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High-resolution monitoring of - Beach topography and its change using unmanned aerial vehicle imagery

Benqing Chen*, Yanming Yang, Hongtao Wen, Hailin Ruan, Zaiming Zhou, Kai Luo, Fuhuang Zhong

Third Institute of Oceanography, State Oceanic Administration, Xiamen, 361005, China

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ABSTRACT

Beaches suffer from considerable degradation due to the dual influences from natural and human-induced factors. Higher resolution topographic data are frequently needed for assessment of the rapid changes and for building the models that can predict the evolution of these natural environments. In this paper, a low-altitude quad-rotor unmanned aerial vehicle (UAV), equipped with a non-metric camera, was used to acquire the two periods of UAV images in a complex beach of Wujiao Bay where the significant geomorphic changes occurred mainly due to the strong scouring of the drainage gullies. A detailed practical technique workflow was presented for deploying the low-altitude UAV for high-resolution monitoring the topography and the changes of the beach. The high resolution orthomosaic with geo-reference accuracy less than 1 pixel and the Digital Surface Model data with high vertical accuracy of approximately 10 cm were achieved by applying the UAV photogrammetry process based on Structure from Motion method to numerous overlapped UAV images. These data were further applied to the topographic change monitoring and analysis of the beach. This study greatly enhanced the applicability of the UAV remote sensing and enriched the existing tools for the high resolution topographic survey and geomorphic change detection in the complex beach.

1. Introduction

Beaches are located in areas with strong land-sea interaction, which are also relatively concentrated areas of human development and activities. The natural erosion process of beaches is frequently accelerated or augmented by anthropogenic actions, which cause significant topographic changes, even over short periods of time. Currently, approximately 50% sandy coastlines in China are suffering from the severe coastal erosion(Luo et al., 2013). To efficiently manage and maintain the beaches, accurate and high-resolution topographic surveys are required to monitor and quantify associated morphological changes. These surveys are typically conducted by using a Real-Time Kinematic or differential Global Position System (DGPS) (Brasington et al., 2000b; Squarzoni et al., 2005), total stations (Fuller et al., 2003; Moss et al., 1999), Terrestrial Laser Scanning (TLS) (Brasington et al., 2012; Fairley et al., 2016; Nagihara et al., 2004) and Aerial Laser Scanning (Dewitte et al., 2008; McKean and Roering, 2004; Notebaert et al., 2009). While these acquisition techniques are increasingly used in geomorphology and result in rich observational datasets, they each have their own limitations.

GPS measurement was the traditional and most commonly used technology for monitoring topography and erosion in beaches. However, this method is limited to only acquiring points and profile data, which cannot present the complete topographic spatial pattern and changes in features, especially in the cases of complicated topography and severely dangerous areas such as steep and unconsolidated slopes. The recently developed TLS can be very accurate, but often requires the arrangement of several scanning stations across several kilometers of narrow beaches due to its limited scanning range of several hundred meters. Although the airborne LIDAR technology is capable of obtaining the spatial elevation data for large-scale coastal areas (Sallenger et al., 2003; White and Wang, 2003), it is high costly and cannot provide data with a comparable spatial resolution and vertical accuracy with respect to TLS and GPS.

With the availability of reliable, low-cost and lightweight unmanned aerial vehicle (UAV) and the rapid development of computer vision algorithms such as the structure-from-motion (SfM), the UAV is becoming a promising technical tool. Furthermore, UAV-based photogrammetry is increasingly being adopted to produce high resolution topography for the study of surface processes (Colomina and Molina, 2014), as a significant supplement to satellite and aerial remote sensing technology. SfM allows for the generation of topography from

* Corresponding author.
E-mail address: chenbenqing@tio.org.cn (B. Chen).

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randomly oriented and distributed photographs (Fonstad et al., 2013; Smith et al., 2016; Westoby et al., 2012). Compared with other approaches, the UAV has the advantages of maneuverability, flexibility, and capability in acquiring images with consumer-grade cameras at very high spatial resolution (centimeter) and high temporal frequency. Recent applications of UAV in the different dynamic environments included vegetation monitoring (Dandois and Ellis, 2010; Jaakkola et al., 2010; Messinger et al., 2016), Antarctic moss beds (Lucieer et al., 2014b; Turner et al., 2014), gully erosion (Gómez-Gutiérrez et al., 2014), glacial dynamics (Immerzeel et al., 2014), landslide (Lucieer et al., 2014a; Niethammer et al., 2012; Turner et al., 2015), fluvial dynamics (Javernick et al., 2014; Miřijovský and Langhammer, 2015), and river bank and gorge erosion(Prosdocimi et al., 2015) and coastal topographic survey and geomorphic change (Clapuyt et al., 2016; Delacourt et al., 2009; Gonçalves and Henriques, 2015; Long et al., 2016; Mancini et al., 2013; Turner et al., 2016).

Particularly in the beach, exploratory researches have shown that the UAVs are very suitable for the high resolution topographic survey and geomorphic change detection by achieving the orthomosaic and digital surface model (DSM) data. Delacourt et al. (2009) developed a set of UAV photogrammetry helicopters equipped with automatic navigation systems to obtain the high-resolution orthomosaic of Porsmillin Beach (French Brittany). Mancini et al. (2013) demonstrated that the accuracy of the elevation data from UAVs was comparable with that obtained by TLS technology in the Ravenna sand dune (Italy). Based on the UAV photogrammetry and accuracy analysis in two beaches, Gonçalves and Henriques (2015) believed that UAVs can replace the conventional flights within the regular coastal monitoring program in the regions, with considerable gains in the cost of the data acquisition and without any loss in the quality of topographic and aerial imagery data. Clapuyt et al. (2016) also assessed the reproducibility of the UAV topographic measurement based on the SfM method, and found the UAV can be used for the monitoring of the multi-temporal topographical changes of beaches if the very high-resolution (centimeter) DGPS are used for field measurements.Long et al. (2016) used UAV images to monitor the topography of a dynamic tidal inlet. Turner et al. (2016)deployed UAV to monitor and assess the post-storm coastal erosion spanning a full coastal embayment. However, in order to extensively assess the accuracy, repeatability and usability of UAVs for monitoring the topography of the beaches, the various cases under different geographical environments are needed.

This study aims at evaluating the applicability of the low-altitude UAV remote sensing for the high resolution topographic survey and geomorphic change detection in the complex beach. The two dates of Oct. 2013 and July 2014 were chosen due to the significant geomorphic changes that occurred as a result of scouring by the gullies in the coast beach during the period. A practical workflow of the UAV photogrammetry method based on SfM was presented to generate a high resolution orthomosaic and extract highly accurate DSM data of the two periods. These data then were used to analyze the geomorphic changes over the nearly one-year period.

2. Materials and methods

2.1. Study area

The beach of the Wujiao Bay (Fig. 1), located in the Dongshan Island, the sixth largest island in China, is concerned in this study. The south-central part of the beach coast (black rectangle region in Fig. 1), an area with 1.5 km length and approximately 200 m average width at low tide, was selected for the UAV monitoring due to its typical geomorphic features. The area was typically characterized by the drainage gullies which were caused by the waste discharge from the aquacultures near the coast, and numerous drainpipes across the beach for allowing the passage of sea water into the aquacultures near the coast. Some of the gullies extend for several hundred meters across the beach, with depths of up to 1 m and widths of 3 m (Fig. 2a), which result in more serious erosions on the beaches. The main hydrodynamic forces for Wujiao Bay are generally tide and seawave. The tidal type is irregular semidiurnal tide, with the mean tidal range of about 2.3 m and the average flow rate of approximae 1.0 m/s. The seawave nearshore is dominated by the wind-driven wave. In the past years, the beach geomorphic features changed quickly as a consequence of several factors including the drainage gullies, strong waves and tide. The beach coastline was also severly damaged (Fig. 2b), which had posed a great threat to the power windmills close to the coast.

2.2. UAV remote sensing system

The MD4-1000 quad-rotor UAV system made by the Microdrones Company was used to obtain the UAV images of the beach. The quad-rotor UAV (Fig. 3) has the advantages of not requiring a runway, low demand of taking off and the landing site, and is suitable for acquiring the UAV images in harsh environments, such as the coasts and the sea-islands. The MD4-1000 system is mainly composed of an unmanned aircraft, remote controller, ground control station and non-metric camera by integrating with many advanced sensors, such as DGPS, inertial navigator, barometer and magnetometer. The UAV can implement the functions of spot hover and GPS position hold in addition to allowing flight by an autopilot along the flight lines determined in the flight plan. The max cruising speed is about 12 m/s. Power is supplied by a Lithium-Polymer battery that is specified for lasting for approximately 88 min. In actual use, the flight duration was controlled for less than 30 min for security with recommended load of 800 g, especially with moderate winds, low temperatures or low air pressure conditions.To monitor larger area , more than one flight would be required with demanding a battery replacement. The MD4-1000 can operate in a wind speed less than 12 m/s, but less than 6 m/s in order to stabilize the flight enough to obtain the high-qualified images with no coverage gap. The ground control station is used to monitor most of the flight parameters and real-time photos by the radio linkage. The main specifications of the quad-rotor UAV system are shown in Table 1.

2.3. Acquisition of UAV images

Prior to the UAV flight operation, a preliminary field investigation is needed to obtain more knowledge about the beach topographic features, distribution of important facilities as well as the existence of any interference to the GPS and magnetometer of UAV. A handheld GPS was also used to determine the take-off and landing position, approximate location of the coastline and boundary of the monitoring area, in order to facilitate the mission planning. A specific waypoint planning package was adopted to determine the flight route and several main flight parameters such as flight height, flight speed, and image overlaps (Table 2). The flight is performed in the direction of the smaller sensor side of the UAV camera.

To study the spatial variability of the topography in the beach in Wujiao Bay, two campaigns were executed to acquire the UAV images in Oct., 2013 and July 2014. As the beach was relatively narrow with a width of about 200 m, a single flight is satisfactory to cover the whole monitoring area for both periods. To ensure the overlap of UAV images and enough coverage for the first time, one more flying route within a flight was conservatively designed in Oct., 2013, compared to the two flying routes in July 2014.

Fig. 4 shows the representation of the overlaps in the two UAV campaigns, together with the camera locations. Most of the areas are imaged in four or more photos. This multi-ray intersection may result in an improvement in accuracy for the extraction of point clouds. The central part of the monitoring area has more overlaps because it was covered in both flying routes.

The day with low wind and tide was chosen for UAV flight in order to acquire the higher quality images in the largest possible area. Before