INTER-TIDAL FLATS SEGMENTATION OF SAR IMAGES USING A WATERFALL HIERARCHICAL ALGORITHM

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ABSTRACT

In this work we describe a scheme to identify 1D structures in SAR images and applied it to a dataset consisting of two TerraSAR-X images acquired over the region of Lisbon with a temporal baseline of 22 days. The aim of this application it to identify the inter-tidal flats along the south bank of the Tagus river. First results show that a proper recognition of the inter-tidal zone is achieved.

1. INTRODUCTION

Knowledge of coastline is the basis for measuring and characterizing land and water resources, such as the area of the land, and the perimeter of coastline. Information about coastline position, orientation and geometric shape is also essential for autonomous navigation, geographical exploration, coastal erosion monitoring and modeling, and coastal resource inventory and management. The coastline detection is, in general, a problem of water and land regions separation ([3], [5]). This is well known problem in remote sensing, as in the monitoring of flooded areas [4]. Automated coastline extraction from digital image data belongs to the boundary detection problem in the field of computer vision and image processing, in which edge detection and image segmentation are two conventional approaches to the boundary detection. In this work we present a morphological-based segmentation approach driven by the *waterfall* hierarchical method, in order to recognize the inter-tidal region in SAR images. Different time datasets from the same area are used: one corresponding to the low tide and the other one to the high tide. Generally the gradient line on water to land transition, of SAR coastal images, is degraded by noise, which makes difficult its identification by a pixel oriented segmentation approach. A grey level image is a discrete surface topography that can be analyzed in terms of its relief characteristics. The *waterfall* transformation [2] modifies that topography by a bottom-to-top tree process of basins flooding, which is done by means of *watershed* [1] and dual reconstruction morphological transformations. Segmentation instability and feature randomness may stand regarding result accomplishment for the proposed features over the entire scene, when standard *waterfall* method is applied. To overcome this problem, hierarchical segmentation improvement is fostered, by doing marker constraint in each step of the *waterfall* segmentation tree. When this is applied over noisy grey level images, regions with higher homogenous background grey signature emerge. A change detection approach was used to detect the location of inter-tidal flats. For each pixel of the two SAR images, registered on the same spatial grid, it was computed the normalized amplitude difference (NAD). This new image gives information about areas whose scattering properties changed between the acquisition times of the two SAR images. Among these areas there are also the inter-tidally lands which have the property of being covered by water in just one of the two SAR images and so have different scattering properties resulting in a different intensity in SAR images. The waterfall algorithm was applied to the NAD, computed from the dataset consisting of two TerraSAR-X images acquired over the region of Lisbon (south bank of Tejo river) with a temporal baseline of 22 days. These SAR images have a spatial resolution of 3 m, which is appropriate to identify the inter-tidal flats characterized by a small spatial extension. Also, it should be noted that improvements are obtained by a previous signal (image) frequency filtering, using the Fourier transform, of the NAD. The first results show that a proper recognition of the inter-tidal zone is achieved.

2. METHODOLOGY

This section describes the hierarchical segmentation methodology used to identify the inter-tidal lands in SAR images of the same area acquired at different times. Taken an image mapped to an 8-bit radiometric resolution, the correspondent *regional minima* (RM) are first computed. The topographical surface of the grey

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image is *watershed* segmented by taken RM as the default binary marker image. An over-segmentation state is emphasized by a high number of small catchment basins. Darker spots in the grey image are filled by a waterfall morphological approach before applying again the watershed segmentation. In order to facilitate the region growing, a set of improved binary markers is fed to the watershed segmentation at each step of the hierarchical waterfall segmentation. It should be noted that in this approach, known adjacent catchment basins remain intact in each new segmentation step. This is a key aspect of our bottom-to-top segmentation method because in this way image regions, with a low backscattering coefficient, grow faster at initial steps of the hierarchical tree. Region's grey stability is the key aspect for its segmentation with the *waterfall* method. The inter-tidal lands are identified from a given RM iteration of the *waterfall* binary scheme. The morphological transformation known as *waterfall* modifies a grey level image surface by flooding all catchment basins, each one from its correspondent minimum value up to the lowest value of the correspondent *watershed* line. Therefore a grey level image is also obtained with the *waterfall* transformation. The general algorithm can be divided in two parts. The first part consists on applying the *watershed* computation to a grey level image $f(x)$, using a binary marker image which is generally by default the correspondent RM set. The result is a binary image of all its catchment basins delimited by the correspondent *watershed* lines. Following, it is computed a grey marker image $s(x)$, such as $s(x) = f(x)$ for all pixels x belonging to the *watershed* lines of $f(x)$, and $s(x) = max[f(x)]$ otherwise. The second part consists on the application of a grey level morphologic transformation known as *dual reconstruction* (1) (also known as *reconstruction by geodesic erosion*) of $f(x)$, taken $s(x)$ as the grey level marker image, until the condition of *idempotence* (2) is satisfied.

$$R^*_f(x) = e^i_f(s(x)) \tag{1}$$

$$e^i_f(s(x)) = e^{i+1}_f(s(x)) \leftarrow \textit{idempotence} \tag{2}$$

The output of the referred transformation is a grey level image with all its catchment basins partially flooded up to their correspondent watershed line lowest pixel value. Following, that modified grey image will enter as the start image of the first iteration of the WFB scheme, in which the same waterfall tasks will be executed. The successive application of the standard *waterfall* algorithm to each waterfall image output characterizes the waterfall hierarchical segmentation method. In the example a single iteration is executed until the condition of idempotence is verified.

Generally, the standard *waterfall* does not take more than eight or nine iterations to complete the segmentation. At each step, a new set of RMs is computed. A set of larger basins is obtained by merging cluster of small catchment basins. Based on the standard *waterfall* method, a new segmentation rule is created to increase the level of segmentation details. At each iteration k, rather than consider the RM of each waterfall image as the set of *watershed* markers, a new set of markers is obtained by merging the RM binary images obtained at steps k and k-1. In other words, being RM_k and RM_{k-1} the RM sets of two consecutive *waterfall* output images, the binary marker set given as input in *watershed* k-iteration is computed as $RM_k = RM_k \cup RM_{k-1}$. With this procedure, all the catchment basins partially flooded are marked again, with the exception of those flooded up to a common *watershed* line pixel. As a result, a high number of flooded basins are recovered. This method is designated as *waterfall-plus* (WFP). As described, the difference to the standard *waterfall* (WFB) method, stands on the input RM marker set to be used in *watershed* segmentation at each step of the hierarchical tree. As a result, catchment basins are merged two by two in a local context. The considerable increase on the total number of segmentation steps reflects a more detailed segmentation image scheme.

3. PROCESSING AND RESULTS

In this section we shortly describe the processing steps and show the first results. Figure 1 display two portions of TerraSAR-X images acquired over the Lisbon region on September 7th and September 22th, respectively.

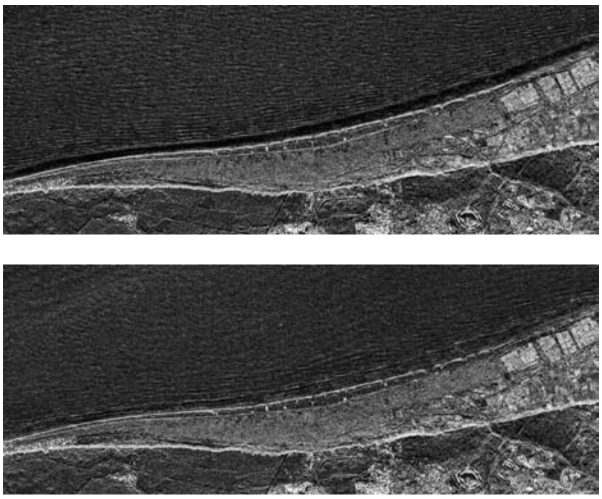

Figure 1: ***Portions of TerraSAR-X images of the south bank of Tagus rives (Lisbon, Portugal) acquired on September, 7th and September, 22th, 2010***

Both portions refer to the same portion of the Tejo river south bank. These images have a spatial resolution of 3 m and a temporal baseline of 22 days. The analysis of these images allows the identification of the inter-tidal flats, which are covered by water only in the second image, shown at the bottom of Figure 1. To better identify differences in the scattering properties of the inter-tidal lands, when covered by water or not, a change detection image I_{CD} was derived using the formula (3), where I_1 and I_2 are the SAR images acquired at times t_1 and t_2.

$$I_{CD} = \frac{I_2 - I_1}{I_2 + I_1} \tag{3}$$

This image normalizes for each pixel the temporal change of radar intensities to their mean value. Figure 2 shows the image I_{CD}. The inter-tidal flats appear as the darker line since in the first image they are not covered by water and so are characterized by a higher scattering coefficient. The image was normalized to the interval [0, 255] using an 8-bit coding. Furthermore, to facilitate the recognition of inter-tidal flats, the I_{CD} image was low-pass filtered (see Figure 3).

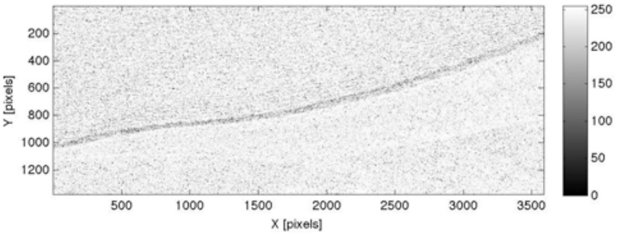

Figure 2: ***Change detection map of images displayed in Figure 1.***

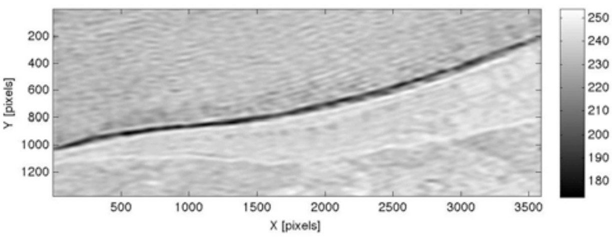

Figure 3: ***Fourier low-pass filtering of map displayed in Figure 2.***

To this filtered image has been applied the methodology presented in section 2. Figure 4 displays the first k steps of the *waterfall* hierarchical segmentation scheme described in section 2. After this step a morphological shape classification of objects according to elongation and thickness quantities over two main perpendicular directions was performed. Proper sized and directional structuring elements were defined for morphological linear opening operators, followed by binary reconstruction. The final results are given in Figure 5, where pixels represented in white are those that fit the classification parameters previously established. In other words, the most significant change in surface scattering properties, from the first image (acquired on September, 7th) to the second image (acquired on September, 22th), is defined by those white pixels, forming the region which seems to be related to inter-tidal lands.

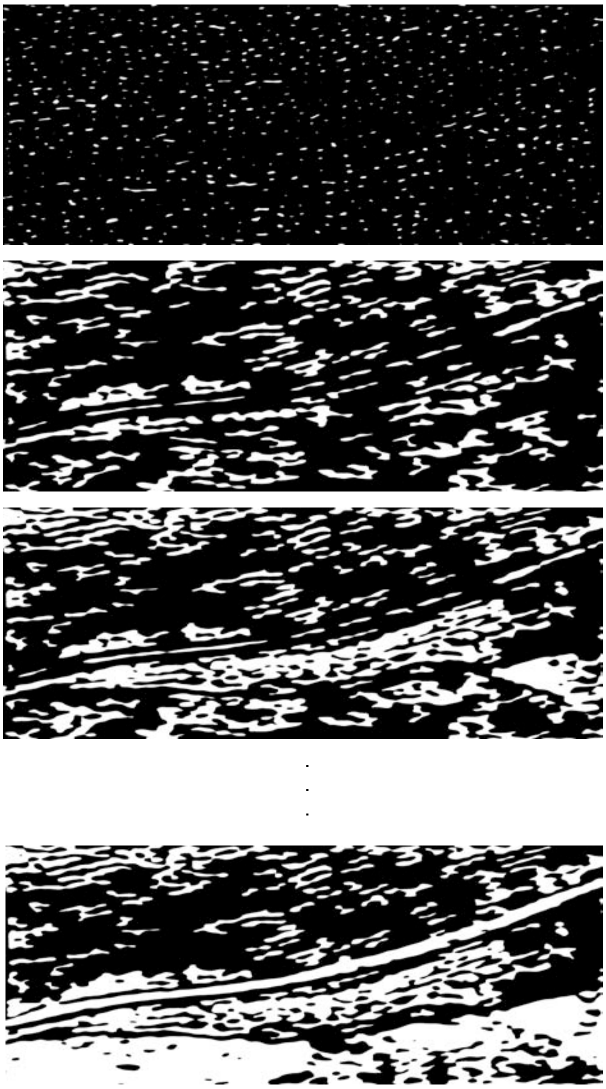

Figure 4: From the top to the bottom steps of the *waterfall* hierarchical segmentation scheme.

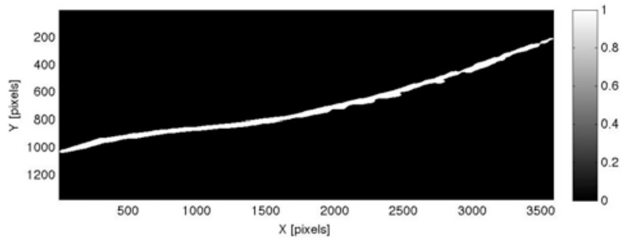

Figure 5: ***Map of the inter-tidal flats.***

4. AKNOWELEDGEMENTS

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5. References

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