Beach Topographic Change Analysis Using Multi-temporal UAV Data

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Abstract. A time-serial topographic change was performed using two kinds of surveying methods, including direct measurement and indirect remote sensing technology for beach topography surveillance. Compared with reference topographic data, the root mean square error was 0.169 m. From May, 2018 to March, 2019, multi-temporal beach topographic change results indicated that the distance between baseline and shoreline varied in the range of -24.82~9.58 meter, and weekly variates are -3.16~0.45 m. The UAV technique can be efficiently used to detect topographic change information in the coastal area.

1. Introduction

The coastal area around Taiwan is ranked 16th of severely vulnerable area in the world by the United Nations Environment Programme (UNEP). It is a big issue for coastal management to cope with coastal erosion and coastline receding. A long-term beach topographic information is needed in coastal management. Topographic survey methods used for monitoring topography change can be categorized into direct and indirect methods, namely in-situ observation and remote sensing methods. Direct measurement, including using a total station or GPS receivers, can be used to obtain beach topographic information. In addition to being time-consuming and labour intensive, large-scale topographic data cannot be efficiently obtained. Remote sensing is a technology in which data regarding objects, regions, or phenomena can be obtained without being in physical contact with the measured target.

Researchers have adopted unmanned aerial vehicles (UAVs) to capture aerial photographs of topography before and after a meteorological event and have compared the maximum wave run-up data derived from UAV imagery, numerical models, and light detection and ranging (LIDAR) surveys [1, 2]. Studies have also compared the survey results from a real-time kinematic dual-frequency global positioning system (RTK-GPS) mounted on a mobile mapping vehicle and repeated UAV aerial photography measurements [3, 4].

UAV imagery technology was employed in this study to resolve the problem of low efficiency in conventional manual sampling technique, to reduce instrument costs of remote sensing technology and
of field surveying, and to reduce the number of measurement errors. UAVs have advantages, such as high portability, low operational altitude, and high mobility. The UAV used in the present study carried a combination of the following devices: a lightweight sensor system equipped with a position and orientation system (POS) consisting of a global positioning system (GPS) receiver, and an inertial measurement unit (IMU). The feature points of multi-view image pairs were matched in this study to obtain 3D positions in a beach area through image matching technology and aerial triangulation adjustment. Moreover, a virtual base station employing real-time kinematic (RTK) positioning (VBS-RTK) was used to measure the actual coordinates of ground control points (GCPs) and those of check points. These coordinates were used to correct the results pertaining to the obtained sand topography and to determine the difference between image matching point clouds and direct measurement data. The multi-temporal images acquired through a UAV-mounted non-metric camera were imported to Pix4Dmapper to obtain the results of ortho-rectified images, digital surface model (DSM), and digital elevation model (DEM) of a test area. Then QGIS was used to calculate the change volume and rate of short-term coastal beach line.

2. Methodology
To obtain accurate topographic data using UAV photogrammetry techniques, users must verify the essential parameters that influence the aerial triangulation results before conducting aerial photography. These parameters, such as GCPs data accuracy, GCP distribution, camera imperfections, and flight planning, have a substantial influence on the position correction of topographic points.

2.1. Setting and Measurement for Ground Control Points
Parameters, such as planar and vertical control measurement, GCP forms, and GCP distribution, should be planned according to the actual situation of beach topography before conducting UAV imaging for beach topography mapping. The GCP distribution should meet the adjustment requirements of aerial triangulation. Specifically, the aerial photos covering the GCPs of an area can be used to improve the computation reliability and accuracy of aerial triangulation adjustment. To verify the reliability of given coordinates for the three reference points, a VBS-RTK positioning method was used to measure and calibrate the control system for the UAV topographic surveying.

2.2. Flight planning
To meet the requirement of direct geo-referencing, aerial photography was conducted with a video camera drone (DJI Phantom 3 pro), with a GPS and an IMU; however, the accuracy of the GPS and IMU were inadequate. Therefore, GPS-assisted aerial triangulation was employed [5]. The use of aerial photogrammetry is more suitable for a rectangular and open survey area. However, beach topography is a narrow terrain. Moreover, finding feature points for conducting image matching is relatively difficult in a homogeneous sand area [6, 7]. The imagery overlap is arranged using the settings of end lap (also called front overlap) and side lap. The mathematical relationship between the parameters of end lap and side lap can be determined through Equation (1) and Equation (2), respectively. The imagery front overlap ratio (left and right images) should be higher than 60% according to mapping standard. The topographic map accuracy pertains to the ground sample distance (GSD) and operational altitude (also known as fly height above ground level (AGL)). The proportional relationship between the AGL and GSD can be derived through Equation (3) according to the resolution of the photosensitive element. The GSD should not be higher than 10 cm according to the mapping standard of a 1/1000 topographic map. The double S-type flying course was adopted in this study to increase the success rate of image matching. Although this caused some disadvantages, such as long flight time, numerous images were obtained from different angles; the course improved the overall overlap rate effectively to cover the measurement area and observations redundancy increasing [8]. All flight settings were performed by a Pix4Dcapture application.
PE = \left( \frac{G - B}{G} \right) \times 100\% \tag{1}

PS = \left( \frac{G - W}{G} \right) \times 100\% \tag{2}

Where PE represents the end lap rate, PS denotes the side lap rate, G is the length covered by a single photo, B represents the flying base length, and W is the route interval.

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\frac{\text{Pixel size}}{\text{Focal length}} = \frac{\text{GSD}}{\text{AGL}}
\]

2.3. Observation accuracy verification and shoreline change analysis

After several flight missions using the above-mentioned UAV system and planning, taken aerial images were imported to an UAV image post-processing software, named Pix4Dmapper, to generate mosaic orthophoto, Digital Elevation Models (DEMs), Digital Surface Models (DSMs), and 3D point clouds. Then observation accuracy for the results was verified according to coordinates of check points derived by a Total Station (TS) System (LEICA 1205+).

With the Contour toolbox in the open-source software QGIS, the DSMs were obtained from previous monitoring to generate a 0-meter contour (near shoreline), and the shoreline changes in the horizontal direction of the beach under the influence of different operating forces in each time period were analyzed.

3. Case study

Yanliao Beach located at northeast corner in Taiwan was selected as the study area for exploring the outcome of using the UAV photogrammetry technique for a practical beach topographic mapping. Figure 1 displays the flying course and distribution of GCPs for the study area at an operational altitude of 70 m by using the aforementioned UAV photogrammetry technique. The parameters’ settings in the flight missions are described as follows. The angle of camera in the Table represents the angle between ground surface and facing direction of camera, near-vertical photography was taken with camera angle setup at 80°. The overlap rate, including end-lap sets 80%, and side-lap sets 30%. And a Double-S route type had been chosen for experiments. Eleven full-control points were measured using VBS-RTK, and Pix4Dmapper, a post processing software, was used to automatically produce orthophotos, DEM, and DSM based on users’ request. The topographic point clouds measured using a UAV were obtained through internal data processing, and the obtained results were used for conducting subsequent comparison between the measured and reference topographies.

For a time-serial shoreline change, there were 14 topographic results derived by the UAV system from May 28, 2018 to March 27, 2019. In this time period of experiments, there were two typhoon events that impacted the test area, namely Typhoon Maria (impact date: 2018/7/9~10) and Typhoon Mangkhut (impact date: 2018/9/15~16).

Figure 1. Flight planning and layout for GCPs and flying courses on Yanliao Beach.
4. UAV capacity test for beach topography

For UAV capacity test, the aerial images were captured at two flight altitudes of 70 and 100m, and the corresponding ground resolution were 3.26 and 4.25cm, respectively. According to properties of image matching, the dynamic changes at the junction between the sea and land in the shallow water area will lead ill-matching points founding. In general, image stitching or feature point matching is not suitable for processing dynamic objects that change with time. A 0-m contour line (viewed as near-shoreline) was used as the land–sea boundary to facilitate the subsequent analysis for eliminating the influence of waves on the beach topography. Because the point number and density in the original image-matching point clouds were considerably higher than those in the reference topography (752 samples points) derived using Total Station, the elevation data in the UAV image point clouds with the same planar coordinates of 752 reference points were linearly interpolated using the weighted distance. A comparative analysis was conducted using image overlaying. A reference contour map was generated using a Kriging function in the Surfer software suite with 752 points. The overall elevation distribution for the reference topography in the study area was approximately 0 ~ 5.55 m. However, the result derived using UAV image matching at an operational altitude of 70 m was approximately -0.31 ~ 5.65m. Moreover, the result derived at an operational altitude of 100 m was approximately -0.35 ~ 5.33m. The elevation difference distribution between the reference topography and the topography obtained using UAV imaging at two flight altitudes is displayed in Figure 2(a) and 2(b).

A normal distribution of the elevation error between the reference topography and the topography obtained using UAV imaging at two altitudes is clearly presented. The statistics for four accuracy indicators, that is, mean error $\bar{y}$, standard deviation $\sigma$, RMSE, and allowable error, are summarized as follows. The mean error of the UAV image topography at an operational altitude of 70 m is 0.032 m, which is smaller than the error at an altitude of 100m. Moreover, the RMSEs at the operational altitudes of 70 and 100 m are 0.169 and 0.176m, respectively [9]. Moreover, a 95% confidence interval in the normal distribution statistics was set to be the range of allowable error to manage the outliers. The allowable error range was limited to $\bar{y} \pm 2\sigma$. Data points with errors that exceed the allowable error range were marked with a circle and represented as blunder points. Most of blunder points occur at near-shoreline and steep-slope area according to results.

5. Results for shoreline change

A total of thirteen shorelines had been extracted using UAV topographic results during 2018/5/28-2019/3/27, then a baseline near-paralleled with shoreline was defined in the following multi-temporal change analysis. Eight profiles (called as S1-S8) located in the area were used to compute a distance
between the baseline and each shoreline. The erosion and accumulation area could also be computed with an open-source software named QGIS. The experimental results shown in Figure 3(b) indicate that the distance difference between result for other time-period and one derived on 2018/5/27 varied in the range of -24.82–9.58 meter, and weekly variates are -3.16–0.45 m. Most of the beach area was affected by erosion according to the annual area change result shown as Figure 3(a).

![Figure 3](image-url)

(a) Erosion and accumulation result  (b) 0-m contour (near shoreline) results

**Figure 3.** Shoreline changes using UAV topographic results derived on 2018/5-2019/3.

### 6. Conclusions and suggestions

Capacity test for the used UAS indicates that the RMSEs derived with the UAV topographic data under the operational altitudes of 100 m and the reference topography can be smaller than 0.2 meter. It inferred that the mapping accuracy derived from the used UAS can meet the requirement of topographic mapping standard of Water Resource Agency, MOEA.

The experimental results in the Yanliao Beach indicate that the distance difference between result for other time-period and one derived on 2018/5/27 varied in the range of -24.82–9.58 meter, and weekly variates are -3.16–0.45 m. The changes were inferred to have been affected by two Typhoon events and northeast monsoon which commonly occurred in northern Taiwan. Most of the beach area were affected by erosion according to the annual area change result.

Through the multi-period topographic data acquired by UAV techniques, the volume change and spatial distribution of the invasion and siltation, and their corresponding relationship with the coastal dynamics can be efficiently analyzed.

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