Geomorphology 226 (2014) 35–43

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

The potential of small unmanned aircraft systems and structure-from-motion for topographic surveys: A test of emerging integrated approaches at Cwm Idwal, North Wales

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ARTICLE INFO

Article history:
Received 25 April 2014
Received in revised form 4 July 2014
Accepted 11 July 2014
Available online 18 July 2014

Keywords:
Small unmanned aircraft system
Structure from motion
Digital surface model
Digital elevation model
Topographic surveying

ABSTRACT

Novel topographic survey methods that integrate both structure-from-motion (SfM) photogrammetry and small unmanned aircraft systems (sUAS) are a rapidly evolving investigative technique. Due to the diverse range of survey configurations available and the infancy of these new methods, further research is required. Here, the accuracy, precision and potential applications of this approach are investigated. A total of 543 images of the Cwm Idwal moraine–mound complex were captured from a light (<5 kg) semi-autonomous multi-rotor unmanned aircraft system using a consumer-grade 18 MP compact digital camera. The images were used to produce a DSM (digital surface model) of the moraines. The DSM is in good agreement with 7761 total station survey points providing a total vertical *RMSE* value of 0.517 m and vertical *RMSE* values as low as 0.200 m for less densely vegetated areas of the DSM. High-precision topographic data can be acquired rapidly using this technique with the resulting DSMs and orthorectified aerial imagery at sub-decimetre resolutions. Positional errors on the total station dataset, vegetation and steep terrain are identified as the causes of vertical disagreement. Whilst this aerial survey approach is advocated for use in a range of geomorphological settings, care must be taken to ensure that adequate ground control is applied to give a high degree of accuracy.

1. Introduction

The use of small unmanned aircraft systems (sUAS) and structure-from-motion (SfM) digital photogrammetry presents a new methodological frontier for topographic data acquisition and is of interest to scientists researching in a range of geomorphological environments (Westoby et al., 2012; Carrivick et al., 2013; Hugenholtz et al., 2013; Tarolli, 2014). Traditionally low-level aerial photography has been acquired using a variety of unmanned platforms including small lighter-than-air blimps, kites, and model fixed-wing and single rotor aircraft (e.g. Wester-Ebbinghaus, 1980; Rango et al., 2009; Smith et al., 2009; Hugenholtz et al., 2013). More recently lightweight (<5 kg), relatively low-cost multi-rotor aerial platforms have been used to capture low-level imagery (Harwin and Lucieer, 2012; Niethammer et al., 2012; Rosnell and Honkavaara, 2012; Mancini et al., 2013; Lucieer et al., 2014). These sUAS can be programmed to fly semi-autonomously at fixed altitudes along flight lines, ensuring optimal image overlap for digital photogrammetry. A key strength of the integrated sUAS–SfM approach is the degree of automation involved. Previously, a high degree of user experience was a prerequisite for both the operation of aerial platforms and the application of photogrammetric methods to extract meaningful topographic data from aerial imagery (Aber et al., 2010). The premise of SfM as a digital photogrammetric technique is that three-dimensional coordinates can be extracted from sufficiently overlapping photography without the need for camera spatial information (Snavely et al., 2008; Westoby et al., 2012). The integration of SfM with sUAS camera platforms offers a rapid and increasingly cost effective option for geomorphologists to produce digital surface models (DSMs), with resolution and data quality proposed to be on-par with, or better than LiDAR (Carrivick et al., 2013; Fonstad et al., 2013). SfM based topographic surveys have recently been used for a variety of geoscientific applications including quantifying rates of landslide displacement (Lucieer et al., 2013), mapping vegetation spectral dynamics (Dandois and Ellis, 2013), producing DEMs (digital elevation models) of agricultural watersheds (Ouédraogo et al., 2014), quantifying coastal erosion rates (James and Robson, 2012), and measuring rates of glacier motion and thinning (Whitehead et al., 2013). The potential of SfM to aid geomorphological mapping, derive measurements of landforms (morphometry) and quantify geomorphological change is evident. Numerous software packages for SfM are now available and include cloud-based processing, which has the additional benefit of not requiring a high-specification consumer computer capable of handling the image processing.

Whilst a range of recent studies have sought to quantify data quality and associated error of SfM techniques (Harwin and Lucieer, 2012;

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http://dx.doi.org/10.1016/j.geomorph.2014.07.021
0169-555X/

Turner et al., 2012; Westoby et al., 2012; Dandois and Ellis, 2013; Fonstad et al., 2013; Hugenholtz et al., 2013; Ouédraogo et al., 2014), further research is beneficial due to the diverse nature of the aerial platforms and consumer-grade digital cameras available for the production of topographic data using this methodology. Existing reports on the effectiveness of integrated multi-rotor based sUAS–SfM approaches describe surveys conducted from relatively low altitudes (<50 m). The aims of this research are to: (1) provide a systematic account of the data acquisition process associated with this new integrated technique; (2) compare vertical spot heights obtained from the sUAS–SfM survey to those obtained from a total station ground survey; (3) highlight important considerations for researchers seeking to use sUAS and SfM approaches to acquire data for topographic investigations; and (4) provide a baseline for the potential spatial resolutions when using a consumer-grade 18 MP compact digital camera at a target flight altitude of 100 m.

2. Study area

The test was undertaken at Cwm Idwal, north Wales (53° 6′50.89″N; 4° 1′38.38″W; Fig. 1) (Appendix A), a large cirque that was last occupied by a glacier during the Younger Dryas Stadial (c.12.9–11.7 ka BP; Bendle and Glasser, 2012). The study area is located on the cirque floor and covers an altitudinal range of ~370 to ~410 m (above ordnance datum). The geomorphology of the site is characterised by a moraine–mound complex ('hummocky moraine') located on both the east and west of Llyn [lake] Idwal (Fig. 1c). These moraines have been the subject of numerous investigations (e.g. Darwin, 1842; Escritt, 1971; Gray, 1982; Addison, 1988; Graham and Midgley, 2000; Bendle and Glasser, 2012) due to their importance for understanding the significance of Younger Dryas glaciers in the British Uplands. The majority of the moraines are 8 to 80 m in length, with the exception being a set of discontinuous stream-breached ridges totalling ~450 m in length which are stacked against the western cirque wall. In places the morphology of the moraines are influenced by glacially abraded bedrock. The prominence of some landforms is also disguised by a peat infill. The southern section of the survey area is characterised by a relatively flat lake infill and steep glacially abraded bedrock slopes. Vegetation on the eastern side of the Cwm is typically restricted to short swards of grass, whereas livestock grazing exclosures erected in the 1950s and 1960s on the western side of Llyn Idwal have promoted the growth of vegetation including a thick cover of common heather (*Calluna vulgaris*), western gorse (*Ulex gallii*), and the occasional rowan (*Sorbus aucuparia*) and silver birch (*Betula pendala*) (Rhind and Jones, 2003). A large part of the moraine–mound complex and surrounding area were surveyed with a total station by Graham and Midgley (2000). A similar area was surveyed by an sUAS to allow a direct comparison between total station based data acquisition, and the sUAS–SfM method used for this study.

3. Methods and materials

3.1. Image and data acquisition

Aerial imagery was acquired using a Canon EOS-M 18 MP camera suspended from a DJI S800 Hexacopter (Fig. 2). A Photohigher AV130

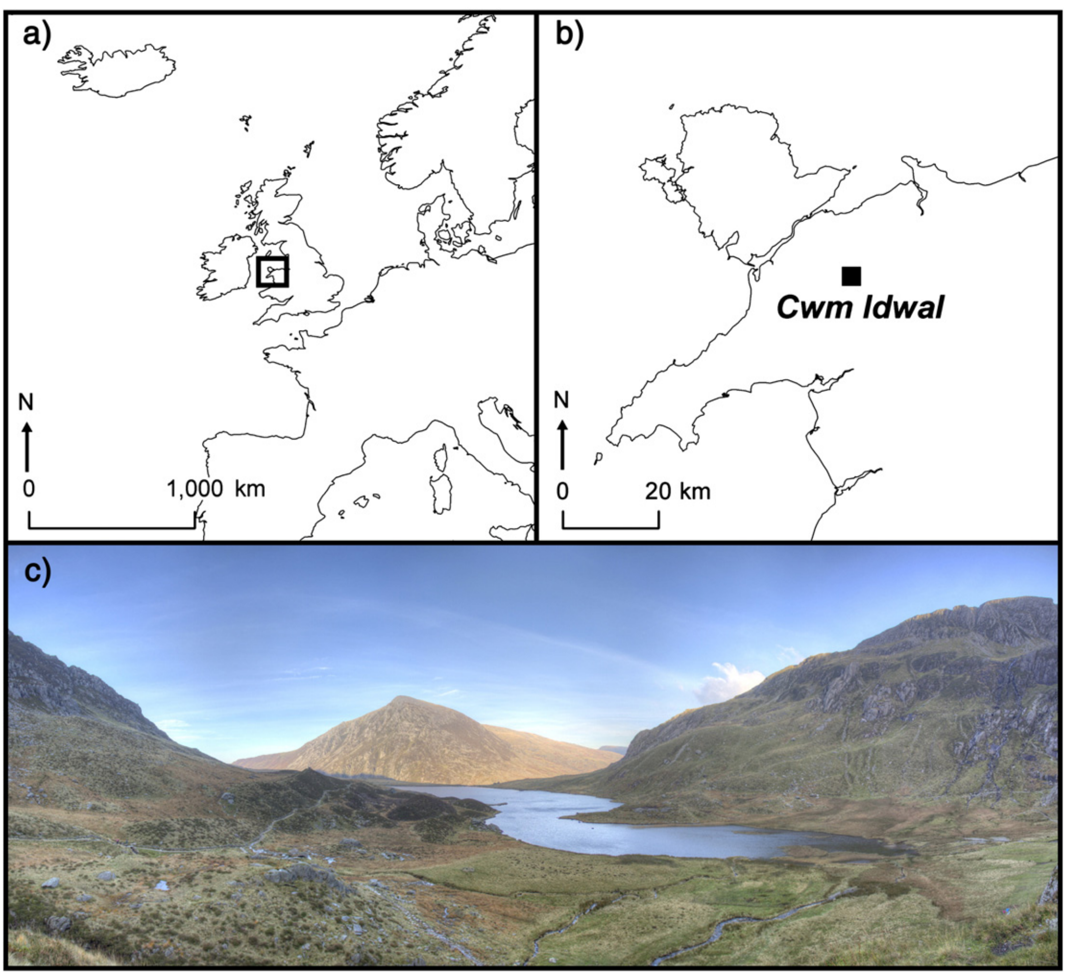

Fig. 1. Maps showing the study site location in relation to (a) North-west Europe, and (b) North Wales. ©Crown Copyright/database right 2014. An Ordnance Survey/EDINA supplied service. (c) A ground-level panoramic photograph of the moraine–mound complex which is located on both the left and right of Llyn Idwal.