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Assessment of shoreline detection using UAV

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***Abstract* – The shoreline is an important feature of the costal morphology. Several methodologies are used to detect such line. In this paper a photogrammetric approach was applied to achieve both an accurate shoreline detection and a DTM (Digital Terrain Model) of the coast using Structure from Motion (SfM) algorithms. The goal of this method is to extract the shoreline from an accurate three-dimensional model of the coast. The proposed approach was performed using an Unmanned Aerial Vehicle (UAV) equipped with a digital camera. In order to avoid regrettable deformations on the 3D model several Ground Control Points were located on the scene, furthermore a precision assessment was performed using check points. The obtained result was compared with a classic RTK-GNSS survey of the shoreline performed by a skilled operator.**

I. INTRODUCTION

The construction of harbours, breakwaters and, in general, all port and marine infrastructures implicates several problems and challenges for the civil marine engineers applied to improve the logistic and the transportation with minimal impact on the surrounding lands, seabed and marine environment. To predict the impact on the shore, civil marine engineers inspect their projects using several mathematical/hydraulic models; such studies are considered an essential preliminary step before to start to build the structure [1].

When the building is completed, further inspections are conducted to check the structure status and shore alteration. In this framework, the shoreline position is very useful to monitor the costal evolution [2]. Indeed, the inspection of the shoreline retreat provides an important index of the sediment transport through the flow of the water and then the impact of the structure on the shore [3,4]. Moreover, in last years the climate change has had devasting effects on the coastal areas, that had deeply changed the morphological features of the coast [5].

Basically, the monitoring of the shoreline plays a fundamental role for the environment protection.

Several methodologies and strategies are used to detect the shoreline [6], and all of these begin from the definition of it, that can be easily declared as the line that marks the transition between the sea and land [7,8]. Due to the sea waves and the tide effect such line is in constant movement. A rigorous definition of shoreline is therefore necessary, in order to perform repeatable and reliable measurements. In this work, the shoreline is defined as the line of intersection between the ground and the mean sea level surface.

Generally, two different approaches have been employed to survey the shoreline [9]:

- Direct survey way, when the surveyor carries out the measurements along the visible shoreline. Such approach is considered as classical way, and is performed using the total station or GNSS (Global Navigation Satellite System) receiver (generally in RTK - Real Time Kinematic mode).
- Remote survey way, when the shoreline is determined using a remote sensing approach, such as LiDAR, satellite and aerial images.

The direct approach allows to limit the survey on a narrow strip of the coast (restricted to the interested area) and to break down the time processing. On the other hand, in some cases the shore is not easy to reach, furthermore the present waterline is different from the theoretical shoreline. Indeed, in order to obtain reliable results, the surveyor divides the operations in two steps: in the former one a dry path of the shore is surveyed, where the heights from the mean sea level are surely positive; in the second step the wet line of the shore before that the terrain slope rapidly changes is detected. Such approach allows to determine the shoreline as spatial linear interpolation between the two surveyed lines [7]. A different GNSS method can also be applied if a geoidal model is available on the instrument controller during the survey: indeed, the operator can search and acquire planimetric coordinates of a path where the points elevation is zero.

The remote survey approach allows to minimize the on-field operations and to reach no-go areas. On the other hand, the post-processing time cannot be neglected. In this case, several approaches have been developed, depending on the platform employed to derive the shoreline. For instance: the process for satellite images or aerial orthophoto may be based on the use of segmentation and classification (supervised or unsupervised) on digital images to detect the visual separation of coastal features [10,11]. On the other hand, the LiDAR data allows to

obtain a DTM (Digital Terrain Model) of the coast and to extract the shoreline as contour line [12]; furthermore if the LiDAR is equipped with a bathymetric laser, the obtained DTM can cover the shallow water as well [13]. Finally, the photogrammetric process is an hybrid solution between the LiDAR and Image-Processing approach since it allows to achieve both a visual distinction water-no water (i.e. using orthophoto) and estimate a DTM of the shore [14,15].
In this work a photogrammetric workflow was developed involving a UAV (Unmanned Aerial Vehicle), equipped with a low-cost digital camera, used to acquire nadiral images of a little sandy beach located on Sorrento coast (Figure 1).

Figure 1- The position of the area of interest

A tuff cliff protects the beach from winds coming from the south. The dominant climate wave is related directly to its geographical setting; indeed, in the winter, the prevalent wave comes from north.
The UAV platform is very flexible, low cost and it can be adapted to different surveys scenario. This platform is widely used in several tasks [16], such as video and photo documentation, monitoring, security and surveillance, inspection, cultural heritage as well as in mapping, precise farming and cadastral applications [17-19]. The flight planning, handling and control are totally automatic, assuring a completed coverage of the survey area, furthermore the flight time consuming is strongly reduced. The survey was conducted during a sunny day with calm wind and sea; in order to obtain reliable results, the acquisition phase was performed in lowest tide conditions of the day.

II. METHODOLOGY

Photogrammetry is the science and technology of obtaining metric information about physical environment from images, with a focus on several applications such as mapping, surveying and metrology. The aim of photogrammetry is to provide procedures for these engineering tasks with emphasis on a specified measurements accuracy and reliability [20].
In this case study the developed procedure is based on automated photogrammetric techniques known as Structure from Motion algorithms, allowing to carry out automatically the classical photogrammetric workflow. The images were acquired with a UAV system equipped with a 3-axis gimbal stabilizer for built-in low-cost camera.
Generally, a typical photogrammetric survey with UAV is based on the following steps [17]:

- Mission planning;
- GCPs measurement;
- Image acquisition;
- Image processing.

Mission planning was performed in field with a specific app (Pix4Dcapture) that allows to plane the mission using several strategies and specific needs. The user can easily adjust the overlap among the images and flight altitude.
The second step it is very important to obtain a scaled and georeferenced 3D model. Six corner targets were located on the area of interests and they were measured using a M-GNSS receiver. Several GNSS strategies can be used to obtain accurate GCPs coordinates with code [21] and phase measurements [22].
Therefore, the flight and then image acquisition can start.

Figure 2-Image classification result

The image processing is the final step for 3D information extraction. The post-processing workflow adopted in this study is the following:

1. Every acquired image is automatically segmented in Pix4D environment (the photogrammetric commercial software used for this work) and manually classified in two areas, in order to detect the sea and the coast zones (Fig. 2);
2. The image orientation process, using SfM algorithms, is performed cutting the image areas recognized as “sea” in the previous step;
3. A DSM (Digital Surface Model) of the shore is then carried out by a classical image-matching

approach keeping a multiplicity factor on image block higher than 3 (Fig. 3);
4. Estimation of a DTM using a linear interpolator is then carried out;
5. Shore line is then detected from a contour line extraction.

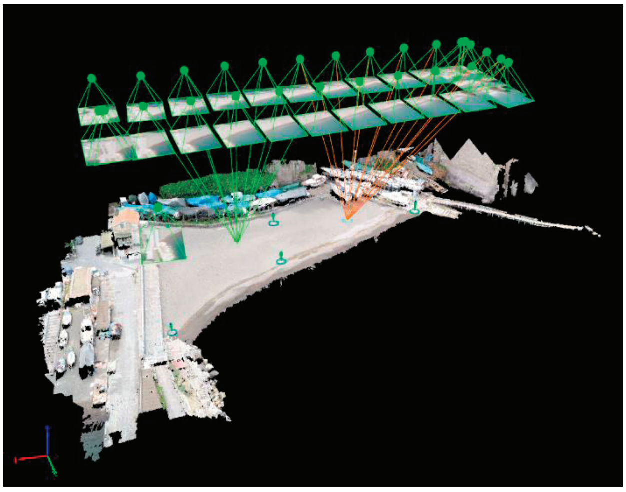

Figure 3- DSM and Image block configuration acquired by UAV- model Phantom 4

The shore offers several challenges and specific problems to the surveyor. Due to the tapered shape, that constrains an image acquisition along a linear axis, the image block configuration could be extremely trick, and it often leads to a bended 3D model (such result is known as "bowl effect") (Fig. 4) [23,24].

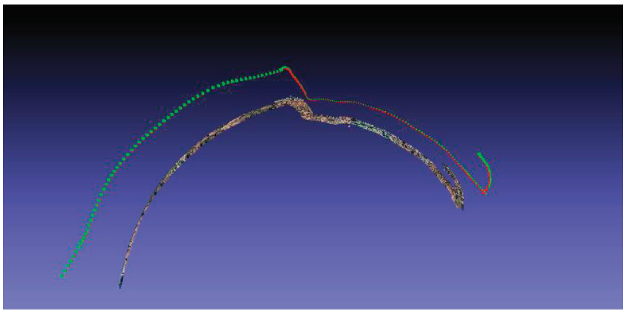

Figure 4-Blow effect due to camera calibration bad estimation of internal camera parameters

A less accurate camera self-calibration could yield a deformation effect on the orientation of image block and then on the final 3D model; this effect can be avoided adding Ground Control Points in the bundle adjustment computation. Indeed, GCPs play a fundamental role to limit this outcome.
In this work a multi constellation GNSS receiver, set in RTK mode, was used to determine the geographic coordinates of the six targets located on the scene. All of them can be automatically detected and marked during the elaboration process. Four of them were used as ground control points (GCPs) allowing to obtain the final DTM correctly scaled and georeferenced according to the chosen datum. The other two points were used as Check Points in order to assess the absolute accuracy of the three-dimensional model.

III. RESULTS

The image dataset was acquired with a quadcopter drone, model "DJI Phantom 4 – pro" equipped with a digital camera optimized for aerial acquisitions. The camera has the following characteristics: CMOS sensor with a pixel size of 2.4 µm and wide-angle lens (equivalent focal length of 24 mm). During the flight 28 nadiral images were acquired at an altitude of 50 metres, assuring a mean GSD (Ground Sample Distance) of 1.5 cm/pixel.
The Bundle Block Adjustment was performed using 4 GCPs as constrain, while 2 CPs were used as check points. All points coordinates were measured using a GNSS survey in RTK mode with an estimated position accuracy of 0.05 metres. The survey was linked to the ETRF-2000 using the Leica permanent network station named ITALPOS, whose nearest station is located at a distance of 1 km from the survey site. The transformation between ellipsoidal height to the orthometric one was performed using the geoid ITALGEO2005.
The obtained results by the bundle block adjustment are reported in table 1. These results provide a potential accuracy of the photogrammetric model, especially the RMSE of check points, that complies with the accuracy magnitude of the RTK survey.

Table 1. Accuracy results of the photogrammetric 3D model.

Type		Error in meters		
		X axis	Y axis	Z axis
GCPs	Mean	-0.001	0.000	0.001
	RMSE	0.017	0.006	0.002
CPs	Mean	-0.002	-0.010	0.022
	RMSE	0.020	0.011	0.023

The densification procedure was conducted using multiscale approach with half image geometric resolution. To avoid false matches, a point must be detected on 3 images at least. The final result provided a dense point cloud of about 9.5 millionsmillion of points (Figure 3).
The DSM was extracted from the dense point cloud setting a cell size of 2 cm and employing a linear interpolator. The shoreline was then extracted as a contour line (Figure 5, red line).

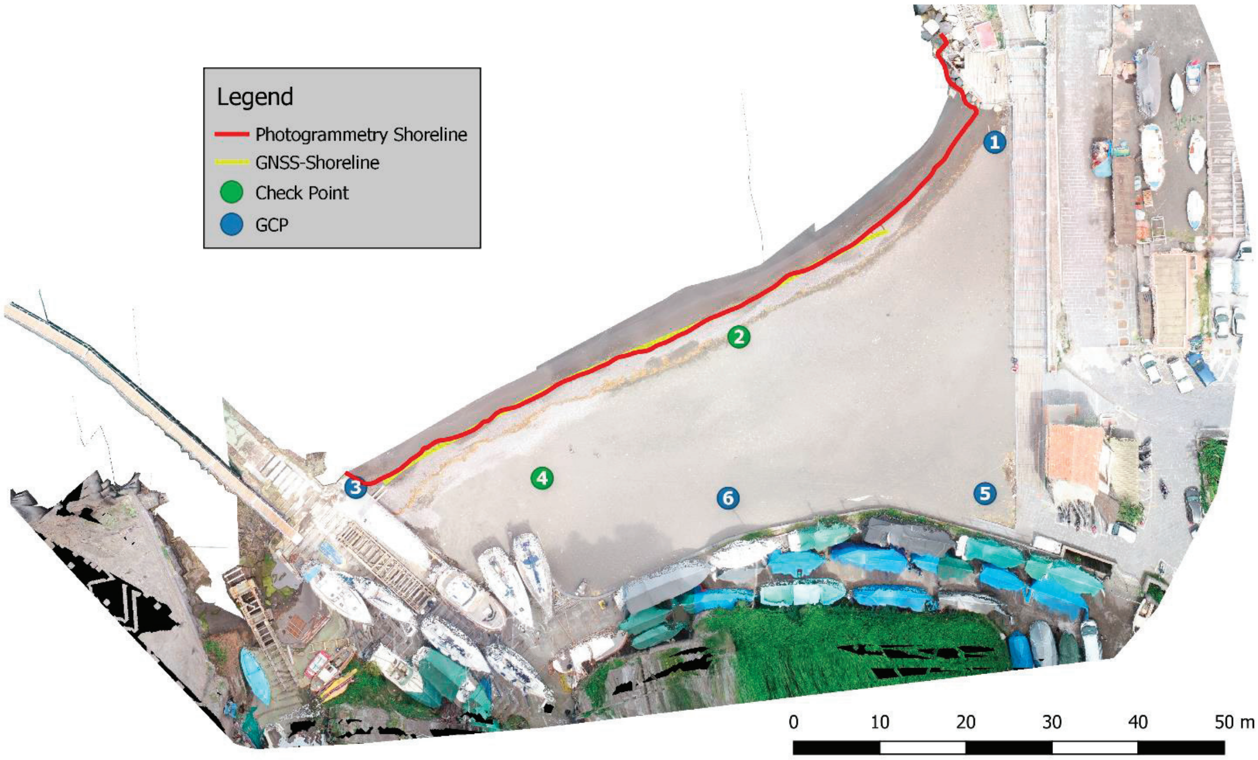

Figure 5 – Orthomosaic of the scene, where is reported the position of the GCPs (blue dot), CPs (green dots) and the shoreline detected by the proposed approach (red line) and the classical RTK-GNSS survey (yellow line)

Moreover, an assessment analysis was performed comparing the obtained result with an independent direct survey based on GNSS-RTK method performed almost at the same time (Figure 4). A former inspection was conducted on the vertex number obtained from the two different approaches as reported in Table 2.

Table 2. Comparison between GNSS based shoreline and Photogrammetry one.

Survey Type	Vertex Number
GNSS	83
Photogrammetry	179

Further inspection was conducted about the planimetric distance between the two lines. Specifically, each distance between a single vertex of the GNSS surveyed shoreline and the nearest segment of the shoreline detected by the photogrammetry is computed; furthermore, an arbitrary sign was assigned to distance in according to the relative position between the two polylines (Figure 5). Such analysis provided a mean deviation of 0.03 meters with an RMSE of 0.23 meters, with a maximum positive deviation of 0.75 meters and the negative one of -0.50 meters.

Figure 6 – Calculated distance (in orange) between the GNSS shoreline and the photogrammetric one.

IV. CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper a method to detect the shoreline based on photogrammetric survey is presented. The obtained results show that the proposed approach allows to obtain a shoreline with comparable accuracy with a direct method and to achieve a polyline with high density vertexes in according to the DSM cell size. Furthermore, the 3D model allows to extract section or additional morphological features.

The data acquisition for the presented case study was realized in low tide condition and with calm sea.

The proposed approach allows to obtain reliable results using a flexible and low-cost way. On the other hand, the methodology can be carried out in specific meteorological conditions; for example if the wind is too strong the UAV cannot fly. Even the wave conditions could be a critical element, that could affect the results. Moreover, the tide condition is a basic requirement for obtaining a reliable solution.

A further development of this approach can be achieved in any tide condition. Indeed, performing a resample image in according with the approach illustrated by Maas [25] it is possible to determine the bathymetry DTM in shallow water using the image acquired by UAV, with sufficient accuracy [26ù]. Such improvement allows to achieve a complete and continue DTM of the dry and wet shore using the same acquisition low-cost platform and the same images. Furthermore, the survey zone could be extended in order to extract several cross sections of the coast and the shallow water seabed with continuity, in order to inspect the evolution of the coast.

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