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Combining Video Imaging and Numerical Modelling for the Extraction of Intertidal Morphology

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ABSTRACT

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In recent years, several techniques for the extraction of intertidal morphology from video images have been developed. These techniques are based on the detection of the shoreline location at a number of instances during a tidal cycle. However, such techniques always assume spatially horizontal water levels, an assumption that is often invalid in coastal regions were pressure gradients associated to inlets are important. Accurate water levels are of fundamental importance for the image processing, since they are used twice in the morphology extraction process: 1) for the rectification of the image coordinates, and 2) when defining the correspondent elevation values (*z*) for the extracted points. In order to include spatially varying water levels in the image processing, this study combines the use of a numerical area model (MIKE21 HD and NSW) and Argus video images. This is carried out by applying the spatially varying modelled water levels for the image processing. The application of the technique at the Teign river inlet (Teignmouth, UK) showed promising results, with a good approximation of the observed morphological changes. Typical root mean square errors (RMSE) of about 0.14 m were found at the intertidal region under the influence of the inlet channel, contrasting with the RMSE of about 0.37 m when assuming horizontally constant water levels.

ADDITIONAL INDEX WORDS: *Argus images,MIKE21 modelling system, intertidal mapping.*

INTRODUCTION

This paper presents a method for the extraction of intertidal morphology by combining the application of a numerical area model and Argus video images. During the last decade, several techniques for the extraction of intertidal morphology from video images have been developed (e.g. PLANT and HOLMAN, 1997; DAVIDSON *et al.*, 1997; HOLLAND and HOLMAN, 1997; AARNINKHOF and ROELVINK, 1999). The basis of all these video methods is the detection of the shoreline location at a number of instances during a tidal cycle, the shoreline being considered the contour line corresponding to the location of the local water level. One source of inaccuracy in these methods comes from the assumption of a spatially horizontal water surface, an assumption that is often invalid in coastal regions were pressure gradients associated to inlets are important (see SIEGLE *et al.*, 2002).

Due to the difficulty in measuring these irregularities in coastal regions due to both the density and spatial extent of the measurements required, the use of numerical models can provide valuable information. The model applied in this study is the MIKE21 hydrodynamic model (HD) and the nearshore spectral wind-wave model (NSW).

The data used in this study originated from the European COAST3D, in which Teignmouth (UK) was one of the studied areas. A detailed description and achievements of the COAST3D project can be found in SOULSBY (2001). Teignmouth is also one of the sites included in the international Argus programme (HOLMAN *et al.*, 1993; HOLMAN, 1994), with five video cameras overlooking the inlet and the sandbar system. Since February 1999 this system gathers hourly video images from the area, providing invaluable information about the area.

The structure of the paper includes the description of the technique applied for the detection of shorelines in the video images, followed by a brief description of the application of the numerical model. This is followed by the description of the combination of both tools and the validation of the results through the comparison with measurements. In the final section, discussions and general conclusions of this study are presented.

SHORELINE DETECTION

In this study a method of defining contour lines with the same pixel intensities in an image is used for the morphology extraction from the images. This is done through the use of the "Imcontour" Routine available in the MATLAB® Image Processing Toolbox. This routine Draws contour plots of the intensity image, automatically setting up the axes so their orientation and aspect ratio match the image. The intensity level to be drawn and the number of intensity contours can be detected automatically or defined manually. The application of this technique is based on the photogrammetric techniques described for the Argus video system by LIPPMANN and HOLMAN (1989). A summary of the technique application is described below:

- based on the oblique images, all the information related to the image is loaded, including the time, image geometry parameters, camera information and tidal level. As the "imcontour" tool works only with the grey scale images, the image is converted to grey scale. This results in an image with 256 grey shades ranging linearly in value from 0 (black) to 255 (white). An oblique image consists of 640 x 480 array of pixels ordered according to a pixel coordinate system (U_i, V_i).
- through the use of the "improfile" MATLAB® routine a sample profile of the pixel intensities is extracted so that the range of pixel intensity values that better represent the shoreline can be defined;
- using the "imcontour" tool the pixel intensity value defined as being the shoreline (mid-point of the drop in intensity) is drawn. The intensity that will best define the shoreline may change from image to image as a function of solar radiation incidence and the composition of the material being viewed (e.g. wet/dry sand, water). However, the abrupt change in intensity values usually verified when comparing water pixels with sand pixels in the images allows the definition of the intensity values that represent the shoreline;
- this selected contour line of same intensity is saved with its U_i and V_i image coordinates, which are corrected for the lens distortion and then rectified using the geometrical parameters for the given image. The image is rectified using as vertical

elevation the local tide level;

- the rectified points with their corresponding elevation are used to create the grid (x, y, z) of the intertidal morphology.

Through the use of additional routines written for this purpose in MATLAB® most of these steps are carried out automatically.

When defining the rectification level (z), these techniques for morphology extraction from video images normally assume that the water surface is horizontal over the region of interest. However, as seen in SIEGLE *et al.* (2002) and briefly in the next section, in regions influenced by high pressure gradients, the water level height is spatially variable.

NUMERICAL MODELLING

As mentioned previously, due to the difficulty in obtaining the needed spatial resolution through measured water levels, the application of a numerical area model can help by providing the water surface topography across the region of interest. In this study the MIKE21 HD and NSW modules are applied for this purpose.

MIKE21 HD simulates the variation of water levels and flows (depth and flux) in response to a variety of forcing functions. The water levels and depth-averaged flows are resolved on a rectangular grid covering the area of interest. A detailed description of the flow module can be found in ABBOTT *et al.* (1981) and ABBOTT and LARSEN (1985).

MIKE21 NSW is a spectral wind-wave model, which describes the propagation, growth and decay of short-period waves in nearshore areas. The model includes the effects of refraction and shoaling due to varying depth, wave generation due to wind and energy dissipation due to bottom friction and wave breaking. The basic equations are derived from the conservation equation for the spectral wave action density based on the approach proposed by HOLTHUIJSEN *et al.* (1989). The various wind formulations in MIKE21 NSW are discussed and compared in JOHNSON (1998).

The model is set up using the surveys obtained during the COAST3D project main experiment (SOULSBY, 2001) and additional data from digitized charts (Admiralty Chart 3155). The final model grid covers the whole estuary and an area of approximately 3.5 km seaward and 4 km alongshore, resulting in a total grid area of 10 x 4 km. The grid resolution is 10 m in x and y directions, resulting in approximately 180 000 water points.

The calibrated and validated model for Teignmouth has been described and applied in studies of the local hydrodynamics and sediment transport (for additional information on the model calibration, validation and example applications, see SIEGLE *et al.*, 2002; SIEGLE *et al.,* 2003; SIEGLE *et al.*, 2004; SIEGLE, 2003).

Using the calibrated model a series of experiments were conducted aiming to quantify the relative importance of tidal range, wave conditions and river discharge on the water surface topography (SIEGLE *et al.*, 2002). These authors found that the water surface topography is directly related to the tidal range, with highest gradients in water levels between the channel and adjacent nearshore region during spring tides. This is particularly important for the image processing, since it is during spring tide conditions that the coastline extraction from images is more important, as this permits shoreline detection over a wider intertidal area. The emerged sandbars at low water spring tide periods play an important role in the funelling and friction effects of the channel. This is clearly seen in the analysis of a sequence of contour plots of water surface topography over the modelled spring tide period, as shown by the example represented in Figure 1.

Combining Numerical Modelling and Video Imaging

In order to carry out the image processing with the best approximation of the real water level distribution, the spatially varying modelled water levels are applied. This process of using the modelled water levels for the morphology extraction requires the inclusion of an additional step in the applied extraction technique described previously. The modelled water levels are used twice in the morphology extraction process: 1) for the rectification of the U_i and V_i image coordinates into x, y and z ground coordinates, and 2) when defining the correspondent elevation values (z) for the extracted points for the morphology grid generation. This additional step in the image processing consists of the segmentation of coastline stretches in an oblique image according to the modelled water level gradients. Figure 2 shows an example of how coastline segmentation is defined on a oblique image. From the overlaid modelled water levels it is possible to define stretches of coastline, according to regions of similar water levels, and consider them separately during the shoreline extraction, processing each defined segment with its corresponding modelled water level. This segmentation is defined according to the balance between the accuracy of the applied technique and processing time, with differences of about 0.05 m to 0.1 m defining each segment. For the example shown in Figure 2, the measured water level offshore (pier) at the given time is -1.98 m, resulting in differences of up to 0.78 m when compared to the water levels in the channel. If these differences are taken into account in the image processing, improvements can be made when extracting the intertidal morphology (as seen later in the technique validation).

TECHNIQUE VALIDATION

In order to validate the technique applied for the morphology

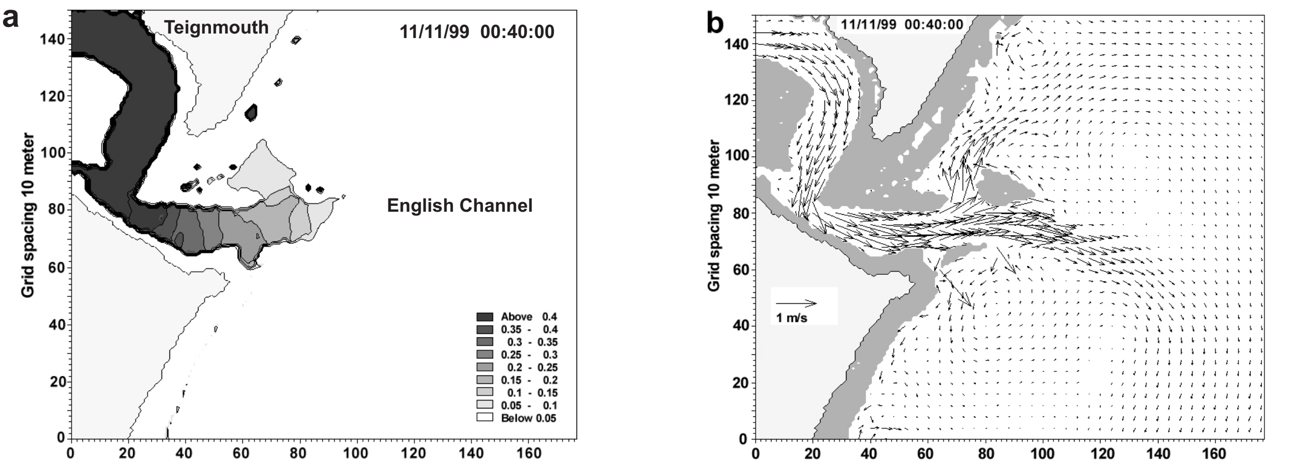

Figure 1. Contour plot of the water surface topography in relation to the offshore water level (a) and velocity vector plot (b) at maximum ebb flow.

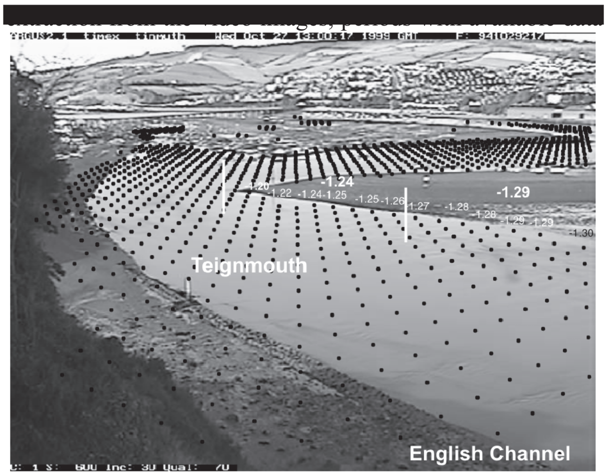

Figure 2. Example of coastline segmentation for the image processing using modelled water levels for camera 1 at 13:00h on the 27/10/1999. Black crosses indicate positions (U_i, V_i) of water levels extracted from the model with elevation values indicated by black labels. Lines show the stretches of coastline processed from average water level. At the given time the offshore water level measured at the pier is 1.98 m.

obtained through traditional surveying techniques are compared for the region of interest. In this study, the COAST3D main experiment survey (25 - 27 October, 1999) is used for the validation purpose. The comparison of the measured morphology with that extracted from images is carried out using interpolated intertidal maps for the periods with available data. Example results from the comparison for the studied period are presented in Figure 3.

In the comparison shown in Figure 3 both spatially constant and varying water levels are applied for the morphology extraction. In general, all the compared profiles present a better result when using the varying modelled water levels, and this improvement is increased for profiles close to the inlet mouth, where higher pressure gradients control the water levels. The use of spatially horizontal water levels results in large differences in the extracted morphology when compared to the surveyed data. As shown by the compared profiles, this difference is significantly reduced when applying the modelled water levels in the shoreline extraction technique.

Quantifying the vertical errors through the use of Root Mean Square Error (RMSE) values also shows the gain in accuracy when using the varying modelled water levels for the image processing. RMSE values are summarised in Table 1 for the compared profiles. Extending the comparison to the map generated by all extracted and surveyed points over the Sprat sandbar the RMSE values are 0.373 m when using constant water levels and 0.144 m when applying the varying modelled water levels. The RMSE values present an even further reduction when comparing some particular profiles at the region under the channel influence (Table 1).

Table 1. *RMSE* (m) values for the compared profiles.*

	modelled water level	constant water level
Profile 1	0.152	0.382
Profile 2	0.226	0.508
Profile 3	0.096	0.565
Profile 4	0.128	0.300
Profile 5	0.120	0.202
Profile 6	0.124	0.266

* Root Mean Square Errors (RMSE) of the compared profiles were calculated through $RMSE = \sqrt{\Sigma(z_e - z_m)^2/n}$, where z_e are the extracted elevations, z_m are the measured elevations and n is the number of compared points.

As shown by SIEGLE *et al.* (2002) the inlet channel at Teignmouth is highly influenced by the pressure gradient existent between the estuary and the adjacent nearshore region. As the processing of the images is dependent on the local vertical elevation, the inclusion of differences in the water level across the channel region is shown to be very important to obtain the correct horizontal position of the shoreline and its associated vertical elevation.

Despite the contouring technique being simple and limited to greyscale images, it is able to define well the contours that best represent the shoreline in most cases. This means that it is able to solve part of the problem of morphology extraction from images, by locating the U_i and V_i coordinates of the shoreline in an oblique image. The second part of the process is the application of the photogrammetric relations to convert the detected U_i and V_i positions in the oblique image into *x, y* and *z* ground coordinates. This part is considerably improved by applying accurate water levels, since they are used in the photogrammetric relations to rectify the coordinates and for the intertidal map definition of vertical elevations.

When the morphology extraction technique is focussed on regions away from the influence of the inlet channel pressure gradients, the assumption of spatially horizontal water levels is accurate and results in good estimates of the morphological features from the images. However, at regions where the water levels present high differentials in relation to the level measured at the pier, large variations in the horizontal and vertical position occur if these differences are not considered in the image processing. This problem is clearly verified through the compared profiles over the Sprat sandbar, where the use of the measured water level at the pier resulted in a residual error of 0.37 m for the extracted intertidal morphology. At some locations (profiles 2 and 3 Figure 3) this error can reach values of over 0.5 m. Applying the modelled water levels results in an improved reproduction of the intertidal morphology, with the overall error being 0.14 m over the Sprat sandbar (for all compared points). At profiles 2 and 3 (which presented errors larger than 0.5 m when using constant water level) the errors are reduced to 0.22 and 0.09 m respectively.

CONCLUSIONS

The overall aim of this paper was to describe and apply a technique to extract the intertidal morphology from video images based on a horizontally varying water level. The applied technique is based on the same principle of previous techniques applied for the shoreline extraction from images (e.g. PLANT and HOLMAN, 1997; DAVIDSON *et al.*, 1997; JANSSEN, 1997; AARNINKHOF and ROELVINK, 1999). This principle is the detection of the shoreline location at a number of instances during a tidal cycle, assuming the vertical elevation of the shoreline being the local water level. However, the main difference in the method applied in this study is the application of modelled spatially varying water levels across the region of interest for the image processing.

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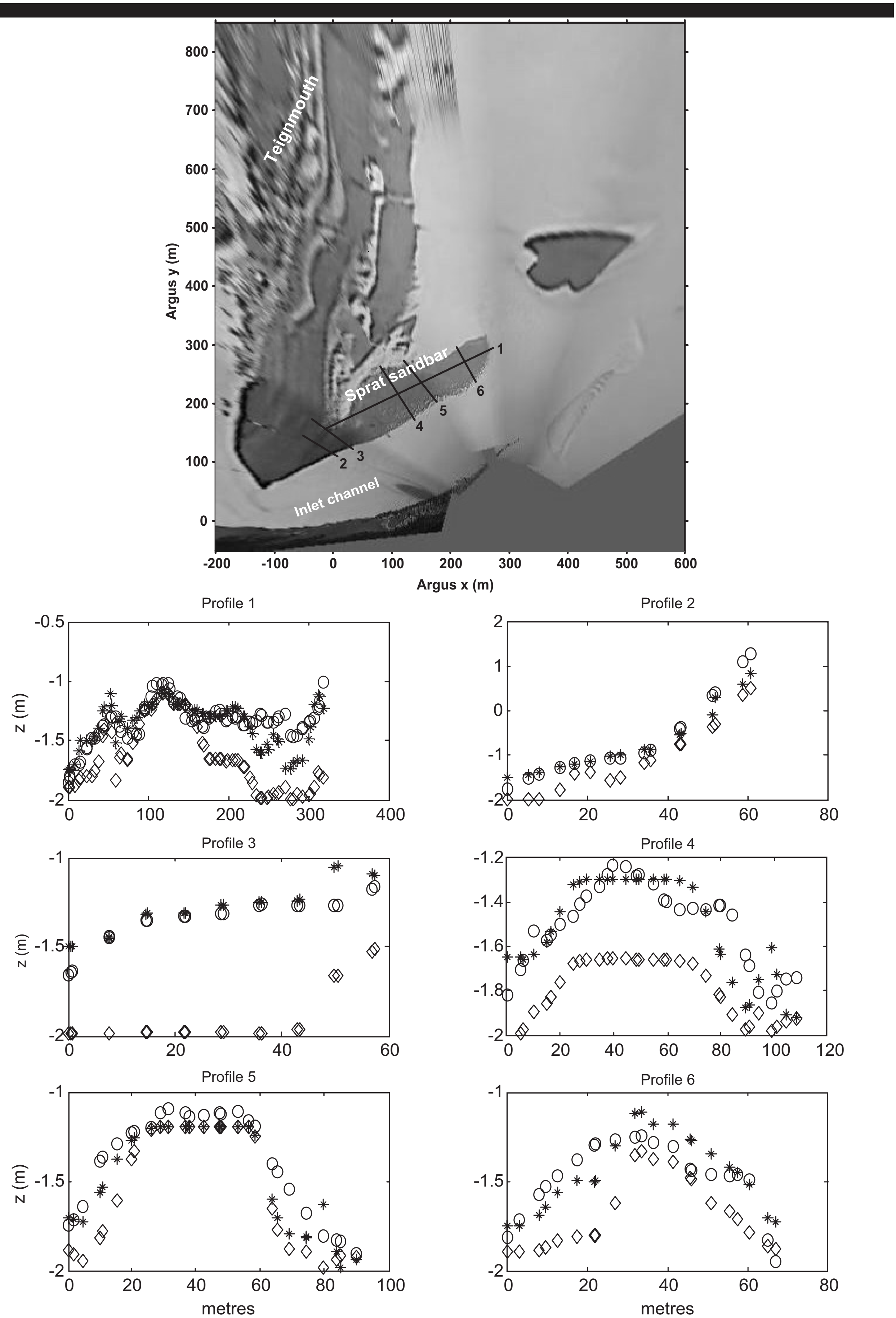

Figure 3. Validation profiles of the morphology extraction technique from the video images (left hand side). Profiles are plotted over a rectified Argus video image of the study area. The right hand side shows the comparison of measured morphology profiles (circles) and extracted from images using the modelled water levels (stars) and a constant water level (diamonds) at the indicated profiles. Survey carried out on 25 - 27/10/1999 and image from the 26/10/1999. Contour lines were extracted from images covering a two day interval (26 - 27/10/1999).

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