



A REVIEW OF UAV PHOTOGRAMMETRY APPLICATION IN ASSESSING SURFACE ELEVATION CHANGES

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Abstract:

Assessing large scale topography and surface elevation changes usually requires temporal remote sensing and aerial photogrammetrically-based data. Usually, very high resolution (VHR) elevation data, for instance, digital surface models (DSM) from light detection and ranging (LiDAR) and unmanned aerial vehicles (UAV), are used to visualise the changes in surface elevation. Therefore, this study attempts to review different case studies of assessing topography and surface elevation changes, specifically on geomorphological change detection (GCD) based on UAV photogrammetry data. The case study areas at Five Finger Strand (NW Ireland), Rosolina Mare (Italy) and Elbow River, Alberta (Canada) were discussed. This paper reviews the theory of UAV, surface elevation changes, and the summary of a related case study of surface elevation changes. The finding can provide a deep understanding of UAV applications in assessing surface elevation changes using UAV photogrammetry data.

Keywords:

UAV Photogrammetry, Topography, Surface Elevation Changes, Geomorphological Change Detection (GCD)

Introduction

The emergence of unmanned aerial vehicles (UAV), specifically in earth science, has revolutionised the way of collecting, processing, analysing, and output visualisation

(Brasington et al., 2021). The conventional methods like physical measurement are extremely risky and dangerous, such as collecting data in dense mangrove forests or slope-mountainous areas. Despite a low-cost, high accessibility, and safe approach, the accuracy of UAV photogrammetry, which is comparable to the physical measurement (i.e., terrestrial laser scanner (TLS) and global navigation satellite system (GNSS)), makes the UAV platform an alternative for data collection (Cucchiario et al., 2020).

UAV photogrammetry data comprises various outputs according to its sensor. If a digital camera comprises a CCD or CMOS sensor of red, green, and blue (RGB) colour, it can usually generate an orthomosaic, a digital surface model (DSM), a point cloud, a tiled model, and other related photo-based output (Aasen et al., 2018). For earth science applications, particularly to evaluate surface elevation changes, DSM is the main data to be used. The temporal DSM data shows earth's topography by quantifying surface change rates (i.e., erosion and accretion) from the old to the latest DSM (Turner et al., 2015; Clapuyt et al., 2016; Chen et al., 2018).

However, multi-temporal analysis of UAV data based on differential DSM should be the most suitable method for generating the best accuracy. The common multi-temporal analysis of UAV DSM is geomorphological change detection (GCD), which has been used for centuries. The method keeps evolving with the emergence of new sub-methods such as the differential of DSM (DoD), slope local length of autocorrelation (SLLAC), and other sub-methods to improve the accuracy of the output.

Hence, this study examines a sub-method in GCD for assessing surface elevation changes at the riverbank based on UAV photogrammetry data. The review focuses on case studies at Five Finger Strand (NW Ireland), Rosolina Mare (Italy) and Elbow River, Alberta (Canada). The review comprises data acquisition, results, and discussion of surface elevation changes for the case study, which led to a better understanding of this issue.

An Overview of UAV Photogrammetry

Introduction to UAV

An Unmanned Aerial Vehicle (UAV) is an aircraft that does not require a pilot on board and uses aerodynamic forces to provide vehicle lift. It can fly and be piloted autonomously, expendable or recoverable, and can carry a lethal or nonlethal payload (Bone and Bolckcom, 2003). These aircraft are varied in terms of size and may be controlled remotely or can fly autonomously. The flight of UAVs may operate with various degrees of autonomy, either under remote control by a human operator or autonomously by onboard computers. In its former existence, it served the purposes of observation and tactical planning, especially in the military field. Now, their use is expanding to commercial, scientific (Mohamad, 2019; Mohamad et al., 2019), recreational, and agricultural (Faical et al., 2014; Brown and Giles, 2018; Wang et al., 2018; Fengbo et al., 2017) and surveying and mapping (Siebert and Teizer, 2014; Turner et al., 2016; Remondino et al., 2011).

According to Tsach et al. (2010), they also call UAVs "drones," and the public widely uses the terminology "drone" instead of "UAV." There are multiple terms used for unmanned aerial vehicles. Some terms related to UAVs include: Remotely Piloted Aircraft (RPA), Unmanned Aircraft (UMA), Automatically Piloted Vehicles (APV), Remotely Piloted Vehicles (RPV), Remotely Operated Aircraft (ROA), and Unmanned Vehicle Systems (UVS). Meanwhile, the

term "remotely piloted vehicle" refers to aircraft electronics flown by pilots using control stations on earth that were introduced by the United States Department of Defense (Eisenbeis, 2004).

Types of UAV

UAVs are classified into several types and categories. Defence agencies have their standards, and civilians have their ever-developing loose categories for UAVs. People classify them by size, range, and endurance and use a tier system that is employed by the military. For classification according to size, the classes comprise tiny, small, medium, and large UAVs. UAVs are also classified according to the ranges they can travel and their endurance in the air, with the US military developing the following sub-classes, which include very low-cost close-range, close-range, short-range, mid-range, and endurance UAVs. For commercial uses such as research, agricultural, industrial, and mapping, the common UAVs that have been used include multi-rotor, fixed-wing, single-rotor, and fixed-wing hybrid Vertical Take-off Landing (VTOL) (Chapman, 2016).

Application of UAV Photogrammetry in Surface Elevation Change Mapping

An Overview of Surface Elevation Changes in the Mangrove Forest Area

McIvor et al. (2013) defined mangrove surface elevation changes as the changes in height from the surface or mangrove substrate, usually measured in relation to a local datum such as mean sea level, over a period of time. The elevation of a point on the earth's surface is the height of that point measured from a reference point or datum. There are two types of processes that trigger the changes in mangrove surface elevation, which are known as surface and sub-surface processes.

Surface processes refer to those processes which occur at or above the mangrove surface, including sedimentation (the deposition of material on to the surface), accretion (the binding of this material in place), and erosion (the loss of surface material). Surface processes include all processes that affect the material arriving at the sediment surface and the fate of this material (Rumsby et al., 2008).

Surface Elevation Changes Quantification Using the Geomorphological Changes Detection (GCD) Method

Geomorphic change detection (GCD) is a technique to measure changes from the geomorphic processes of erosion and deposition that are inferred from repeat topographic surveys (James and Robson, 2012; Kasprak et al., 2019). Because of the quantitative and spatially explicit results it yields, geomorphic change detection is rapidly becoming a more common tool in the monitoring of rivers and, in particular, restoration monitoring (Gillan et al., 2016). The greatest challenge in employing such techniques is quantitatively distinguishing changes because of geomorphic processes from those changes because of noise and uncertainty inherent in the digital elevation models (Wheaton et al., 2010; Anderson, 2019; Sofia, 2020).

DEM of Difference (DoD) is a technique to quantify the volumetric change between successive topographic surveys based on two different DEMs and is considered part of the GCD method. While the essence of the technique is relatively simple, distinguishing between real geomorphic change and survey noise requires appropriate approaches to error analysis to ensure that DoDs are reliable. This method is essential in the GCD method when DEMs are constructed from

fusions of data gained using different survey or analysis techniques, causing the vertical error to be spatially and/or temporally variable across component DEMs (Wheaton et al., 2010).

Geomorphic Change Detection (GCD) was applied volumetrically, using DEMs or in the plan where geomorphological features were delimited by remote sensing imagery or cartography. Here, it was concerned with volumetric GCD where two DEMs that share the same geodetic control (Bannister et al., 1998) were subtracted from one another to reveal a mosaic of morphological change (James et al., 2017).

DEMs of difference (DoD) are calculated to detect changes in the soil surface topography over time and to quantify the volumes of sediment that have been eroded and deposited (Candido, 2019). Georeferenced DEMs from different periods are subtracted from each other to produce a raster of morphological change, as shown in Equation 1, where t_2 is the present DEM and t_1 is the old DEM data.

$$DoD = DEM_{t_2} - DEM_{t_1} \quad (1)$$

Assessment of Surface Elevation Changes Using UAVs

To calculate surface elevation changes, multi-temporal DEM data is needed. In the geospatial and geomatics fields, DEM is considered the final product upon the completion of the data collection process. In aerial photogrammetry, airborne is still an efficient platform for collecting data as a photograph of the earth's surface, after the ancient platforms such as air balloons during the ancient photogrammetric era (Amad, 2012). Airborne photogrammetry will continue to collect the data until the flight path is completed, and it will usually be able to complete flight missions much longer because of its large fuel tank and long durability even during poor weather conditions (Boukoberine et al., 2019).

DEM data is now much easier to obtain because UAVs provide much cheaper and lower-cost flight missions. The market already has enough low-cost UAVs to perform aerial photogrammetry data acquisition, though the duration of each flight does not even reach one hour due to the inability to withstand bad weather (Hardin and Jensen, 2011; Whitehead and Hugenholtz, 2014). However, this technology still provides an opportunity for a researcher to obtain the DEM data much more easily and frequently, with a lower budget compared to using airborne as the platform. Because of the evolution of aerial photogrammetry's data acquisition, the study of surface elevation changes using GCD analysis will increase, more methods will be invented by researchers, and it will help this field keep evolving in the future.

Related Case Studies

Five Finger Strand, NW Ireland

Through their study, Guisado-Pintado et al. (2019) assessed the applicability, limitations, and effectiveness of using TLS and SfM-UAV techniques for 3D mapping when used over a complex beach-dune system in northwestern Ireland. They used a study area with a range of terrain types incorporating a flat beach, cobble ridge, sparsely vegetated foredune up to a well-developed (N20 m) and fully vegetated dune system and presented an approach for the application of vegetation filters for TLS and SfM UAV based on the use of GPS as a benchmark across this range of surface terrain to better explain the major sources of error in DEMs.

They carried out a conventional coastal survey following best practises reported in the literature concerning errors and their mitigation for topographic surveys, using both TLS and the SfM-UAV, to create optimal DEMs using the best possible analysis for each sensor and analytical procedure. For each technique, two DEMs, at 0.2 m and 0.5 m resolutions, were generated using Natural Neighbour binning as an interpolation method and the minimum value within a 0.1 m cell size to account for vegetation filtering. Furthermore, a DoD was performed for each pair of DEMs. Since the DEM generated from the SfM-UAV was subtracted from the TLS-DEM, spatially positive differences in elevation were represented in blue (SfM-UAV higher than TLS) and negative (SfM-UAV lower than TLS) in red. The comparison between the two DEMs (resolutions of 0.2 m and 0.5 m, respectively) shows that, although not significantly, final DEM resolution influences the resulting 3D topographic differences (Z_{diff}). In this respect, the total area of detectable change was increased from 47% to 48% when increasing the cell size, leading to a difference of $\pm 300 \text{ m}^2$ in areas with negative and positive differences, respectively.

The DoD histogram (Figure 1a) reveals that 96% of the differences are in the range of -0.5 m to 0.5 m and 64% between just -0.21 m and 0.21 m, suggesting that after vegetation filtering, there are still other variables accounting for differences between both techniques. The TLS and SfM UAV DEM modelled differences follow a quasi-Gaussian distribution, where most of the differences are lower deviations in elevation $\leq \pm 0.7 \text{ m}$, corresponding to the surface of around 3700 m^2 . In terms of volumetric differences (on a cell-by-cell basis, the DoD depth multiplied by cell area and summed for those areas), the total volume of difference between both DEMs accounts for 273 m^3 (32% positive and 68% negative differences).

Elbow River, Alberta, Canada

In their study, Tamminga et al. (2015) used remote sensing imagery collected with small unmanned aircraft systems (UASs) to address the controls on channel change associated with a major flood. They documented reach-scale spatial patterns of erosion and deposition using high-resolution (4–5 cm/pixel) orthoimage and digital elevation models (DEMs) produced from photogrammetry. Significant bank erosion and channel widening occurred, with an average elevation change of -0.24 m.

The year 2012's images were processed with the EnsoMOSAIC UAV package, and the 2013 images were processed with Pix4D software. Both software suites calculate internal camera orientations and calibration parameters for subsequent steps. The Pix4D software automates traditional photogrammetric steps and incorporates novel algorithms for determining camera positions and matching key points between images (like the scale-invariant feature transform (SIFT) (Lowe, 2004)). The process then involves automatic aerial triangulation (AAT) to calculate ground coordinates regarding the measured GCPs and bundle block change (BBA) iteratively to optimise mosaic accuracy. Once the BBA error was minimised, a digital elevation model (DEM) was generated and used to orthorectify the image mosaic. The resulting orthomosaics and DEMs had spatial resolutions of 5 cm/pixel and 4 cm/pixel for the 2012 and 2013 surveys, respectively.

Observable flood effects from the orthomosaics can be examined in more detail with the use of the DEMs and the change detection analyses applied. Pre- and post-flood DEMs and the DoD were shown in Figure 1b. The planform changes in the orthomosaics are supported by the topographic data, with low-flow channels clearly demarcated in detrended DEMs. The DoD

shows variable changes in elevation, with overall reliable change detection because of the high-magnitude elevation changes relative to the minimum threshold. Of the 183,447 m² study area, 89% of vertical change was above the detection threshold. Spatial variations in the DoD reflect infilling of pre-flood low-flow channels and the carving of new channels, along with significant bank erosion.

Summaries of area and volumetric erosion and deposition using GCD are shown in Table 1. For these analyses, area changes reflect the total surface area within a vertical change bin, and volumetric changes were calculated as area distributions multiplied by the depth of elevation change for each area. Overall, the study reach experienced a net volumetric change of $-38,988 \pm 23,860$ m³, much of which is because of bank erosion. The conservative error values for interpolated bank areas explain the high uncertainty in this estimate. This net volumetric change corresponds to a net elevation change of -0.24 ± 0.15 m averaged over the study reach. However, scour and fill were both significant throughout the reach, as 36% of volumetric change was depositional and 64% was erosional. If it excluded the areas of bank erosion from the change detection to focus on the active channel bed, the net volumetric change would be 14.775 ± 4277 m³. Given the accuracy of elevation data for the active channel, uncertainty was substantially reduced, showing a net depositional budget in the channel bed itself.

Rosolina Mare, Italy

In their study, Taddia et al. (2019) found that aerial photogrammetric data was gained during flight repetitions by using Unmanned Aerial Vehicles (UAVs) with the camera in a nadiral arrangement to monitor a long-term complex dune system. It carried six different surveys out between November 2015 and December 2017 in the littoral of Rosolina Mare (Italy). Aerial photogrammetric data was gained during flight repetitions by using a DJI Phantom 3 Professional with the camera in a nadiral arrangement. The processing of the captured images comprises the reconstruction of a three-dimensional model using Structure-from-Motion (SfM). Each model was framed in the European Terrestrial Reference System (ETRS) using GNSS geodetic receivers in Network Real Time Kinematics (NRTK).

The analysis of the DoD in Figure 1c thus shows how the phenomenon is clearly detectable through two years of monitoring. A polygon was selected to be the most representative as possible (Figure 1c). The stable dunes region shows a mean value close to zero, with a discrepancy (-0.029 m) that is comparable to the 0.046 m standard deviation. This is due to the very low rate of evolution of stabilised back-dunes, especially if assessed over a two-year period only. Conversely, the study area was characterised by significantly positive mean values ($+0.229$ m and $+0.359$ m), respectively, and thus they describe an actual ongoing deposition caused by aeolian transport. Again, this confirms the high dynamics of the dune system seaward. Min/max values point out that few outliers are still present in the stable dunes region despite the performed data filtering and that the polygons of the other zones are not perfectly homogeneous.

Summary of the Case Study

This sub-section displays the comparison of case studies at Five Finger Strand, Rosolina Mare, and Elbow River in assessing topography and surface elevation changes based on the UAV photogrammetry method (Tamminga et al., 2015; Guisado-Pintado et al., 2019; Taddia et al., 2019). The review comprises mean, median, standard deviation, root-mean-square error (RMSE), as well as volumetric error, which comprises erosion, deposition/accretion, and net

change. Table 1 tabulates the comparison of all case studies based on the following accuracy benchmarks.

Table 1: Comparison of Case Study Related to GCD at Riverbank

Case study area	Five Finger Strand, NW Ireland	Rosolina Mare, Italy	Elbow River, Alberta, Canada
Mean error (m)	1.59	0.229	0.032
Min-Max range error (m)	2.49	0.433	0.320
Standard deviation error (m)	1.59	0.055	0.007
RMSE (m)	-	-	0.088
Erosion (m ³)	-500	-80	-89294+22284
Deposition/accretion (m ³)	+200	+40	+50306+8528
Net change (m ³)	-300	-40	-38988+23860

The other results were shown in Figure 1, which displays the DoD for geomorphological change detection for each study area; Figure 1a (Five Finger Strand, NW Ireland), Figure 1b (Rosolina Mare, Italy) and Elbow River, Alberta, Canada. According to Figure 1, each study area displayed a clear surface elevation change in which erosion is dominant compared to accretion and deposition. Most of the case studies were carried out due to post-disaster events such as storms (Figure 1a and 1b) and floods (Figure 1c).

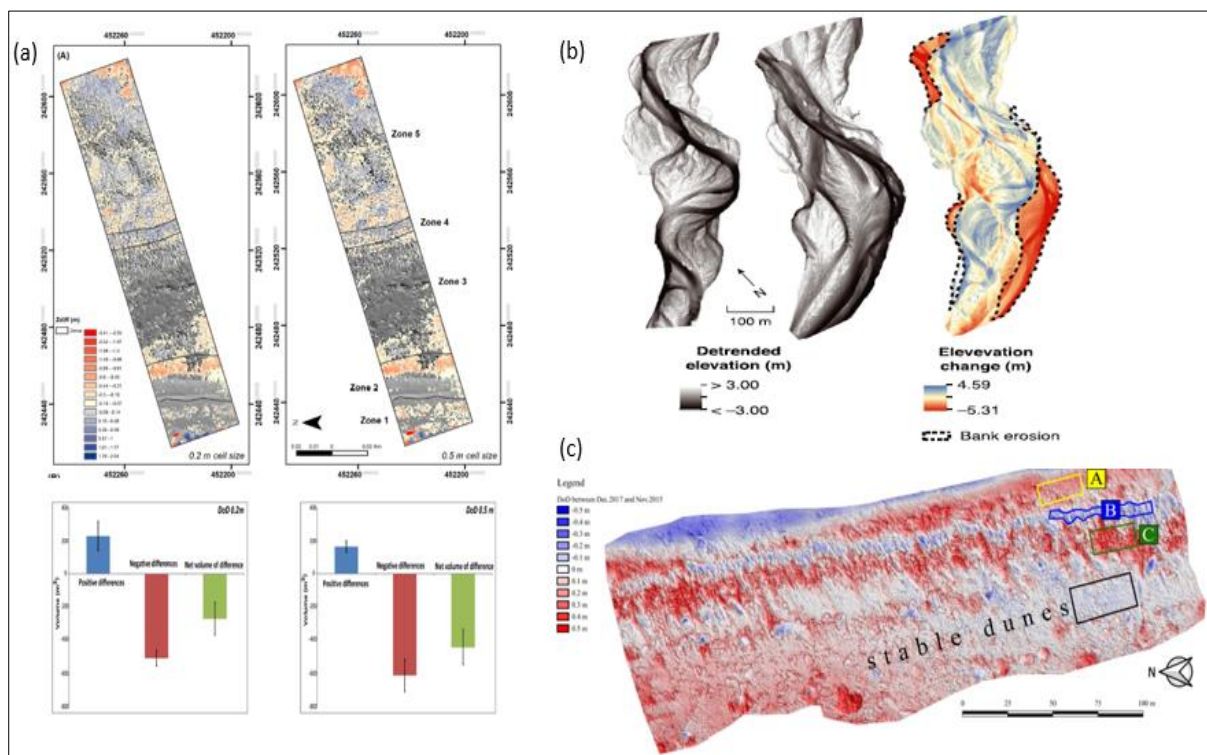


Figure 1: DoD Output Using GCD Method at Various Study Areas Showing Red (Erosion) and Blue (Accretion/Deposition); (a) Five Finger Strand, NW Ireland (Guisado-Pintado et al., 2019); (b) Rosolina Mare, Italy (Taddia et al., 2019); (c) Elbow River, Alberta, Canada (Tamminga et al., (2015))

Conclusion

Surface elevation changes based on UAV photogrammetry data at the riverbank can be assessed using multi-temporal analysis of UAV data based on differential DSM. Based on the case study findings at Five Finger Strand (NW Ireland), Rosolina Mare (Italy), and Elbow River, Alberta (Canada), all results showed unbalanced surface elevation changes in which erosion is more dominant than accretion and deposition, as all net changes in Table 1 showed negative rates. The case studies also showed that the accuracy of the vertical accuracy of DSM generated by the UAV RGB sensor is comparable to the physical measurements like total station, TLS, or GNSS. As a result, the review of the preceding study effectively summarised the application of UAV photogrammetry in assessing topography and surface elevation changes, particularly along riverbanks.

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