Application of remote sensing video systems to coastal defence monitoring

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ABSTRACT


Shoreline stability is an important issue along much of the Mediterranean’s Coasts. European project MEDDOOC INTERREG BEACHMED-e focused on the strategic management of beach protection for the sustainable development of the Mediterranean coastal zone. In the framework of this project, a video system has been installed in Valras (Gulf of Lions / France) to monitor coastal evolutions and recent protection works. Over the past 20 years, coastal video remote sensing techniques represent an efficient alternative tool to classical in situ surveying techniques. Coastal video monitoring is based on Time exposure images (Timex) acquisition and photogrammetry technique which allows transforming 2D image coordinates into the corresponding 2D real world coordinates. This paper presents the use of video monitoring technique to estimate the impact of engineering works. Important beach retreat has been observed for decades along the 3 km of Valras beaches and 12 breakwaters have been built until 2007. From January to May 2008, a new similar protection, a submerged breakwater and 95,000 m$^3$ sand nourishment have been added. As Empirical Orthogonal Function (EOF) analysis has become an established method for investigating temporal beach fluctuation, EOF is performed using weekly video monitored shorelines over a 6 months period. The results show: (1) the natural erosion / accretion phases of the already protected shoreline, (2) the impact of beach nourishment and the trend toward the equilibrium position of the restored shoreline, (3) the efficiency of video monitoring for shoreline management.

ADDITIONAL INDEX WORDS: Video monitoring, Empirical Orthogonal Function, Engineering work

INTRODUCTION

Coastal zones of the Mediterranean Sea are territory of particular interest for sustainable strategic development. Quantitative analysis of sandy beaches evolution play an essential part in the integrated management of coastal zones. They are especially critical when planning coastal defence and assessing their efficiency. The European project MEDDOOC INTERREG BEACHMED-e and more precisely the OpTIMAL (Optimisation of Integrated Monitoring Techniques Applied to Coastlines) subproject focused on the development and the implementation of measurements techniques to characterize erosion for the sustainable use of the resources.

Monitoring of near-shore systems has traditionally relied on in situ measurements of waves, currents, sediments transport and morphological changes. These technologies provide data of high quality, but have limited resolution in time and space because of the expense and logistical difficulties associated with deployment. Satellite and airborne remote sensing techniques have improved the spatial coverage of measurements with reasonable resolution. However, the use of these techniques is not cost-efficient for the purpose of long term, high resolution monitoring of the near-shore processes imply in coastal management. Over the past 20 years, shore-based video remote sensing systems have provided an alternative low cost tool to remotely survey coastal areas.

The use of shore based video systems has been introduced by the Coastal Imaging Lab, University of Oregon, in the beginning of the 1990s. Coastal video monitoring is based on Time exposure images (Timex) acquisition and photogrammetry technique which allows transforming image coordinates into the corresponding real world coordinates (Holland et al., 1997). The so-called ARGUS system have been recently used in the Coast View project (Davidson and Medina, 2007) for developing video-derived Coastal State Indicators (ICSs) in support of coastal management. With the increasing offer of video cameras and video technologies, several systems have been developed in the past years and tested in the framework of the OpTIMAL project.

In December 2007, a Kosta System video station has been installed in Valras (Gulf of Lions / France) to monitor coastal evolutions and recent protection works. The aim of this paper is to present the use of video monitoring technique to estimate the impact of engineering works by combining weekly shoreline detection and Empirical Orthogonal Function (EOF) analysis.

The paper is set out as following: Section 2 gives details on the study site and the description of the Valras video station. Section 3 describes the methodology used to automatically detect the shoreline position from the video system, as well as the EOF technique used for this study. The results and the conclusions are presented respectively in Section 4 and 5.
STUDY SITE AND VIDEO SYSTEM

Valras is a beach resort located on the Gulf of Lion, Mediterranean Sea, France. The Gulf of Lion is a microtidal area (spring tidal range of about 0.4 m) and the wave climate is characterized by a significant annual wave height of 0.83 m, a peak period of about 5 seconds, and a south-east direction. The sandy beaches of Valras stretch between the Orb and the Aude river-mouth (Figure 1). The 3 km of Valras coastline are highly eroded since the building of the harbour jetty entrance in the 1960s. The longshore drift, induced by East wind storm, is stopped by this jetty located on the west side of the Orb river-mouth. Hence, important beach retreat has been observed and 12 breakwaters have been built until 2007. From January to May 2008, a similar protection, a submerged breakwaters and 95,000 m³ sand nourishment have been added.

Images acquired by the video station usually show a strong contrast between blue sea water and yellow sandy beaches. Different algorithms have already been developed and proved their efficiency to automatically detect the position of the shoreline (Plant and Holman, 1997; Osorio, 2005; Aaronskopf, 2003). They are based on color information or on the brightness level recorded by the CCD sensor of the video.

However, these techniques can be limited when the contrast between water and sand is blurred (fog, rain, high turbidity level, algal bloom, sun reflections). In this study, the technique used is based on a mathematical approach. The RGB and HSV models are combined as six independent parameters treated by a clustering algorithm based on a k-mean function (Morichon et al., 2008; Dailoulo, 2008). This function aims at discriminating two clusters respectively referred to as the wet area (sea water) and the dry area (sand). Then, a selection criteria allows to automatically detect the two parameters which centroids are the most distant, with the less diffusive distribution, and the best ratio between the number of points in each cluster. Finally, the clustering algorithm is used on the selected couple to detect the position of the edge between water and sand (Figure 3). Based on this technique, a serie of shorelines were detected on rectified plan-view images. The first step consisted in selecting the most appropriate images for the analysis. The images were selected on a weekly basis, during calm days (and after periods of calm conditions), for a weak sea water level variation according to the tidal gauge located at the Sète Harbor. Between December 2007 and June 2008, 19 shorelines detection were performed. The maximum sea level range recorded by the gauge for the 19 shorelines was about 20 cm. The error induced during the video detection of the shoreline by the sea level variation is proportional to the slope of the beach.

EOF Analysis

The empirical orthogonal function (EOF) technique is used to define the patterns of spatial and temporal behaviour of the shoreline position. The EOF method determines the shape of the expansion functions directly from the data, rather than from an a priori selection of shape functions. Developed from the early to mid 1900s (Pearson, 1901; Hotelling, 1933), the EOF technique has become widely known and used across a broad range of scientific disciplines with the advent of electronic computing. In the coastal sciences the first application of the EOF technique was realised by Winant et al. (1975) to analyse beach profile measurements. After this pioneering study, EOF has become a commonly applied technique in morphological research to investigate beach response over time scales of month to decades (Larson et al., 2003; Rhouey, 2004).

The EOF technique may be described briefly as follows. We denote the discrete shoreline position by \(y(x_l, t_k)\), where \(x_l\) is longshore position and \(t_k\) the time of the data points, with \(1 \leq l \leq L\) and \(1 \leq k \leq K\). Thus, the idea of EOF analysis is to expand \(y\) as a linear combination of functions of space and time:

\[
y(x_l, t_k) = \sum_{p=1}^{L} C_p(t_k) e_p(x_l)
\]

where \(e_p\), often referred to as the spatial eigenfunctions, are determined directly as the eigenfunctions of the correlation matrix.
of the data $A$, together with their corresponding eigenvalues $\lambda_p$:

$$A e_p = \lambda_p e_p$$

Hence, if $A$ is real and symmetric it has $L$ real eigenvalues, and its eigenvectors may be chosen as mutually orthonormal, that is,

$$\sum_{l=1}^{L} e_p(x_l) e_q(x_l) = \delta_{p,q}$$

Where $\delta_{p,q}$ is the Kronecker delta. The correlation matrix $A$ is calculated from the data. It has $L \times L$ elements $a_{ij}$ of the form:

$$a_{ij} = \frac{1}{K} \sum_{k=1}^{K} y(x_i,t_k) y(x_j,t_k)$$

Finally, the temporal coefficients $c_p(t)$ called also weightings, may be calculated from equation (1) and (3):

$$c_p(t_k) = \sum_{p} y(x_i,t_k) e_p(x_i)$$

Several properties of real symmetric matrices may be used to aid the interpretation of some of the calculated quantities. For instance, the trace of $A$ is equal to the sum $\sum_{i=1}^{L} \lambda_i$.

RESULTS

First, the 19 detected shorelines are projected in a common coordinate system in which the $x$-axis is parallel to the longshore direction, and the $y$ axis is parallel to the cross-shore direction. In order to separate the already protected part of the beach (East to the station) and the nourished part (West of the station), EOF analysis has been performed respectively for the East part and the West part of Valras. For both EOF Analysis, over 98% of the mean square value of the data is captured by the first three functions.

The subsequent eigenfunctions correspond to the variation about the time mean, and so on.

Figure 4. (a) East beach surface evolution (m$^2$) and corresponding error bar. (b) Correlation between beach surface evolution and the 1st temporal mode.

Figure 5. (a) West beach Surface evolution (m$^2$) and corresponding error bar. (b) Correlation between beach Surface evolution and the 1st temporal mode.
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Figure 6. Spatial EOFs for shoreline of the East part of Valras: (a) 1st mode, (c) 2nd mode, (e) 3rd mode. Related temporal function: (b) 1st mode, (d) 2nd mode, (f) 3rd mode. Shoreline reconstructed with the first 3 eigenfunctions (g) for the 6th of January (post storm).

Figure 7. Spatial EOFs for shoreline of the East part of Valras: (a) 1st mode, (c) 2nd mode, (e) 3rd mode. Related temporal function: (b) 1st mode, (d) 2nd mode, (f) 3rd mode. Shoreline reconstructed with the first 3 eigenfunctions (g) for the 18th of March (well developed salient).

Figure 8. Spatial EOFs for shoreline of the West part of Valras: (a) 1st mode, (c) 2nd mode, (e) 3rd mode. Related temporal function: (b) 1st mode, (d) 2nd mode, (f) 3rd mode. Shoreline reconstructed with the first 3 eigenfunctions (g) for the 6th of January (post storm).

Figure 9. Spatial EOFs for shoreline of the West part of Valras: (a) 1st mode, (c) 2nd mode, (e) 3rd mode. Related temporal function: (b) 1st mode, (d) 2nd mode, (f) 3rd mode. Shoreline reconstructed with the first 3 eigenfunctions (g) for the 5th of April (during the beach nourishment).
CONCLUSION AND PERSPECTIVES

An application of remote sensing video systems to coastal defence monitoring has been presented. EOF technique was applied to shoreline contours extracted from 10 min times-average images at constant sea level (CSI). The results shows that this approach allows to quantify: (1) the beach surface, (2) the natural erosion / accretion phases of the already protected shoreline, (3) the impact of beach nourishment and the trend toward the equilibrium position of the restored shoreline. The technique presented in this study seems to be a suitable tool to coastal engineering purpose, as previously shown by Kroon et al. (2007). Nevertheless, the short duration of the video monitoring period still not allows an accurate appreciation of the coastal defence efficiency. Moreover, the three first modes together account for over 99.5% of the mean square of the data. This is a large proportion of the variance for analyses of this kind (Reeve et al., 2008) and, as expected, the EOFs describe the variability in the shoreline behaviour efficiently. In the near future, a considerable interest will be brought in continuing the Valras video monitoring, as EOF analysis is a suitable tool to initiate the development of a data-driven model for predicting nearshore morphological evolution (Aubrey, 1980; Hsu et al., 1994; Rihouey, 2007; Reeve et al., 2008).

LITERATURE CITED


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