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Structure from Motion (SfM) method to characterize fluvial sedimentology in Way Semaka river in Lampung province, Indonesia

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Abstract. Structure from motion (SfM) has been applied recently in fluvial sedimentology. This application is due to the availability of many low-cost unmanned aerial vehicles/drones, which can help overcome challenging terrain, provide efficient and reproducible and high-accuracy topographic images and data. The current study describes the application of SfM to build a geomorphological model and estimate the surface water velocity of the Way Semaka River in the Bandar Negeri Suoh (BNS) region in the West Lampung area. Way Semaka is a river type with an extensive 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 proven by current meter measurements onsite with an RMS error of 0.25. Manual geomorphic unit level 2 analysis revealed that 9% of the coverage consisted of basins for the channel's zone, 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

One of the geological footprints that has important information about natural resources found on earth such as hydrocarbon reservoirs, mineral resources, water resources, and flood risk management [1]. Geometry and heterogeneity are examples of depositional models that are needed and essential for economic and social aspects. Several problems remain in question today, mainly how fluvial deposits can be used to reconstruct geological history. One of the essential parts of a fluvial system is a channel that connects all river networks and provides information about the dynamics of sedimentation and the basins from which the sediments originate [2].

Structure-from-Motion (SfM) with multi-view stereo (MVS), is a combination of advances in computer vision and conventional photogrammetry used for topographic survey techniques. This method can produce a dense three-dimensional (3D) point cloud with high resolution of an object or surface at an affordable operating cost. SfM, while it is only applied to geoscience applications that have relatively transformative effects on scientific disciplines [3], provides a very economical and spatially fast 3D survey over a wide area. The density and level of point accuracy comparable to other survey methods can be seen in Table 1. Several pragmatic reasons for using this SfM method, namely the data obtained in the form of data resulting from unmanned aerial vehicle (UAV) shooting, which UAV for now has developed very rapidly and is easy to use even for ordinary consumers. Thus, the image data obtained from the UAV has made the SfM photogrammetric method more attractive than conventional photogrammetry; for example, [4] developed a complex photogrammetric concept orthorectifying photos obtained from drone surveys.

Table 1. Relationship between the SfM photogrammetric characteristics and area, density, and accuracy [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, SfM can generate more than ordinary topographical contour because the extracted orthophoto motion is obtained from a full 3D color point cloud. One of the newest methods in the field of geoscience that utilizes SfM has considered the extraction of other information besides the primary fluvio-morphological data and the development of the SfM method in the fluvial environment, for example, is topographic mapping and surface water velocity.

For applied fluvio-morphological investigations in the modern era, sophisticated technology has been presented, which provides an excellent opportunity to obtain more accurate and detailed topographic contours, mapping automation, and quantitative modeling of river shape and activity. Field mapping and morphometric analysis provide basic templates for various toolkits for integrative river science. Morphometric analysis is often used as a classification exercise to identify specific features, process zones, and "river landscape" parts of continuous data, although its analysis can produce continuous derivative outputs.

River flow monitoring is a significant thing that the development of research and management of river science. An essential component in calculating the flow of a river is velocity. This can be obtained using in situ velocity meters such as ultrasonic meters, current meters, and acoustic Doppler current filters (ADCP). The use of terrestrial and aerial radar and camera sensors is an example of several long-range flow monitoring techniques that have been introduced in recent years. Image velocity is a river flow monitoring technique using a camera. Large-Scale Particle Image Velocimetry (LSPIV), Fujita in 1974 [6] developed the first image velocity technique in outdoor environments to apply the classic Particle Image Velocimetry (PIV) technique for fluvial (large-scale) environment. The application of image velocity has been successfully used in various river flow monitoring applications [7-8].

This study aims to introduce SfM and a detailed description of the methods used; make an initial sedimentological analysis about 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. Image's acquisition, processing, and accuracy

Photos are the core data in carrying out the SfM reconstruction; thus, digital cameras are the primary tools used to collect data. Photos used as input significantly affect the quality of the resulting model; this applies to other photogrammetry techniques. The photos obtained during the acquisition can improve accuracy and reduce time; they can also improve processing efficiency. Turner et al. [9] showed that absolute spatial accuracy <1 m can be achieved with coordinated photo images. The addition of ground control points (GCP) can be added during processing on cameras that do not have geotagging capabilities.

Determination of specific and objective locations is the optimal strategy in obtaining the required number of photos and the level of overlap. The overlap between adjacent photos> 60% has resulted in a reasonably good model [10]. The function of the area size and the amount of overlap between images is the definition of the total number of photos required. The main thing in object reconstruction must be visible in at least three photographs for the SfM algorithm to find individual points, and this is a general rule. Fewer photos may cause cracks, holes, or distortion in the SfM model compared to more photos. However, the large number of photos can result in extended processing times, and the resulting file is large, making it challenging to manipulate after processing.

Before applying the UAV and SfM techniques to the Way Semaka Sub-watershed, the test was carried out regarding the absolute accuracy and relative reconstruction of the open field. The UAV-SfM technique has a mean horizontal and vertical error of 2-5 m measured using GCP when reconstructing it in absolute space. The measurement comparison between the object of the SfM reconstruction and the direct measurement (the object whose size is known) becomes a test of relative accuracy. This relative test did not produce a statistically significant difference, indicating that the relative accuracy rate was very high in the SfM reconstruction. The results of this test indicate that the UAV-SfM technique can be applied to map medium-scale fluvio-morphology (1-100 meters) in the Way Semaka Sub-watershed.

2.2. Surface flow water velocity

2.2.1. Current meters

The ideal flow meter should respond instantaneously and consistently to any change in water velocity. There are different types of flow meters available, and they are grouped into three main categories: electromagnetic current meters, mechanical current meters, and Acoustic Doppler speed meters. In this research, to measure the surface flow water velocity is using the mechanical current meter.

2.2.2. PIVlab

Thielicke and Stamhuis developed PIVlab software as a Graphical User Interface (GUI) in MATLAB, which functions to analyze particle image velocity [7] and can be used for LSPIV applications [8]. For ease of use, tutorials and software can be downloaded for free from the internet. Image analysis in PIVlab is carried out on extracted georeferenced images. The analysis stage is carried out in a sequence of continuous frames. The multipass window deformation is applied with two interrogation paths: (i) 64 to 32 px^2 and (ii) 32 to 16 px^2. The chaotic height vector and the contrasting riparian vector were removed during the final image processing. The assessment lasts 5 minutes, referring to the power of the computer and the selection of the number of frames.

3. Results and Discussions

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.

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 use of PIVlab in analyzing water flow velocity is described in Figure 1. The yellow arrow is a velocity vector which is calculated as an average indicating direction and magnitude. The pattern formed at each location is a vector. No tracer could be seen above the constructed barrier, which should have resulted in a velocity pattern. There are several reasons for this absence, such as (a) carrying out the measurement process when no leaves or twigs are floating in the river, (b) the river is muddy, which results in difficulty distinguishing floating particles; and (c) the flight is carried out at an altitude of 80 m, which resulted in the absence of an adequate record of particle size. The measured distance must be predefined to convert the frame pixels to their actual size. The width of the point bar known when measured at the location becomes a reference. Statistics and graphs can be obtained using the PIVlab based on the cross-section or designed area.

The middle of the river has a higher speed; this is due to the high depth and the absence of obstacles. Meanwhile, the two lanes on the left and right have slow velocity due to rocks and vegetation. The middle point bar yields a very slow velocity, as expected. This is because there is no sufficient turbulence pattern to get the velocity field. The middle of the river has a speed > 1.4 m/s, which is more significant when compared to the left side, which is 17 m away, and the right side is 23 m from the bank because there are no significant obstacles. Two locations have very low velocities, at a distance of 3–5 m and 29–39 m from the left side of the cutting edge, because of vegetation and rocks.

Figure 1 illustrates that the Way Semaka Sub-watershed has pockets of discontinuous floodplain, confirming a partially limited valley arrangement. Sometimes, the boundary is the boundary of the valley itself (i.e., the hillside). The channel has a reasonably tortuous plan shape, partly due to 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 sediment storage, a small number of planar units, and many transitions between individual units indicate a fairly complex habitat.

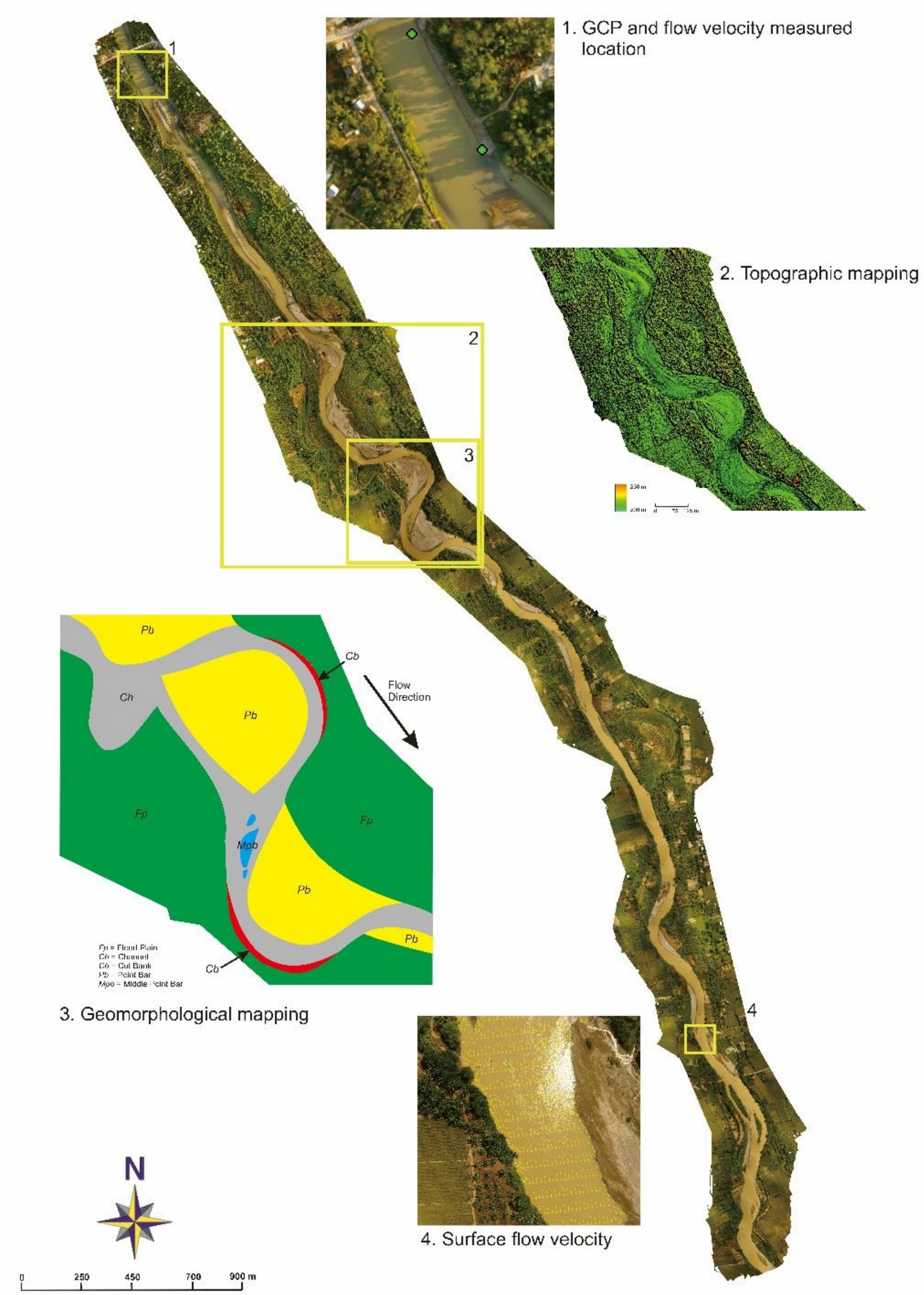

Figure 1. SfM applications to detect fluvio-morphological characteristics of the Way Semaka sub-watershed.

The large-scale (> 1 km) fluvio-morphological characterization that has been carried out requires cost efficiency, especially the amount of GCP usage. Recent studies also suggest that using a suitable GCP saves costs and produces a suitable model [12-13]. Developments in UAV technology such as more optimal battery performance, ease of data retrieval, and software that demands less CPU make UAV-based frameworks a sensible choice for robust and accurate (> 1 km) wide area fluvio-morphological characterization.

Comparing the proposed framework performance with geomorphological environmental classification techniques becomes the following work. Remote sensing methods are needed to overcome the shortcomings of UAV images related to resolution and spatial coverage. However, some aspects of fluvio-morphological characterization can be obtained from UAV images. For example, the high-resolution image textures required for SfM implementations can also interfere with implementing frameworks over large areas. If the image texture is disturbed, SfM will not detect a feature match between the overlapping images and fail to produce an orthomosaic image at the measured location. So further research is needed to address these issues before the framework is adopted for monitoring large areas.

The RGB images collected for this study allow a qualitative assessment of fluvio-morphological features (such as topographic mapping and calculations of surface water velocity) but do not facilitate quantitative depth estimation. Some authors have highlighted that RGB images present a limited radiometric resolution which precludes restoration of topography in darker parts (e.g., shadows and deep water) [14]. Such problems can affect the level of accuracy in all calculations that are reflected in the error value.

4. Conclusion

The 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 Way Semaka Sub-watershed features 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 groove zone, 9% coverage consists of basins, 35% coverage consists of convexities, 9% planar features, and 37% coverage consists of transition zones.

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