Structure from Motion (SfM) to Characterize Fluvial Sedimentology: Case Study Way Semaka River

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Abstract. Structure from motion (SfM) has seen rapid uptake recently in the fluvial sedimentology. This uptake is not least due to the widespread availability of cheap unmanned aerial vehicles/drones, which help mitigate the challenging terrain and deliver efficient and reproducible and high-accuracy images and topographical data. The current study describes the application of SfM in order to build a geomorphological model and estimates surface water velocity of Way Semaka River in BNS region, West Lampung. Way Semaka river is river type with a large meandering system and stable extension tectonic regime, relatively. River morphology approximately 96.62 m width and 4 m depth in straight (relatively) area, whereas in channel area approximately 171.22 m width and 5 m depth. The velocity range between 0.39 – 1.56 m/s based on image analysis and proven by current meter measurements onsite with an RMS error 0.25. Manual geomorphic unit level 2 analysis revealed that for the zone within the channel, 9% of the coverage consisted of basins, 35% of the coverage consisted of convexity, 9% consisted of planar features and 37% of the coverage consisted of the transition zone.

Keywords: SfM, sedimentology, fluvial, Way Semaka, BNS

1. Introduction

River deposits are an important part of the geological footprint, including important information about natural resources found on earth such as hydrocarbon reservoirs, mineral resources, water resources and flood risk management [1]. The need to obtain fluvial depositional models such as geometry and heterogeneity is very important in all economic and social aspects. Despite their importance, there are a number of unresolved issues regarding how fluvial deposits were interpreted from the ancient sedimentary record. Influence channels form a ubiquitous component of all river networks and represent sediment archives containing information about the dynamics of these sites and, through their sediment origin, the basins from which they originate [2].

Structure-from-Motion (SfM) with multi-view stereo (MVS), hereinafter collectively referred to as SfM, is a topographic survey technique that emerged from advances in computer vision and traditional photogrammetry. It can produce high quality dense three-dimensional (3D) point cloud of an object or surface at minimal financial cost. While SfM has only been applied to geoscience applications relatively recently, in a short period of time it has had a transformative effect on scientific disciplines [3], providing very cost-effective and fast 3D surveys of spatial, spatial extent. density and with point accuracy comparable to other survey methods (Table 1). There are also very pragmatic reasons for the rapid uptake of SfM photogrammetry; allows unmanned aerial vehicle (UAV) data to be used more easily and consumer-grade UAVs have come a long way in the last decade in electronic sophistication, ease of use and cost reduction. So, UAV image data has made SfM photogrammetry attractive in comparison to traditional photogrammetry; for example, [4] had to develop a complex photogrammetric procedure to orthorectify images from drone surveys.

Table 1. Typical properties of major survey approaches. [5]

	Without SfM	**With SfM**
Spatial extent (km^2)	TS, dGPS: <1.0 TLS: <5.0 AP: <50 ALS, MBES:<100	Ground-based platforms: 0.01 to 1.0 Airborne platform: <5.0
Spatial density (pts/m^2)	TS, dGPS: <5.0 AP: <10 ALS, MBES: <10 TLS: <10,000	1 to 10,000
Point acquisition rate (pts/hr)	TS: 10^2 dGPS: 10^3 AP, MBES: 10^4 ALS, TLS: 10^6	Millions
Point accuracy (m)	TS: <0.001 dGPS: <0.005 TLS, MBES: <0.05 ALS: <0.2 AP: <0.5	0.01 to 0.2

However, Structure-from-Motion can provide more than just DEM because a full 3D color point cloud is initially generated from which orthophoto mosaics can be extracted. Recent branches of SfM's work in geoscience have considered the extraction of meaningful information beyond standard fluvio-morphological data products and the development of new methods to expand the potential application of SfM in fluvial environments for example, topography mapping and surface water velocity.

In the modern era of applied fluvio-morphology investigation, emerging technologies provide great opportunities for producing more accurate and detailed topographic maps, automating mapping procedures, and quantitatively model river forms and processes. Morphometric analysis and field mapping provide critical templates for various toolkits for integrative river science. Although morphometric analysis can produce continuous derivative outputs, it is often used as a classification exercise to help identify specific features, process zones, and 'river landscape' component parts of continuous data.

Monitoring of river flow is very important for the development of research and management of river science. An important component in calculating river flow is velocity. This is achieved through the use of in situ velocity meters such as current meters, acoustic Doppler current filters (ADCP), and ultrasonic meters. Various remote flow monitoring techniques have been introduced in recent years, including the use of radar and the use of terrestrial and aerial camera sensors. The use of cameras to monitor river flow has been used through a technique known as image velocity. Large-Scale Particle Image Velocimetry (LSPIV), the first image velocity technique introduced in outdoor environments, was originally developed by Fujita (1997) [6] who applied the principles of the classical Particle Image Velocimetry (PIV) technique to fluvial (large-scale) field conditions. Image velocity has been used successfully to monitor river flow in many different applications [7][8].

The aim of this paper is to provide an introduction to SfM and a detailed description of the methods used; make an initial sedimentological analysis in relation to the geometry and internal architecture of fluvial sedimentology, including surface water flow velocity. The focus here is to outline a practical workflow that earth scientists and practitioners interested in deploying SfM can apply to geomorphological research.

2. Materials and Methods

2.1. Images acquisition, processing, and accuracy

Digital photos are the basic input for SfM reconstruction; thus, digital cameras are the primary data collection tools. As with other photogrammetric techniques, the quality of the input image limits the quality of the model output. Geotagging images during acquisition can improve accuracy and reduce processing time and effort. Turner et al. (2014) [9] show that absolute spatial accuracy <1 m can be achieved with geotagged imagery. Cameras without geotagging capability can still be used, but require restrictions from ground control points (GCP) in the processing stage.

The optimal strategy for obtaining the required number of photos and the degree of overlap is site specific and objective. In our experience > 60% overlap between adjacent photos is usually sufficient [10]. The total number of photos required is a function of the area size and the amount of overlap between images. As a general rule, the main features in the reconstruction must be visible in at least three photographs in order for the SfM algorithm to find individual points. Fewer photographs may cause cracks, holes, or distortion in SfM models. However, an excessive number of photos can result in long processing times and unnecessarily large files that are difficult to manipulate during post-processing.

Before applying the UAV and SfM techniques to the Way Semaka Sub-watershed, we tested the absolute and relative accuracy of our reconstruction in the open field. In absolute space, the UAV-SfM technique has a mean horizontal and vertical offset of 2-5 m, as measured by reconstructing the SfM performed with GCP. Relative accuracy is assessed by comparing measurements of objects in the SfM reconstruction with ground-based measurements of the same feature (eg, ground control objects of known size). The one-way test of variance between these measurements did not produce a statistically significant difference, indicating a very high degree of relative accuracy in the SfM reconstruction. Our test results give confidence that the UAV-SfM technique is suitable for examining the features of the Way Semaka Sub-watershed at a medium scale (1-100 meters).

2.2. Surface flow water velocity

2.2.1. Current meters

An ideal current meter should respond instantly and consistently to any changes in water velocity. There are different types of current meter available on the market. They are grouped into three major categories: mechanical current meters, electromagnetic current meters, and the more recently introduced Acoustic Doppler velocity meters. In this research, to measure the surface flow water velocity is using mechanical current meter. The first series of measurements were carried out through equipment installed on the river surface. The river surface has the advantage of following the surface flow velocity. After three consecutive measurements carried out for 5 minutes, the mean surface velocity was determined to be 0.34 m/s. The second measurement and so on can be seen in table 2.

2.2.2. PIVlab

The PIVlab software was developed by Thielicke and Stamhuis as a Graphical User Interface (GUI) in MATLAB for particle image velocity analysis [7], but can also be used in LSPIV applications [8]. This is free software, downloadable from the internet, meanwhile providing tutorials for easy use. Image analysis in PIVlab is carried out on extracted georeferenced images. Analyses were performed on a continuous sequence of frames. The multipass window deformation is applied with two interrogation paths: (i) 64 to 32 px^2 and (ii) 32 to 16 px^2. Both the unreliable height vector and the perverted riparian vector were removed during image post-processing. The analysis lasts 5 minutes, based on computer capabilities and the number of frames selected.

Table 2. GCP locations and surface water velocity locations include surface water velocity data from the flow meter & PIVlab[7].

GCP	Lat	Long	Velocity current meter (m/s)	Velocity PIVlab (m/s)	RMS error
1	-5.203340985	104.276977	0.34	0.57	0.25
2	-5.240679011	104.298941	0.62	0.77	0.26
3	-5.204309011	104.277563	1.45	1.49	0.27
4	-5.212021032	104.282493	0.57	0.68	0.29
5	-5.212545991	104.282622	1.33	1.56	0.31
6	-5.21352198	104.28365	0.89	0.98	0.32
7	-5.219899016	104.287472	0.42	0.71	0.35
8	-5.220987992	104.288718	0.71	1.35	0.37
9	-5.232144976	104.296531	0.36	0.39	0.05
10	-5.23926096	104.297974	0.74	0.68	0.06

The results of the water flow velocity analysis using the PIVlab are depicted in figure 1. The yellow arrow is a velocity vector that is calculated as an average indicating direction and magnitude. Vectors are only visible in locations where natural patterns occur. No tracer is visible above the constructed barrier which should generate a velocity field. There are many reasons for this absence, such as (a) the measurement period is carried out if there are no leaves or branches carried by the river, (b) the river is muddy so it is difficult to distinguish floating particles, and (c) the flight height is 80 m, so no may note sufficient particle size. A known distance must be defined to convert the frame pixels to their real dimensions. The point bar width that is known when measured at the location becomes a reference. PIVlab has the ability to provide statistics and graphs based on the cross section or designed area.

A greater speed is depicted in the middle of the river, due to the low depth and absence of obstacles, while there are also two lanes on the left and right. The two positions of slow velocity are due to the presence of vegetation and rocks that are also depicted. The upstream portion of the river with the barrier constructed is represented as expected, at zero or very low velocities because there is no sufficient turbulence pattern to obtain the velocity field. The greater velocity (> 1.4 m/s) occurred in the middle of the river between 17 and 23 m from the left side of the bank, because there was no major obstruction. There are two points whose velocity is close to zero at a distance of 3–5 m and 29–39 m from the left side of the cut bank, due to the presence of vegetation and rocks.

2.3. Fluvio-morphology

As figure 1 illustrates, the Way Semaka Sub-watershed has pockets of discontinuous floodplain, confirming that this is a partially limited valley arrangement. Sometimes, the boundary is the boundary of the valley itself (i.e. the hillside). The channel has a fairly tortuous plan shape, partly as a result of transitions between the margins and partly from the bends themselves. The groove has limited capacity to adjust laterally unless there is sufficient width of the valley floor. This range is characterized by a partially delimited valley with moderate sinuosity, a discontinuous floodplain controlled by a valley.

Manual geomorphic unit level 2 analysis [11] revealed that for the zone within the channel, 9% of the coverage consisted of basins, 35% of the coverage consisted of convexity, 9% consisted of planar features and 37% of the coverage consisted of the transition zone (Figure 1). Larger basins, more temporary storage of sediment, a small number of planar units, and many transitions between individual units indicate a fairly complex habitat.

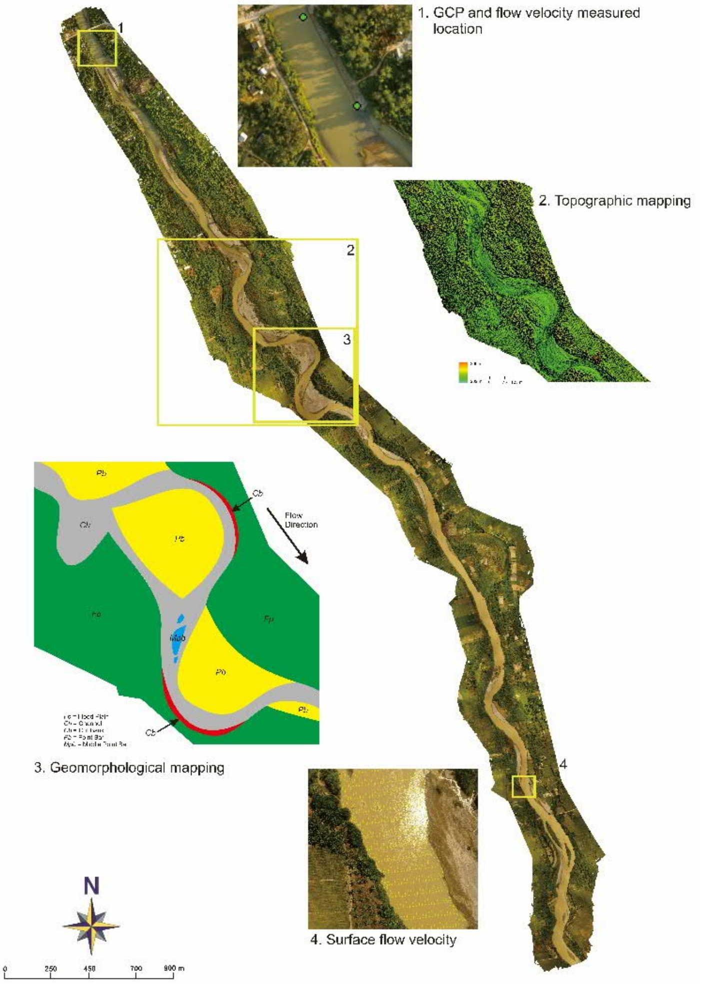

Figure 1. SfM applications to detect fluvio-morphological characteristic of the Way Semaka Sub-watershed

3. Discussion

Based on the proposed framework to be used for large-scale (> 1 km) fluvio-morphological characterization, it is necessary to increase its cost-effectiveness by reducing the amount of GCP to be applied. Recent work by several authors (eg, [12][13]) has contributed to addressing this gap in knowledge. This, coupled with improved UAV battery performance, data retrieval and less CPU demanding software make a UAV-based framework a reasonable choice for robust and accurate wide area (> 1 km) fluvio-morphological assessments. Subsequent work should compare the performance of the proposed framework with existing classification techniques for geomorphological environments.

The strong trade-off between resolution and spatial coverage suggests that some aspects of the fluvio-morphological characterization can be obtained from UAV imagery but that a supporting remote sensing method may be needed to address the remaining aspects. For example, the strong reliance on image textures required for SfM implementation can also interfere with large-area implementation of frameworks. If the texture of the image is disturbed, SfM will not detect a feature match between the overlapping images and fail to produce an orthomosaic image of the surveyed area. Therefore, further research is needed to address these points before such a framework can be adopted for large area monitoring. The RGB images collected for this study allow a qualitative assessment of fluvio-morphological features (such as topographic mapping and surface water velocity calculations) but do not facilitate quantitative estimation of depth. It has been highlighted by some authors that RGB images present limited radiometric resolution which hinders restoration of topography in darker parts (eg shadows and deep water)[14]. These problems can affect the level of accuracy in all calculations which is reflected in the error value.

4. Conclusion

Based on aerial photograph data and current meter measurements can describe the fluvio-morphological conditions in the Way Semaka Sub-watershed. The test results give confidence that the UAV-SfM technique is suitable for testing the features of the Way Semaka Sub-watershed on a medium scale (1-100 meters). The speed range is between 0.39 - 1.56 m/s based on image analysis and proven by measuring the current meter at the location with an RMS error of 0.25. Manual geomorphic unit level 2 analysis shows that for the zone within the groove, 9% coverage consists of basins, 35% coverage consists of convexities, 9% planar features and 37% coverage consists of transition zones.

5. References

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