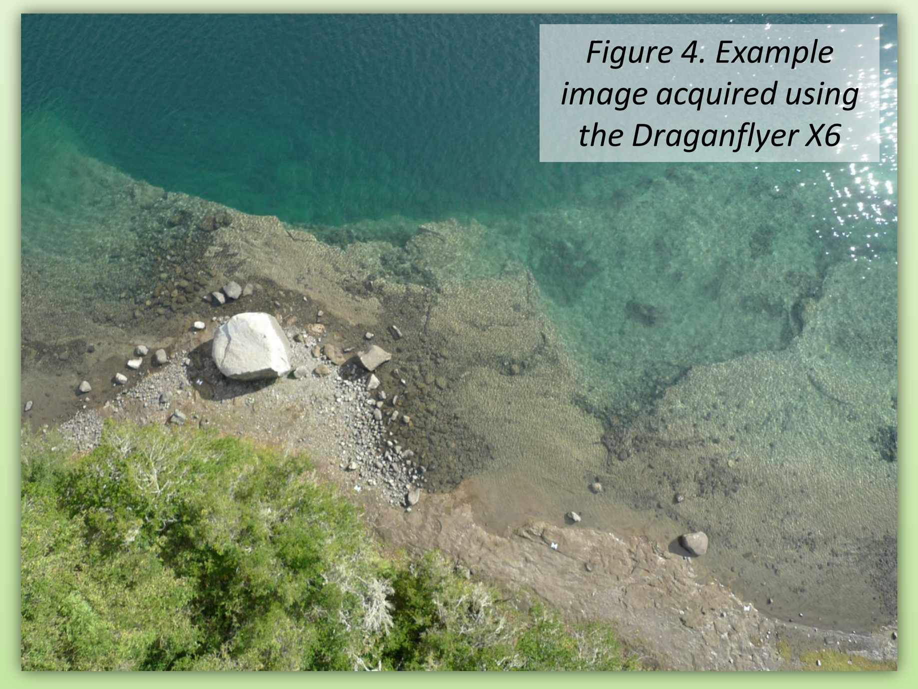

Figure 4. Example image acquired using the Draganflyer X6

Ground Control

Artificial ground control points (GCPs) were made and distributed across the site prior to image acquisition (Figure 5). GCPs were surveyed in using a total station or dGPS and were important for subsequent georeferencing of the imagery.

Figure 5. An artificial ground control point (GCP)

Validation Data

A traditional topographic survey was conducted at each site using a total station or dGPS, as a means of validating the topographic data obtained from the UAS-SfM approach. Data were collected in both exposed and submerged areas. Where possible, water depth was recorded to the nearest centimetre.

5. Data Processing

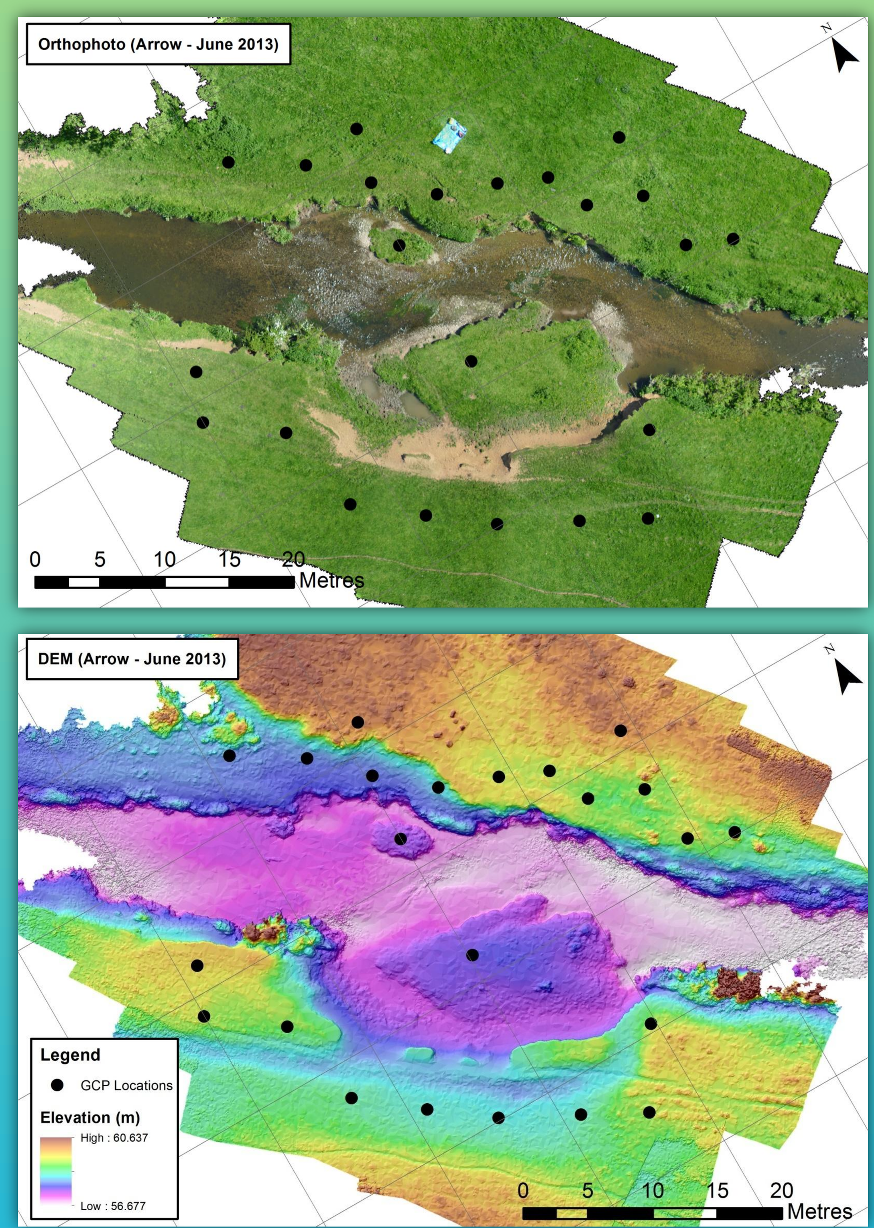

Figure 6. Example Orthophoto and DEM (River Arrow)

Structure-from-Motion Photogrammetry

Imagery was processed using SfM software package PhotoScan Pro v.0.9.1.1714 (Agisoft LLP), which works by matching conjugate points from multiple, overlapping images and estimating camera positions to reconstruct a 3D point cloud of the scene geometry[7]. GCPs were used to optimise the image alignment and georeference the dataset. Outputs included an orthophoto and a digital elevation model (DEM) – Figure 6.

Refraction Correction

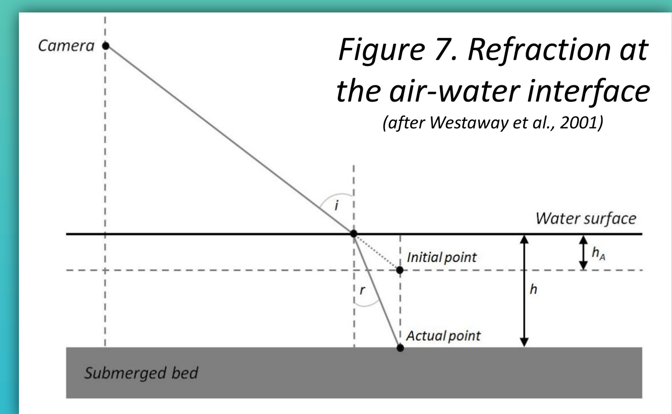

Figure 7. Refraction at the air-water interface (after Westaway et al., 2001)

In submerged areas, outputs are affected by refraction which causes an overestimation of the true bed elevation (Figure 7)[4].

We tested a simple refraction correction procedure to remove this effect. Water depths (h_A) were estimated by mapping the water's edge from the orthophoto, extracting DEM elevations along this edge, interpolating a water surface elevation across the channel and subtracting the underlying DEM. Water depths were multiplied by the refractive index of clear water (1.34)[8] & the difference between original (h_A) & corrected water depth (h) was then subtracted from the original DEM.

6. Results

Accuracy, Precision & Repeatability

(1) San Pedro **Importance of GCP layout**
- Linear GCP alignment causes DEM tilting and therefore poorer accuracy & precision values (Fig 8).

(2) River Arrow **Demonstrates repeatability**
- DEM in exposed areas more accurate & precise than in submerged areas.
- Error scales with water depth in submerged areas.
- Refraction correction (RC) improves DEM accuracy by 3-5cm, but does not completely eliminate refraction effects (Figure 9).

(3) Coledale Beck **Shallower water = no need for RC**
- Dense vegetation degrades DEM accuracy in exposed areas (Table 1, Figure 10).
- High accuracy in submerged areas before RC – due to greater proportion of waters shallower than 0.2m.

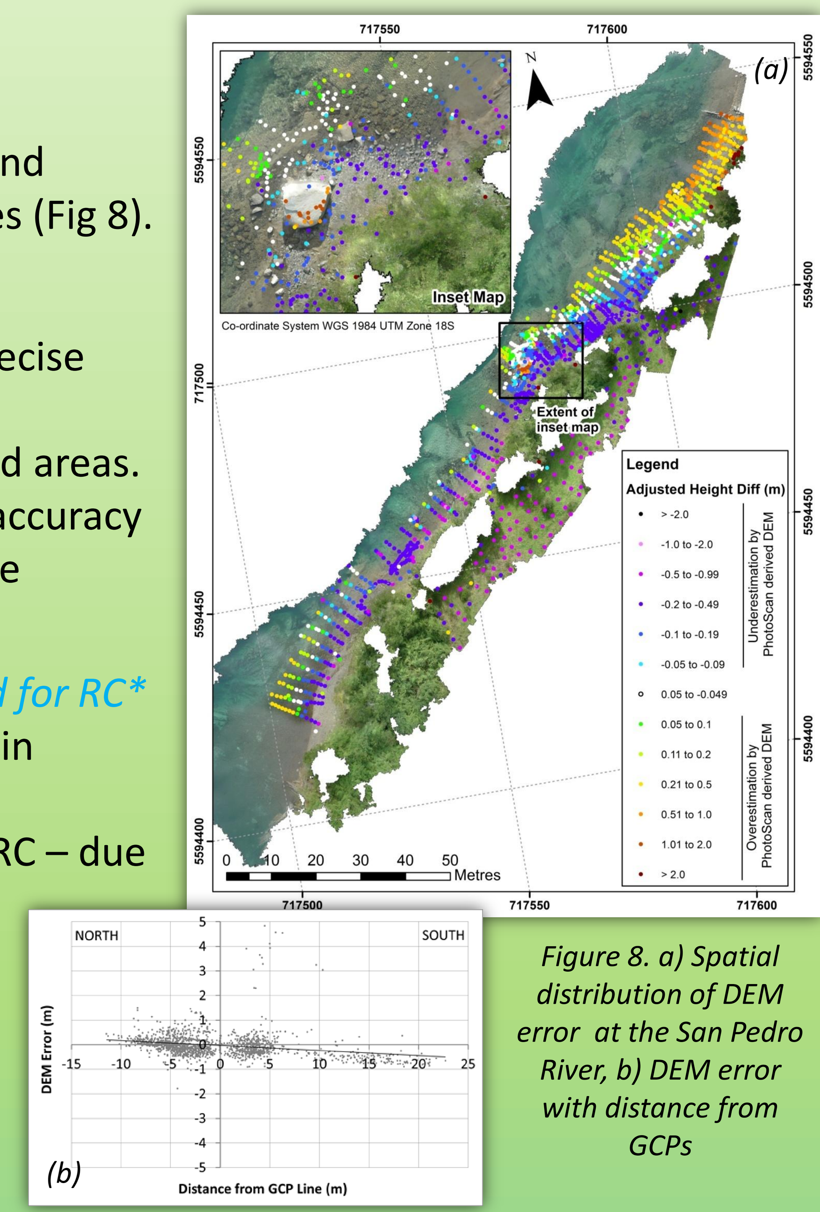

Figure 8. a) Spatial distribution of DEM error at the San Pedro River, b) DEM error with distance from GCPs

Table 1. DEM accuracy & precision statistics for all sites.

Site Location		San Pedro River	River Arrow			Coledale Beck
Date of survey		*May 2012*	*May 2013*	*June 2013*	*Aug 2013*	*July 2013*
ACCURACY *Mean error (m)*	Exposed	-0.164	0.005	0.004	0.044	0.111
	Submerged (NC)	0.026	0.089	0.053	0.063	0.017
	Submerged (RC)	-0.084	0.056	-0.004	0.024	-0.025
PRECISION *Standard deviation (m)*	Exposed	0.332	0.019	0.032	0.069	0.203
	Submerged (NC)	0.278	0.076	0.065	0.084	0.074
	Submerged (RC)	0.300	0.080	0.068	0.084	0.078

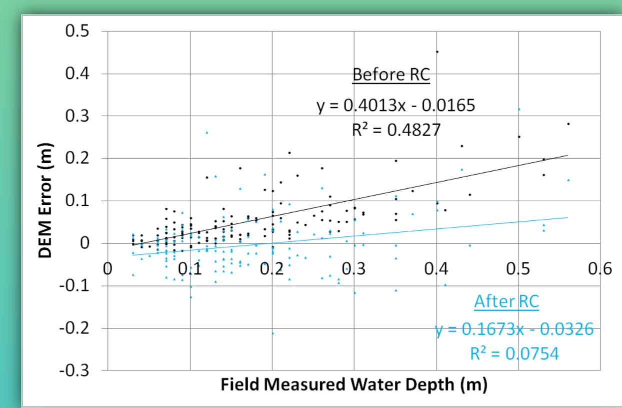

Figure 9. Effects of refraction correction on DEM error (River Arrow June 2013)

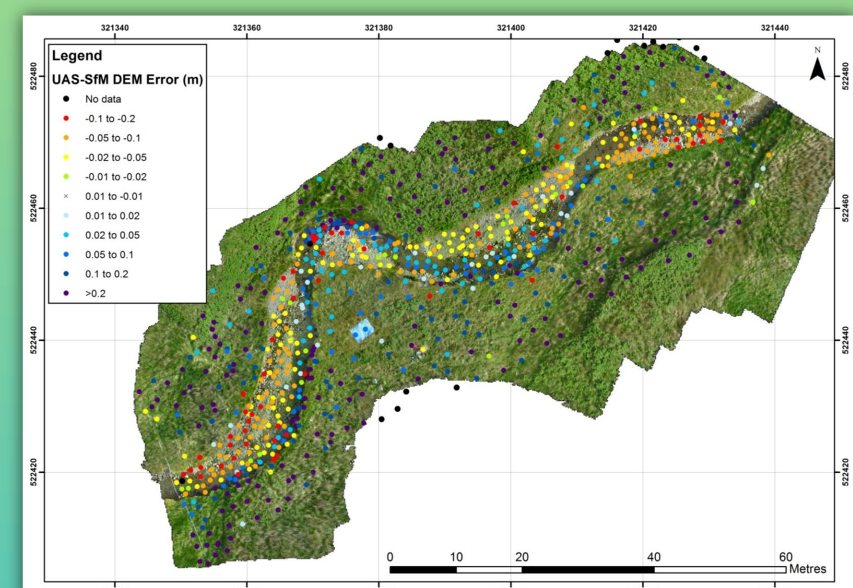

Figure 10. Spatial distribution of DEM error at Coledale Beck

7. Discussion & Conclusions

A UAS-SfM approach is capable of quantifying fluvial topography…

- At hyperspatial resolutions (c. 1cm) over mesoscale lengths of channel.
- With high accuracy and precision – approaching those possible with TLS in exposed areas.
- Using a single method for both exposed and submerged areas, provided RC is applied.
- In a rapid and flexible way, which may also be cost effective.
- In submerged areas up to 0.7m deep, where water is clear, there is adequate illumination and provided RC is implemented.

Further robust testing needed but the UAS-SfM approach shows great promise as a quantitative tool for geomorphology

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