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Using UAS optical imagery and SfM photogrammetry to characterize the surface grain size of gravel bars in a braided river (Vénéon River, French Alps)

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ABSTRACT

This paper explores the potential of unmanned aerial system (UAS) optical aerial imagery to characterize grain roughness and size distribution in a braided, gravel-bed river (Vénéon River, French Alps). With this aim in view, a Wolman field campaign (19 samples) and five UAS surveys were conducted over the Vénéon braided channel during summer 2015. The UAS consisted of a small quadcopter carrying a GoPro camera. Structure-from-Motion (SfM) photogrammetry was used to extract dense and accurate three-dimensional point clouds. Roughness descriptors (roughness heights, standard deviation of elevation) were computed from the SfM point clouds and were correlated with the median grain size of the Wolman samples. A strong relationship was found between UAS-SfM-derived grain roughness and Wolman grain size. The procedure employed has potential for the rapid and continuous characterization of grain size distribution in exposed bars of gravel-bed rivers. The workflow described in this paper has been successfully used to produce spatially continuous grain size information on exposed gravel bars and to explore textural changes following flow events.

1. Introduction

Grain roughness and grain size distribution (GSD) of riverbed sediment in gravel-bed rivers have been a long-standing focus of interest for fluvial scientists (Rice and Church, 1998, 2010). On the one hand, grain roughness influences flow resistance, the variability and magnitude of shear stress (Naot, 1984; Robert et al., 1992) and the sediment supply of bedload transport (Paola and Seal, 1995; Vericat et al., 2008), and it is an important parameter in hydraulic modelling (Milan and Heritage, 2012). On the other hand, GSD exerts a significant control on the habitat of many benthic organisms.

In gravel-bed streams, grain size and surface roughness shows substantial heterogeneity at different scales (Leopold et al., 1964; Bluck, 1976; Lisle and Madej, 1992; Ashworth, 1996; Rice and Church, 2010; Milan, 2013; Storz-Peretz and Laronne, 2013; Guerit et al., 2014). At the reach scale, it may be represented by patches or facies of similar texture and grain size (Dietrich et al., 2005; Nelson et al., 2009), defining a textural mosaic. This sedimentary mosaic is particularly complex in braided settings, where the spatial distribution of patches reflects the main morphological components of the braided landform (Storz-Peretz and Laronne, 2013; Guerit et al., 2014).

Development of a completely satisfactory method for measuring grain size and surface roughness in gravel-bed rivers (Hodge et al., 2009a) has been made difficult by the multiscale heterogeneity of riverbed sediment. The most widely followed procedure by fluvial scientists has been the grid-by-number Wolman count (Wolman, 1954; Rice and Church, 1996; Bunte and Abt, 2001). Surface grain size has also been measured using the photosieving approach, which uses high-resolution close-range imagery (taken 1–2 m above ground level) and image processing techniques (Ibbeken and Schleyer, 1986; Butler et al., 2001; Rubin, 2004; Graham et al., 2005; Buscombe, 2008; Detert and Weitbrecht, 2013). However, while these methods provide rapid and objective ways for sampling grain size, they are best suited for patch-scale studies (Heritage and Milan, 2009; Milan and Heritage, 2012; Woodget, 2015). This is because a large number of samples is needed for a complete characterization of the large-scale sedimentary mosaic (Woodget, 2015). Consequently, fluvial scientists and engineers require a more rapid and objective technique that is capable of providing fast, continuous, and accurate grain size measurements at river reach scales (a few hundred meters in length).

Remote sensing approaches have revolutionized the production of fluvial topographic data over the last two decades (Hohenthal et al., 2011; Brasington et al., 2012), and these new technologies could deliver

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a satisfying alternative to the classical ways of measuring grain size and surface roughness (Heritage and Milan, 2009; Brasington et al., 2012; Woodget, 2015). Carbonneau et al. (2004, 2005), Verdú et al. (2005), Dugdale et al. (2010), and Tamminga et al. (2014) have successfully employed high-resolution aerial imagery and image texture analysis for grain size determination over large areas, the so-called aerial photosieving approach. This method depends on high-resolution images and light conditions as well as sediment color and texture, and they are limited by pixel size and the need for field calibration (Carbonneau et al., 2005; Verdú et al., 2005). Dugdale et al. (2010) used manual calibration performed directly on the aerial images to replace field data. However, a systematic bias was identified in their results, leading to a consistent overestimation of median grain size. Aerial-image calibration is restricted by the user's ability to discriminate smaller size classes and by pixel bleeding effects (lighter colored stones falsely illuminate adjacent pixels, resulting in clasts appearing to be larger than they actually are).

Another alternative approach is based on the use of terrestrial laser scanning (TLS). Several recent studies demonstrate that TLS-derived three-dimensional point clouds provide grain-scale altimetric fields that can be used to infer grain size (Smart et al., 2004; Entwistle and Fuller, 2009; Hodge et al., 2009a, b; Hohenthal et al., 2011; Milan and Heritage, 2012). Based on this, Heritage and Milan (2009) and Brasington et al. (2012) used grain roughness obtained from TLS point clouds to retrieve grain size data in gravel-bed rivers. Also, Milan et al. (2009) and Milan and Heritage (2012) showed grain roughness change maps derived from TLS data. However, TLS surveys are expensive and time-consuming for large-scale applications.

The recent growth and spread of unmanned aerial systems (UASs), coupled with the development and improvement of SfM (Structure from Motion) algorithms (Westoby et al., 2012; Fonstad et al., 2013; Dietrich, 2016; Smith et al., 2016), has enabled the production of highly useful topographic models of fluvial surfaces (Brasington et al., 2012; Micheletti et al., 2014, 2015; Tamminga et al., 2014). The UAS-based SfM photogrammetry provides reconstructions of unvegetated and exposed fluvial topography comparable to those derived by airborne and terrestrial LiDAR (Westoby et al., 2012; Smith and Vericat, 2015), with the main advantage of less expensive equipment. Therefore UAS-based SfM photogrammetry could seemingly provide high quality, spatially distributed roughness and morphology data that are needed by hydraulic and morphodynamics models (Tamminga et al., 2014). For example, some recent morphodynamic models (i.e., Lauer et al., 2016) considered lateral variations in grain size, and UAS-derived SfM terrain models may have the potential to feed them with the required data in this regard.

This paper reports the testing of optical imagery acquired from UAS in connection with SfM and multiview stereo (MVS) photogrammetry to retrieve the GSD of surface bed sediment in a braided gravel-bed river (Vénéon River, French Alps). As it was already mentioned above, previous TLS experiments (Aberle and Smart, 2003; Heritage and Milan, 2009; Brasington et al., 2012) showed that surface roughness computed from 3D point clouds can be used as a proxy of grain size in gravel beds. Here we followed the same approach, using instead SfM-derived point clouds. Three main objectives guided this research: (i) determine the best roughness metric for a percentile estimate from 3D point clouds; (ii) explore whether capturing the spatial variability of surface grain size is possible from distributed roughness information; and (iii) investigate whether detecting changes in surface grain size from roughness information is feasible.

2. Study site

The Vénéon River is a tributary to the Romanche River in the Southern French Alps, draining a 316-km^2 catchment in the Ecrins Massif (Fig. 1A, B). The physical landscape of the basin is dominated by steep rocky slopes, colluvium deposits, and modern and relict periglacial and glacial landforms. Current climate conditions are those typical of a continental, relatively dry and cold climate. The main water source of the Vénéon is La Pilatte glacier, determining a glacial-nival hydrological regime, with the highest discharges between May and August related to snow and glacier melting. High-magnitude flood discharges are related to high temperatures combined with the occurrence of storm-induced heavy rainfalls. The lowest discharges occur between January and March when snowfall dominates. An EDF (Electricité de France) gauging station that has gathered data from 1989 to the present is located upstream of the study site. The mean hourly discharge of this gauging record is 12 m^3 s^{-1}, while the maximum and minimum hourly discharges are 206 and 0.1 m^3 s^{-1}, respectively. The estimated biannual and decadal peak discharges are 110 and 168 m^3 s^{-1}, respectively.

The study reach comprises a 2.5-km-long and 100- to 200-m-wide river reach where the Vénéon develops a braided planform (Fig. 1C). This braided channel is located upstream of a major obstruction related to a large left-bank rock avalanche deposit. The mean channel slope is 0.013. The catchment area at the study reach is 235 km^2. Two single dominant channels can generally be distinguished within the overall braided plain. Several seasonal bar-top channels that cut bar surfaces are present. Water flows permanently in the two main anabranches, while bar-top channels are only active during summer high flow events. A 20-m-high hydropower dam (the *Plan du Lac* dam) was built between 1941 and 1943 immediately downstream of the study reach (Fig. 1). This hydropower dam is managed by EDF.

Bed sediment of the study site is mainly composed of well-rounded and subspherical granitic and metamorphic gravels and cobbles. On exposed gravel bars, the bed sediment is randomly packed, exhibiting a ‘normally loose’ state (sensu Church, 1978) without strong imbrication or well-developed grain arrangements (e.g., clusters, stone lines). Discrete small patches (decametric to metric scales) of sand and fine gravel are spread throughout the coarse framework of gravel bars. Conversely, the underwater channel is depleted in sand sediment; and the bed state is ‘underloose’, composed mainly of closely packed and imbricated coarse particles and grain structures.

3. Material and methods

3.1. Field data acquisition

3.1.1. UAS surveys

Five UAS flights were carried out over the study reach between April and July 2015 using the same unmanned vehicle, a rotatory-wing quadcopter equipped with a GPS for automated flights (Fig. 1C). The capabilities of the vehicle were limited to favorable weather conditions (no rain, wind velocity up to 11 m s^{-1}). Flight height was ~30 m, and the average flight velocity was ~5 m s^{-1}. Images were taken at 1-s intervals using a GoPro HERO 3 + Silver camera (2.77 mm focal length) that was mounted on a Gyro Stabilised Gimbal platform. Images were recorded with a resolution of 5 Mpx (2624 × 1968 pixels), using a narrow field of view (28 mm equivalent focal length).

The SfM-derived point clouds were georeferenced using a set of 92 ground control points (GCPs; Fig. 1C) marked along the study reach using a target design automatically detected by the photogrammetric software (AgiSoft PhotoScan). The targets were deployed in the field and this operation took between 1 and 2 h before every flight. To save time during the successive drone surveys, target positions were marked with paint in those areas overlapping over consecutive flights. The GCP coordinates were measured in the RGF Lambert 93 coordinate system (EPSG 2154) using a dGPS in RTK (Real Time Kinematic) mode (10 s). A unique position of the dGPS receiver was chosen on an elevated point covering the whole study reach, where good satellite constellation coverage was achieved. Furthermore, to increase the accuracy of dGPS data, the coordinates of the receiver position were referred to those of a permanent geodetic point from the IGN (National Geographic Institute) network during post-processing.