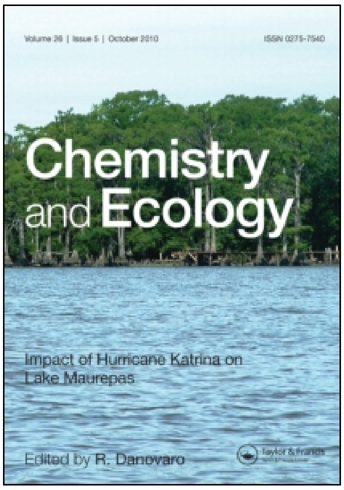

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Evaluation of a nourishment programme with a webcam: the case of Levanto (La Spezia, Italy)

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This paper presents the results of a monitoring programme of the littoral of the town of Levanto (La Spezia) to evaluate the efficiency of a nourishment project carried out on a gravel beach. The study was carried out with a webcam, one of the most innovative techniques for monitoring coastal evolution. This technique makes it possible to automatically obtain a continuous, real-time set of images of high quality that can then be processed with dedicated software to provide information on the morphodynamic conditions of the beach. The image processing technique, [based on the studies carried out by the Coastal Imaging Laboratory of Oregon State University to develop the Argus System], was developed by the Dipartimento per lo Studio del Territorio e delle sue Risorse (Dip.Te.Ris.) and the Dipartimento di Matematica (Di.Ma.) of the University of Genoa. The research was focused on studying the variations in the shoreline following a nourishment programme as revealed by a comparison of the processed images, which made it possible to reconstruct the evolution of the beach in the short- and medium-term and thereby evaluate the efficiency of the intervention.

Keywords: webcam system; beach nourishment; shoreline; coastal evolution; Liguria

1. Introduction

Liguria's development has historically been coastal and this environmentally sensitive area is where the region's economic activity and population is concentrated. The economic value of the area's coastal resources, the density of the population, the infrastructure and the urban development have created a fragile dynamic land-sea interaction that requires integrated management techniques to mitigate risks.

An adequate knowledge of the coastal system is essential for developing management programmes. One of the most important things to understand is the morphodynamic characteristics of the beaches and their response to wind-wave events of different frequencies, not only to protect the beach but also the houses and other structures lying immediately behind them.

The use of webcams to monitor coastal evolution is increasingly common throughout the world. This project studied the morphodynamic evolution of the gravel beach of Levanto (La Spezia,

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Italy) following an artificial nourishment programme carried out in 2005. The study was conducted under the auspices of the Interreg IIIC Beachmed project – (subproject Optimal). The technique used provided a continuous real-time set of valid, high-quality images, largely avoiding classical field campaigns with all their attendant problems [1], except to confirm the information obtained.

The investigative technique provides for the processing of the images to highlight the morphological and hydrodynamic characteristics of the coast, thus making reading and interpreting the information easier [2].

The method in question, developed by Oregon State University [3,4], provides different types of images, each type with its specific use.

The snapshot image, which is an instantaneous photo of the site being monitored, provides information on the wave propagation along the coast.

The time-exposure image created by digitally averaging image intensity over some minutes of image acquisition is produced by processing and superimposing snapshots images of a acquisition cycle. This process eliminates random momentary sea conditions. The processing of these images increases the colour intensity of the pixels, making it possible to distinguish morphological features that it would otherwise be difficult to see [5].

The variance image, which is acquired at the same time as the time-exposure images, further enhances the contrasts already achieved by processing the time-exposure images and makes it possible to distinguish submerged foreshore structures.

The system was used as the basis for the processing technique developed by the Dipartimento per lo Studio del Territorio and the Dipartimento di Matematica of the University of Genoa on a Matlab® 6.1 platform for the management and processing of the photos obtained from Levanto.

2. Material and methods

2.1. *Monitoring system*

The monitoring system used was produced by the company GE.Co.s.r.l., and consisted of two fixed colour webcams and a broadband connection. The webcams automatically obtained high-definition (1280 × 960 pixels) images of the beach at regular intervals and were remote programmable (it was possible to modify all the parameters remotely and intervene in the case of any break-down). The images obtained were sent in real time to a FTP site.

The equipment was installed at a height of 16 m a.s.l., on the roof of a building to the east of the study site, with a good elevation for monitoring the area (Figure 1). Both webcams were oriented towards the western part of the beach.

The system was configured to take three series of images a day at 8.00 a.m., 12.00 noon and 4.00 p.m. Each series consisted of two sets of four images taken at two-minute intervals. The two webcams obtained images of two distinct tracts of the beach: webcam 1 provided a panoramic image of the beach; webcam 2 provided detailed images of the extreme western part of this beach, which consists of two sectors that had been the site of the nourishment programme.

2.2. *Image processing*

The image-processing system was installed on a Matlab® 6.1 platform. The procedures for obtaining time-exposure (media of 4 images of one adquisition cicle) and variance images were developed. An image georeferencing and rectification system was also developed.

Figure 1. Study area.

The mathematical procedure used to produce the time-exposure and variance images provided for the calculation of every colour level, that is the red, green and blue that characterise every single pixel in an RGB image. The processing of variance images is generally based on the variance statistical parameter (σ^2) but we preferred to adopt the standard deviation (σ) as it provides better contrast between the actual beach and the run-up in the swash zone and so makes it easier to identify the shoreline.

The georeferencing technique used was based on the classical approach of Abdel-Aziz et al. [6] where it is possible to pass from one reference system (3D) to another (2D) by finding the solution to the minimum squares of a linear system knowing the intrinsic webcam parameters (DLT coefficients) [7]. Having solved the equation it is possible to find the geographical coordinate of every single pixel in the webcam image.

The literature presents numerous works on image rectification, that is reorienting the image to provide a bird's-eye view, all based on the intrinsic size of the webcam [8]. Instead, our method used georeferencing, appropriately written in Matlab® script, and a georeferenced image.

2.3. *Application area*

We investigated the beach of Levanto, a town on the eastern coast of Liguria (Italy) (Figure 1). The physical unit it belongs to extends from Punta Picetto to Punta Mesco and has a wind exposure of

180° (from 140° E to 320° W); therefore the area is primarily exposed to the action of the wind coming from SW, which causes littoral drift towards the east, and secondly to the wind coming from SE and southerly wind [9].

The wind-wave data of Levanto were acquired from the Rete Ondametrica Nazionale (RON – National Ondometric Network) buoy at La Spezia, which lies about 32 km from the beach. The RON [10] and Medatlas [9] data covering the decade 1996–2006 revealed that the reigning sea came from the SW.

The beach, which extends for 900 m, is delimited by two capes, Punta Levanto and Punta Mesco; two groynes interrupt the lateral continuity of the beach, whose natural evolution is further compromised by a submerged parallel breakwater lying between the two central groynes. The backshore is principally gravely, (medium diameter = 3.50 mm), while the foreshore, as far as the surf zone is sandier (D50 = 0.2 mm).

In February 2005 the western sector of the beach was nourished with 16,000 m^3 of suitably crushed and treated quarried gabbroic and basaltic gravel (mean grain size 20–30 mm). The monitoring programme, from June 2005 to June 2006, was specifically conducted to define the evolutive trend of the nourished sectors.

3. Results

3.1. *Image elaboration*

Utilising the specially-developed software it was possible to obtain different types of images.

The time-exposure image presented in Figure 2 shows how the processing eliminated random momentary surface conditions to provide a net definition of the shoreline. Even greater contrast

Figure 2. Time-exposure image taken at 12.00 noon on 4 November 2005.

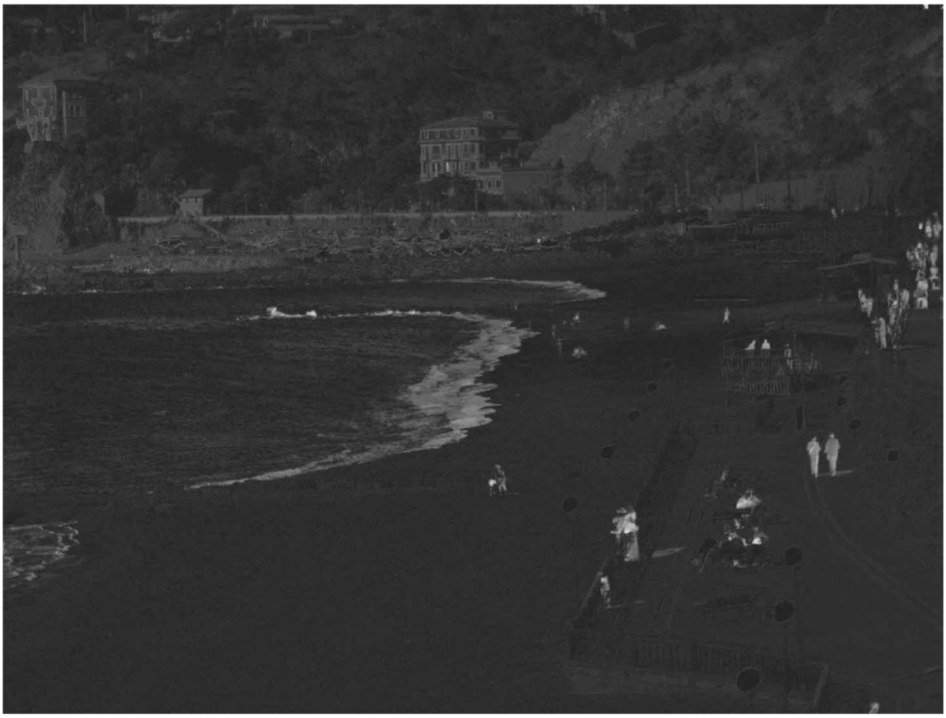

Figure 3. Variance image taken at 12.00 noon on 4 November 2005.

Figure 4. The image shows the base points for the determination of the geographical coordinates (+) and their corresponding georeferenced coordinates (•).

was obtained with the variance images (Figure 3) which show the variations between the images of each time-exposure cycle.

The georeferencing, using eight base points obtained with a differential GPS system, also provided good results. Figure 4 shows the differences between the base points used and the georeferenced coordinates.

The reliability of the technique can be seen in Table 1, which reports the Gauss Boaga geographical coordinates actually measured and their corresponding georeferenced coordinates (Figure 4). The level of error is obviously greater further from the webcam.

Finally, the rectified image (Figure 5), using the georeferenced matrix, shows an excellent correspondence to the real coordinates and the reconstruction in those sectors closest to the webcam. Further away the image becomes distorted as the georeferencing introduced greater errors at the extremity of the image.

Table 1. The Gauss Boaga geographical coordinates of the base points and their corresponding georeferenced points.

Point	Real GBN	Reconstructed GBN	Real GBE	Reconstructed GBE
A	4890814.986	4890814.364	1548772.350	1548773.232
B	4890842.557	4890842.839	1548741.024	1548740.512
C	4890874.285	4890874.643	1548718.215	1548717.652
D	4890870.895	4890873.687	1548714.808	1548712.127
E	4890885.940	4890885.903	1548690.389	1548690.520
F	4890943.444	4890942.067	1548639.525	1548640.593
G	4890995.261	4890987.075	1548592.314	1548600.819
H	4891052.217	4891059.494	1548535.275	1548527.947

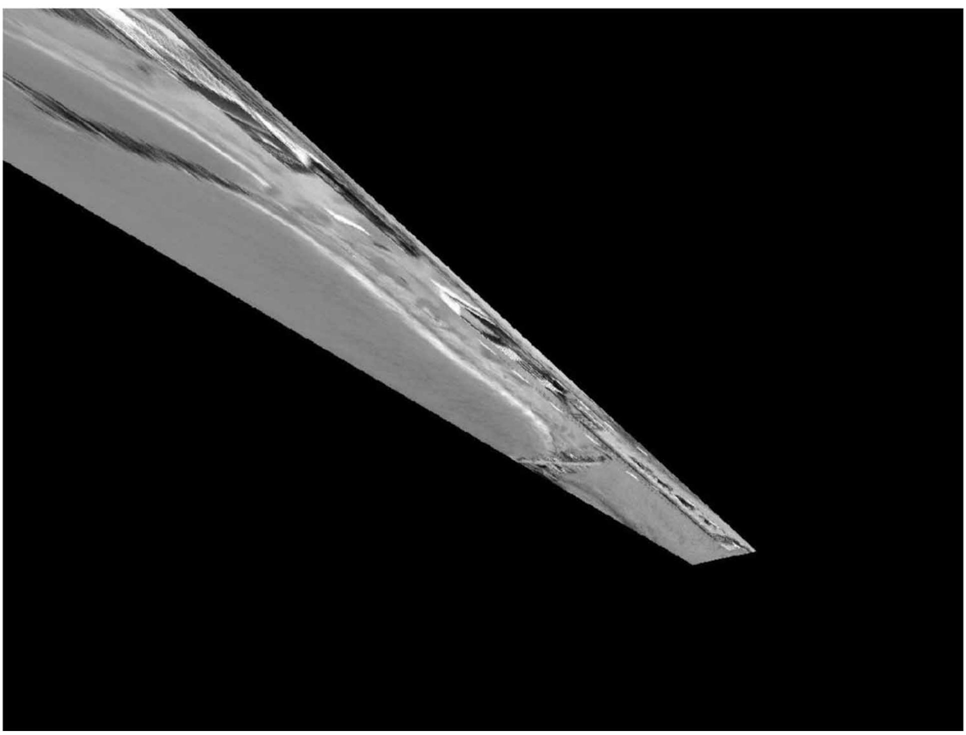

Figure 5. Rectified time-exposure image taken at 12.01 p.m. on 4 November 2005.

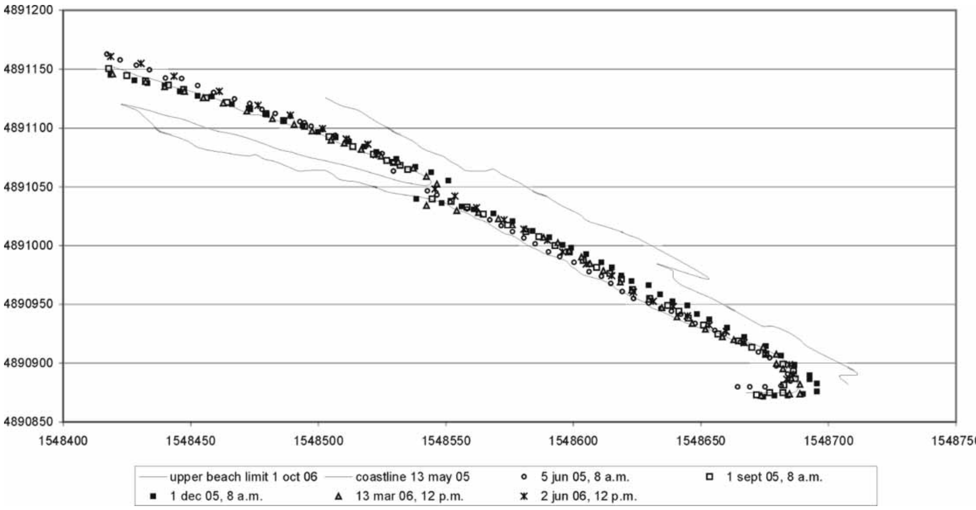

Figure 6. Monthly variation of the coastline during the period June 2005–June 2006.

3.2. *Nourishment monitoring*

The study was carried out to analyse the variations in the shoreline following a nourishment programme of Levanto 2005 with a webcam monitoring system [11–14].

The shoreline considered is represented by the point of contact between the pixels belonging to the wetter and drier zones, the colour intensity of the former being less than the latter, which represents the run-up at the moment the picture was taken. The evaluation of the effectiveness of the programme was performed using time-exposure and variance images [15,16]. It was possible to trace the changes in the shoreline on a daily and monthly basis and so reconstruct the seasonal evolution. The various shorelines were manually digitised from the timex and variance images using dedicated software and then compared to reconstruct the morphodynamic evolution of the beach.

Figure 6, showing the monthly trend of the shoreline, reveals a slight retreat in winter followed by recovery in summer, in other words a typical seasonal evolution, governed by the force of the waves, had developed. The nourishment had given the beach overall stability.

The images of June 2006 reveal that the westernmost sector of the beach did not show signs of retreat. So it can be supposed that that sector suffered no loss of material between 2005 and 2006, contrary to the central sector where there was a modest retreat.

The eastern zone, which did not benefit from the nourishment programme, underwent a modest retreat. This situation could probably be explained by a delay in the morphodynamic evolution of this part of the beach rather than erosive phenomena but it would also be possible to hypothesise that this down-drift tract had not benefited from the nourishment as the groynes in the other two sectors had correctly retained the new sediments. In fact, the advance of the shoreline after the nourishment had anchored these structures more firmly to the shore, improving their efficiency.

4. Conclusions

The study of Levanto enabled us to demonstrate the evolution of a gravel beach following artificial nourishment. The comparison of digitized images provided us with information on the response of the beach to the depositing of 16,000 m^3 of borrowed material with dimensions of 20–30 mm, greater dimension than the native material on the beach (average dimension = 3.5 mm). The use of the webcam images enabled us to obtain fast, continuous, daily information on the evolution of the shoreline. The data obtained were then compared to highlight the evolution of the beach. As a single year of monitoring is not sufficient to fully understand the complex dynamics that govern the littoral tract, we can say that our analyses merely provided us with sufficient material to highlight the more evident characteristics of the evolution of a gravel beach following a nourishment programme. The digitising of the data-set demonstrated that, overall, the beach remained stable over the observation period (2005–2006). The processing system, based on current standard procedures, provided good-quality images and reliable data. Its use in highlighting the salient characteristics for tracing the evolution of the beach in the medium term and accurately evaluating the effectiveness of the intervention was confirmed.

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