In: Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS, Vienna, Austria, July 5–7, 2010, IAPRS, Vol. XXXVIII, Part 7B

MONITORING OF BEACHES AND SAND DUNES USING DIGITAL AERIAL PHOTOGRAPHY WITH DIRECT GEOREFERENCING

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Commission VII

KEY WORDS: Photogrammetry, Change Detection, Matching, DEM/DTM, Georeferencing, Direct

ABSTRACT:

This paper presents an efficient methodology for coastal monitoring based on digital aerial photography acquired periodically, using a Zeiss-Intergraph DMC camera, with a spatial resolution of 10 cm. Images are delivered with exterior orientation given by the direct georeferencing system used by the company providing the images. An assessment of those exterior orientation parameters was done using field check points. It could be concluded that the positional accuracy of 3D coordinates determined by photogrammetric means using the exterior orientation elements has root mean square errors better than 30 cm, which can be accepted for the purposes of this type of work. This level of accuracy was achieved for four different flights. It was decided not to do an aerial triangulation. DSMs were obtained by stereo-matching (least-squares with region growing) using program DPCOR of the software package BLUH. Sand areas are normally very bright and difficult for the matching. Since images were acquired with relatively small sun elevation the automatic extraction of a DSM was very successful. Using check points the vertical accuracy of the DSMs was found to be 30 cm or better. Orthoimages were created using the extracted DSM. The resulting datasets for the four different dates were integrated in a GIS and the method proved to be a very useful tool for the detection of areas where significant volumetric changes occurs and for the quantification of those beach changes.

1. INTRODUCTION

The western part of the Portuguese coast is subject to significant degradation due to the action of the ocean (Ferreira, et al., 1995). Coastal areas are also under a strong anthropic pressure, which have as consequence the destruction of dunes and other natural protections. Significant morphodynamic changes occur in short periods of time which need to be monitored. In order to detect and quantify those changes and foresee the near term evolution of the coastal areas, both for safety and economic reasons, very frequent surveys, are required.

Field survey monitoring programmes are carried, using GPS, in sensible coastal areas in Portugal, in order to detect and quantify changes (Baptista et al., 2008, Gonçalves et al., 2009). However, they are still time consuming and usually applied in small areas if surface models are to be obtained.

Airborne surveying techniques are more cost effective and can achieve a positional accuracy appropriate for coastal evolution assessment. Elevation changes in beach landforms, due to natural or antropic origin, can be of several meters, even in short periods. Elevation errors of a few decimetres in digital surface models (DSMs) are therefore still acceptable for the detection of essential relief changes in coastal areas.

Laser scanning is nowadays a commonly used technique for coastal monitoring. It has an important advantage in that the final DSM/DTM is obtained essentially in an automatic manner (Baltsavias, 1999). However, besides being still quite expensive, laser scanning alone does not provide the image component, which is also very important for the interpretation and detection of the morphodynamic changes.

Aerial photography, especially with the recent digital aerial cameras, can provide important information to the assessment of changes while allowing a high degree of automation. That is the case if direct georeferencing (DG) can be accurate enough to avoid aerial triangulation and if the DSM generation can be fully automated by stereo matching.

Images of sandy areas may be difficult to treat in terms of standard photogrammetric procedures. For example, for the purpose of aerial triangulation, in the absence of man made features, well defined ground control points (GCPs) may be difficult to obtain, especially in the case of high resolution images. When large parts of the images are occupied by water also tie points cannot be obtained. These are additional reasons to use the exterior orientation data given by DG, if it is accurate enough.

This paper describes the exploitation of aerial photography acquired in the scope of a coastal monitoring program in the Portuguese northwest coast through the referred methodology . Part of the area does not have man made features to be used as GCPs. There is usually a need for fast data production immediately after image acquisition, so there is a strong interest in relying on DG. One of the objectives of this study is to determine the best accuracy achievable using image data provided by a private company.

In this work some basic photogrammetric processing tools, such as the stereo matching, 3D coordinate determination, interpolation algorithms to generate a regular grid DSM, ortho-rectification and image mosaicking were used. Complementary, some tools of the BLUH software package, created at the Institute for Photogrammetry and Geoinformation, University of Hannover (Jacobsen, 2000), and other programmed by the authors were applied to optimise the procedure efficiency. DSM and orthoimage data integration and analysis were carried using a commercial GIS software.

2. APPLICATION AREA AND DATA ACQUISITION

The application area has an extension of 15 km to the south of the city of Porto, which includes in the north part the estuary of the river Douro (Figure 1). The area is subject to strong effects of the sea (Intensive action from the ocean), which produces significant changes, especially during winter.

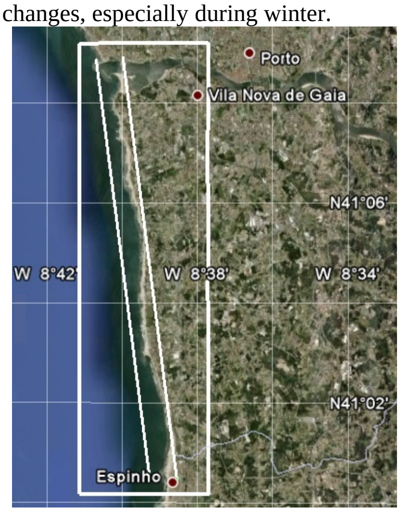

Figure 1. Map of the area with the flight plan (created with Google Earth)

In the scope of the monitoring program, it was decided to acquire aerial digital photography twice a year, before and after winter. In this way it is possible to assess the effect of winter storms over the beaches. It was also decided to acquire photographs in very low tide condition in order to map as much as possible the intertidal area.

Figure 2. Example of part of the study area, in the estuary of river Douro, near the city of Porto

The data was acquired with a digital camera Zeiss-Intergraph DMC which allows to obtain images with a ground sampling distance (GSD) of 0.1 meters. The 15 km of the study area were covered by a total of 100 photos in two strips, with a 60% forward overlap and 30% side lap. Figure 1 shows the centre lines of the two strips.

The pan-chromatic images, used in the process of digital surface model (DSM) generation, have a dimension of 7680 by 13824 pixels, with a pixel size 12 µm. According to the camera specifications the focal length is 120.000 mm, the principal point is at the image centre and images are virtually distortion free.

The base-height ratio in digital cameras is smaller than in conventional analogical cameras. In the present photos a parallax of 1 pixel (10 cm on the ground) corresponds to a height difference of 34 cm, on average.

Images were acquired by a private company, using GPS/INS direct georeferencing equipment (IGI Aerocontrol) and standard processing techniques as for any other large scale topographic mapping work. According to the information provided (Municipia, 2009), a boresight calibration was performed after the camera was mounted and all the relative positions of GPS, IMU and camera were measured with total stations. GPS positioning of the flights was done relative to the Portuguese network of GPS permanent stations (IGP, 2009). The reference system used was ETRS89. The data processing software was IGI Aero-office. According to the processing reports provided, exterior orientation parameters are given in UTM coordinate system with appropriate corrections of scale factor and meridian convergence.

During the monitoring periods four flights were done. Table 1 contains information about date and start time of the image acquisition. A full flight is carried in less than 10 minutes.

Flight no.	Date	Start time (UTC)
1	14-Nov-2008	09:25
2	23-Apr-2009	08:06
3	18-Nov-2009	10:42
4	5-May-2010	14:11

Table 1. Date and start time of the four flights

Some of the times were early in the morning, which would be inconvenient for normal photogrammetric purposes. In the present case, since the area of interest is essentially sand, that can be an advantage because some shadow effects occur in the sand that facilitate the stereomatching.

3. ANALYSIS OF THE EXTERIOR ORIENTATION

One of the objectives of this work is to assess if the results provided through the adopted methodology were appropriate for the main objectives of large scale mapping of coastal areas without field work requirements. Several assessments were done, some without and some with check points.

An algorithm of space intersection incorporated in the BLUH software package was used. It gives the point of shortest distance between the straight lines defined by the co-linearity equations, together with the corresponding y-parallax.

3.1 Relative orientation

The first verification done was to see if the exterior orientation parameters of consecutive photos provide an accurate relative orientation. That is essential if stereoscopic viewing is required as well as if calculation of 3D coordinates.

For selected stereopairs a total of 15 homologous points per pair were manually measured and the corresponding y-parallaxes were calculated. Table 2 shows the root mean square of the y-parallaxes for a pair of each flight. In general y-parallaxes were not larger than 1 pixel and showed a systematic trend within each stereopair.

Flight number	RMS y-parallax (pixels)
1	0.7
2	1.0
3	1.1
4	0.6

Table 2. RMS of y-parallaxes (1 pair per flight)

3.2 Repetition of 3D coordinates

The second test consisted in analysing the repeatability of 3D coordinates determined from stereopairs, in different flights and different strips. Six points were chosen, distributed along the study area and were measured 8 times: twice in each flight, in pairs of different strips. These were well defined points in man made features, mainly road paintings, that did not change between flights. The standard deviations were calculated for all sets of 8 measurements and are listed in table 3.

Point #	σ_X (m)	σ_Y (m)	σ_Z (m)
1	0.25	0.28	0.31
2	0.27	0.28	0.22
3	0.29	0.29	0.13
4	0.30	0.27	0.20
5	0.28	0.31	0.13
6	0.29	0.31	0.20

Table 3. Standard deviations of coordinates measured in different stereopairs, of different flights

3.3 Accuracy assessment with check points

The third test consisted in comparing 3D coordinates of well defined check points surveyed on the field using dual frequency GPS receivers, with centimetric accuracy.
Table 4 shows the statistics (mean and standard deviation) of the errors found. The mean values of a few decimetres in X and Y (2-3 pixels) indicate the systematic effects introduced by errors in the exterior orientation. Standard deviations are smaller, closer to 1 pixel, which indicate the obvious conclusion that if an aerial triangulation was performed errors would become of the order of the image resolution. Height errors show also systematic trends but larger standard deviations because attitude errors produce variable height errors along the images.

Pair	No. pts	X Mean±Std (m)	Y Mean±Std (m)	Mean±Std (m)
1	6	0.24 ± 0.08	-0.09 ± 0.16	0.24 ± 0.11
2	4	-0.05 ± 0.06	0.23 ± 0.02	0.39 ± 0.06
3	5	0.18 ± 0.10	0.43 ± 0.22	-0.29 ± 0.25
4	4	0.16 ± 0.14	0.48 ± 0.07	-0.10 ± 0.27
5	6	-0.30 ± 0.16	-0.14 ± 0.17	-0.03 ± 0.25
6	3	-0.39 ± 0.18	-0.06 ± 0.05	-0.24 ± 0.32
7	6	0.26 ± 0.10	-0.23 ± 0.08	-0.10 ± 0.07
8	4	-0.34 ± 0.11	0.21 ± 0.01	0.09 ± 0.35

Table 4. Statistics of errors found in check points

Results obtained with the check points agree with the results of repeated coordinate measurements presented in table 3.
In general it can be concluded that planimetric and altimetric accuracy are of the order of 0.3 metres
This planimetric uncertainty is acceptable for orthoimage production in relatively large map scales, such as 1:2000 or even 1:1000. Height uncertainty is of the same order and is suitable for a quick assessment of the degree of erosion or accretion and quantification of volumetric changes in sandy beaches and dunes.

4. DSM AND ORTHOIMAGE GENERATION

4.1 Stereo matching and DSM generation

For the DSM generation conjugate points were obtained using program DPCOR, of the BLUH software packages (Jacobsen, 2000, Rieke-Zapp and Nearing, 2005). It implements the least squares matching with region growing (Gruen, 1985, Otto and Chau 2000). This algorithm works in image space and doesn't require image orientation or epipolar geometry and only needs a seed point per stereopair. It produced very successful results over the sand and rocks near the sea.
From the homologous points 3D coordinates were calculated by the intersection algorithm. Points were accepted with the following criteria:
1 – only accept correlation above 0.8.
2 – only accept y-parallax smaller than 2 pixels (large values probably correspond to wrong matches)
3 – only accept heights within an interval of expected values: greater than –2 m (the minimum in the lowest tides) and smaller than 10 m. Other heights are either wrong matches or are outside of the interest area.

Points were extracted with 3 pixel spacing in rows and columns. A final single grid was obtained by averaging heights of all points in 1m by 1 m cells. Figure 3 shows an extract of one of the DSMs created in this way.

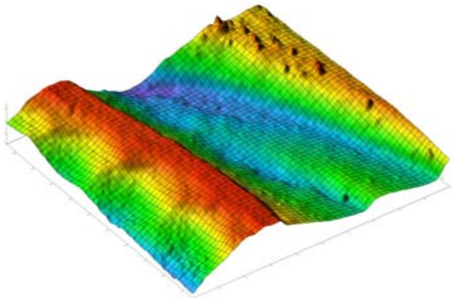

Figure 3. Portion of one of the DSMs generated

A mask was created to limit the areas of beach and dunes. This mask was applied to the 4 grids created from the different flights.
Good detail was extracted, as is the case of small shrubs in dunes and marks of tyres in the sand. The success of the matching was also very good in most of the cases. Usually sand is difficult for stereo matching but as in this case most of the images were taken early in the morning, and some in November, illumination conditions provided shadows in the sand that helped in the matching. Figure 4 shows shaded relief images of two portions of DSMs: (a) obtained in the first flight (November, 9:25 am, local time) and (b) the fourth (May, 3:11 pm). Success was not so good in the second case (black dots indicate no matching). Since these areas of empty pixels were

never very large they were filled by interpolation and in general no significant relief detail was lost.

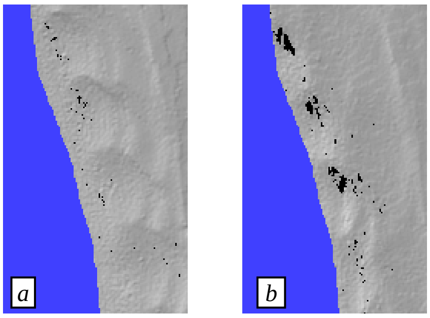

Figure 4. Sample images of different matching success due to different illumination: (a) November, 9:25 am (b) May, 3:11 pm

Finally it was possible to do an error assessment of the extracted DSM. Within the monitoring programme, GPS field data is collected (dual frequency kinematic) along lines over the dunes. For one of the DSMs the data was collected with only a difference of a few days. Figure 5 shows the points over the shaded relief image of the DSM.

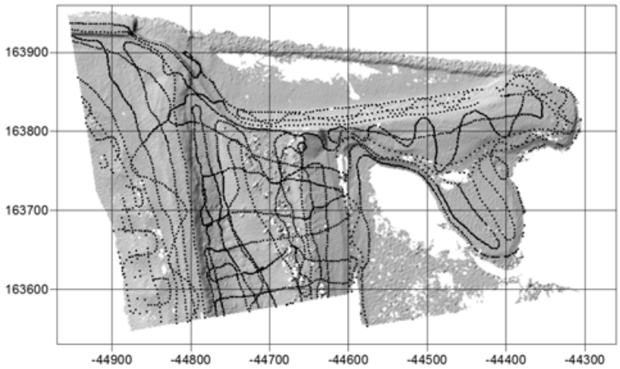

Figure 5. DSM and GPS points used to assess the accuracy

For a total of 3700 points a RMSE of 0.17 meters was found. This result is slightly better than what was found in other images with check points. In general, without aerial triangulation, the 30 cm is a more secure assumption of the accuracy of the DSMs.

4.2 Orthoimage generation

Images were ortho-rectified individually with the DSM extracted, restricted to the mask of beaches and sand. In order to have a complete view of the surrounding areas, outside the DSM area a DTM derived from large topographic map data of scale 1:2,000 was used. Since this DTM does not correspond to the present form of the terrain surface, the quality of the orthos in these areas is not good. They should be seen as research grade products, worth for the analysis of change detection in the interest areas, which are the sandy beaches and the dunes.
Cut lines were defined for all ortho images, choosing the most central parts in order to minimise residual relief distortions. Mosaics of 1 km by 1 km were created.
The following figures show some examples of significant changes detected on the orthoimages, as well as on the DSMs. Figure 6 shows an example of a significant change in a sand bank that got separated in the estuary of the river Douro: image 6a is from November 2008 and image 6b from May 2010. Images 6c and 6d show the effect on the DSMs.

Figure 7 shows the retreat of the shore line in a small area. The four image samples are from the 4 dates. The most significant change occurred on the winter of 2010 (3rd to the 4th image).
Figure 8 shows a cross section from the two extreme dates (November 2008 and May 2010). Images and DSM allow for a very detailed assessment of changes.

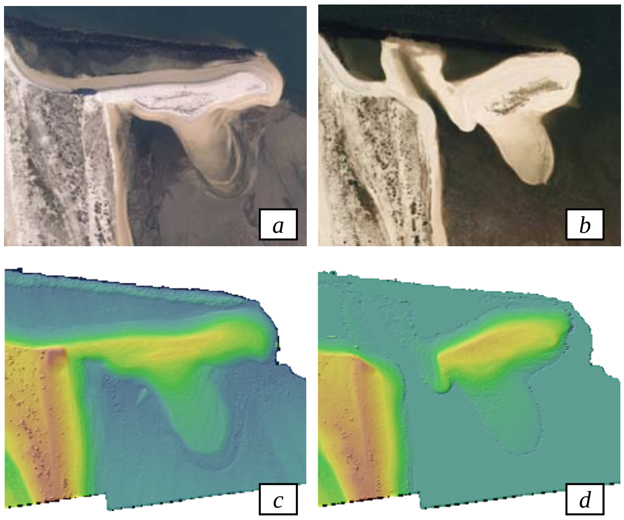

Figure 6. Example of a change detected between Nov-2008 and May-2010: on orthoimages (*a* and *b*) and on DSMs (*c* and *d*)

Figure 7. Example of retreat of the coast line along the 4 dates. The most significant change occured from image *c* to *d*.

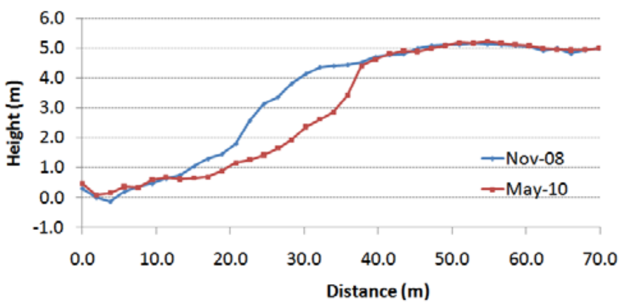

Figure 8. Example of a cross section corresponding to images 7*a* (Nov 2008) and 7*d* (May 2005).

5. DISCUSSION AND CONCLUSIONS

The positional accuracy, both planimetric and altimetric, just using the DG information, was estimated as 30 cm, far from what would be achievable by aerotriangulation. Nevertheless, it is compatible with large topographic map scales, such as

1:1000, according, for example, to the USGS standards (USGS, 1999), considering a contour spacing of 1 meter.
The existing changes in dynamic areas, such as this one, are very significant and become clearly detectable. Results presented in the previous section show the usefulness of both orthoimages and DSMs in detecting and quantifying these changes.
The fact that no GCP collection was required for an aerial triangulation is an important advantage. On one hand it allows for a very fast response in deriving DSM and orthoimages after the data acquisition. On the other hand it allows for reasonably accurate mapping in locations were only natural features exist, such as in beaches, dunes and river estuaries.
This methodology has proven to be useful for researchers interested in coastal dynamic studies and also for decision-makers with responsibilities in the management of the coastal zone. .

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Acknowledgements

This project was supported by Parque Biológico de Gaia, EEM. The BLUH Software was provided by the Institute for Photogrammetry and Geoinformation of the University of Hannover.