Automated Waterline Extraction for Optimal Land Use
A Case Study in Crete

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Abstract: Coastal areas in Greece play an important role to the economic growth of the country. Especially in the islands as a major tourist destination, new tourist infrastructure is continuously being built. To optimize land use and protect current infrastructure, we need to properly define the waterline. In addition, the waterline is changing dynamically due to climate change and weather conditions, so it has to be monitored. The proposed framework is focused on the automatic extraction of waterline from aerial images using advanced image processing techniques. We plan to integrate the Greek cadastral data in the framework and along with spatial data analysis to be able to proceed with both coastal and cadastral data. Additional functionalities are provided to the planners, through metrics for distance and surface area calculations, in order to extract useful information for sustainable region planning of the coastal area. The results can be visualized in the images with the metrics of interest.

1 INTRODUCTION

Coastal zones are among the most productive areas in the world, offering a wide variety of valuable habitats and ecosystems that have always attracted humans and human activities. Currently, more than 200 million European citizens live near coastlines, stretching from the North-East Atlantic and the Baltic to the Mediterranean and Black Sea.

As an example, the island of Crete produces about one fifth of the GDP of Greece only in the summer (Synolakis *et al.,* 2008). The economy of the Chania region in North Western Crete is predominately based on tourist and agriculture and it is a very famous tourist destination. This intensive concentration of population and excessive exploitation of natural resources puts enormous pressure on our coastal ecosystems leading to biodiversity loss, habitat destruction, pollution, as well as conflicts between potential uses, and space congestion problems. The rapid economic growth of the coastal areas has driven the public and private sector to make investments in infrastructure. The urbanization and development of these areas has led to the construction of new roads, small villages, entertainment facilities and infrastructure for sport activities. The intense touristic development has led to the environmental downgrading of the areas near the waterline. The coastal areas are quite fragile landscapes as they are also among the most vulnerable to climate change and natural hazards. Risks include flooding, erosion, sea level rise, as well as extreme weather events. As negative factors we have human interventions and natural phenomena due to the climate change. Around 30% of the Greek coastline is affected by erosion (Valavanidis and Vlachogianni, 2011). In Greece, the way spatial planning confronts these phenomena is inadequate.

In our approach the main value of the research is to extract automatically the waterline and metric measurements helping the development planners to consider the risks for the coastal areas and to plan further actions.

Waterline extraction is mainly obtained through satellite images (Liu *et al.,* 2013), (Zhao *et al.,* 2008). The identification of shoreline from historical and aerial images using topographic data and digital image-processing techniques has been addressed in Boak and Turner, 2005. Aerial photogrammetry has already been used to provide shoreline information and shoreline dynamics (Dolan *et. al.,* 1978).

In our approach we use aerial images from HMGS Greece (HMGS, 2015) and Google Earth (Google Earth, 2014) to extract automatically the waterline.

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We demonstrate our approach for the town of Georgioupoli in North Western Crete (Fig. 1). The proposed framework includes algorithms to extract the waterline and provides a graphical user interface to allow the user to extract spatial information about the coastal area. The user can measure distances and areas of interest and the results can be visualized directly on the images.

Figure 1: The chosen area for the demonstration of our framework.

In addition, we are working on the extension of the framework to the connection with the Greek cadaster in order the user to be able to access and process cadastral data. The overall task is to effectively manage and associate spatial information from aerial images and information extracted from cadaster. This information can be visualized in the images with the objects of interest together. The goal of the framework is to: a) Automatically extract the waterline from aerial images b) to extract metric information about area, size for objects of interest and c) to provide spatial information for coastal management to people for a sustainable development of the whole region.

2 PROPOSED METHODOLOGY

The waterline estimation method is based on advanced image processing techniques and consists of two main steps. The first step provides an estimation of the coastline based on region segmentation using a local thresholding method, while the second step optimizes the results of the first step based on edge detection using active contours. Figure 2 presents the block diagram of the proposed methodology. Blocks inside the dashed lines refer to methods of waterline extraction, while blue and gray boxes refer to the functionalities of the framework.

Initially, a preprocessing step is performed on the input images to remove noise and enhance strong edges. Aerial photos usually provide a good spatial coverage of the coast, but they also are inevitably distorted by noise. A Gaussian filter is applied to reduce noise without blurring the edges. Another issue that usually arises is the presence of clouds and shadows that can deform the data and make it hard to process the image correctly. We manage this problem by using an anisotropic diffusion technique (Perona and Malik, 1987) that emphasizes strong edges, like coast area buildings, and enhances them or suppresses weak edges.

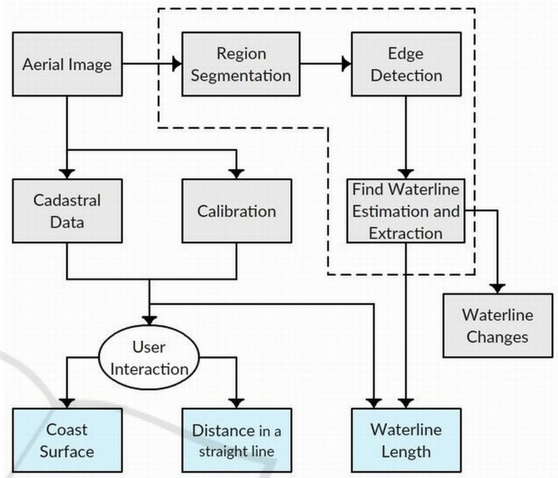

Figure 2: Proposed methodology for waterline extraction with the extension to connect to cadastral data.

The first step aims to segment the image into two regions; land and sea. The pixels which are located on the borders of these two regions will constitute the waterline. To accomplish this task, we developed a region segmentation algorithm using local thresholding. It is preferable to use a local threshold because a global threshold gives false estimations as a result of intensity heterogeneity of the image.

More specifically, we divide the image into square overlapping blocks with B width and check the bimodality of intensity in each of them (Liu and Jezek, 2004). For every block, we assume that there is a mixture of two Gaussian distributions (land and sea), and we test against the null hypothesis of having just one overall class. We formulate the likelihood test based on the corresponding probability destiny functions.

In practice, if the block passes the test, we expect that there are two clearly separated areas, i.e. land and sea, so that we can compute the threshold using Otsu's method (Otsu, 1979). This method automatically performs clustering-based image thresholding of a grayscale image by maximizing the weighted between-class variance. In this way, subareas of land are assigned the value 1, while pixels within sea areas are assigned the value 0. As a postprocessing step of this method, a concatenation of overlapping blocks is performed in order to recreate the whole image in a binary form and morphological operations are applied in order to remove small objects and fill the black holes. Subsequently, we use the canny edge detector, an edge detection operator, for the detection of edges in the images. The final binary image is in the form of a white area that belongs to land and a black area that belongs to sea. The result of the canny edge detector refers to coastline.

Most of the times, the extracted coastline needs improvement, because of unexpected effects in the image, such as waves, people and intensity distortion across the coastline. To be able to handle these issues we used an open active contour method based on the classical active contour model (snakes) (Kass *et al.,* 1998) with free boundary conditions. A snake is an energy-minimizing spline guided by image forces and external constrain forces. It consists of an initial contour C_0 near to a contour in the image and searches for deformations of C_0 which let it move towards the actual image contour. We implemented an automatic process using active contours with free boundary conditions (Shemesh and Ben-Shahar, 2011). We initialize the curve using the extracted coastline from the first step and we compute iteratively the next possible position of the curve following the gradient of the image defining its edges. After a certain number of iterations defined by user, the procedure stops and outputs the estimated waterline.

As far for the framework we developed, its implementation layout and functionality follow. Figure 3 presents the screen of the application where two central windows are devoted to the visualization of the original (left) and processed (right) image, respectively. The left section of the application depicts the parameters of the waterline extraction algorithm and provides the space for adjusting the algorithmic process. The right section presents the functionality of the software in association with the coastline analysis.

The top left box of the framework refers to the first method's parameters. Sigma and filter's size affect the Gaussian filter.

Sigma refers to standard deviation of Gaussian distribution. Increasing the standard deviation the intensity of the noise is reduced, but also appears high frequency detail attenuation. We have set the number of 2 as a default value. A larger size filter, corresponds to a larger convolution mask, but also affects the details quality of the image. We have set 7 as a default value. It is optimized for the filter size to be about 3*sigma+1, because, in this way, almost the whole Gaussian bell is taken into account. Then, the user chooses the number of iterations and kappa value, which refers to anisotropic diffusion. Kappa controls the sensitivity to edges and it is usually chosen experimentally (the default value is 8), while the number of iterations must be 5-15, since a higher number may result in blurring the true edges (the default value is 5). Next the block size B is defined. This size depends on the initial image size, because every block needs to contain necessary information for our method. We choose 5-8% of total image size, with default value 300. Next to the setting of the parameters, the user can proceed with the first waterline estimation using region segmentation.

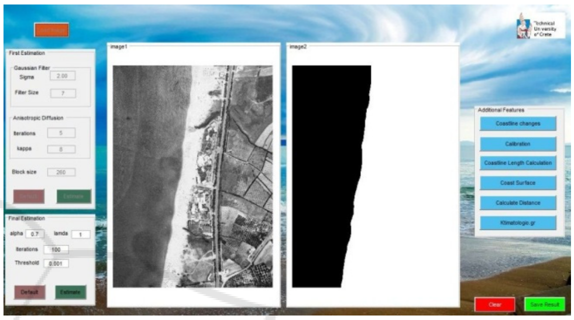

Figure 3: On the left is the original image. On the right, the estimated waterline can be extracted by finding the borders between the water (black) and land (white).

When the first step is completed, the user chooses the parameters for the second step. Alpha parameter controls the internal energy function's sensitivity to the amount of stretch in the snake (elasticity). A large value for alpha decreases the possibility the snake to change and so the method's efficiency, so normally alpha value should be less than 1. In our case, we have set it to 0.7. Iterations must be defined properly, because there will be a point that no significant energy differences are detected. A proper number of iteration is 100-300. We also provide an optional threshold to control the energy differences. If the deference between two consecutive energy values is below the threshold, the process stops and the final result is shown at the images section.

As far for the cadastral data association with the extracted waterline results, in our application there is a link, called 'ktimatologio.gr' (which means cadaster), that opens the map of Greece in the internet browser and the user can measure real world distances, such as buildings. Then by pressing the 'calibration' button the user can choose two points from the initial image which contain the same building or any other chosen area. A textbox then opens to enter the known distance and the measurement unit (Fig. 4). Now, we are able to compute the distance per pixel (pixel factor) by dividing the inserted distance by total number of pixels contained between two chosen points.

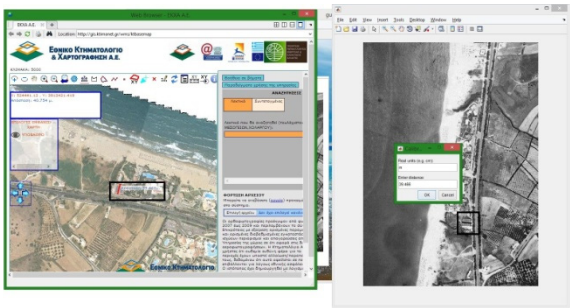

Figure 4: (ktimatologio.gr-calibration). The green box shows the selected area (tennis court) from ktimatologio.gr, the Blue box shows the same area from aerial image. We can also see the text box where we import the real units and the distance.

Figure 5: The computed length of the estimated waterline.

Moreover, the user is able to perform waterline length calculation by multiplying the total number of pixels that belong to the waterline by the pixel factor computed above. The measurement units are the same as the user has inserted at the previous step (Fig. 5).

In addition, the option to compute the area and perimeter of a surface of interest, like area of buildings, distance from waterline or beach surface area, is provided by pressing the coast surface button. A new window opens where the user can select a polygonal area at the image. The task performed is the computation of the total number of the pixels which belong to the perimeter, then the multiplication by the pixel factor in order to show the perimeter in real world units.

Finally, the computation of the total number of the pixels which belong inside this polygonal area is multiplied by the square of pixel factor in order to show the surface. Figure 6 displays an example of this operation.

Figure 6: Computed perimeter and surface of an area selected by the user.

Another similar function provided is the calculation of the distance between two points. By pressing calculate distance, a new window opens where the user can choose two points of the image. As in the previous case, we compute the total number of the pixels that belong to the chosen line, multiply by pixel factor and show the results (Fig. 7). This can be useful, if we have images of the same area but from different time periods and want to track the erosion of the coastline.

Figure 7: Computed distance of a straight line selected by the user.

As a final feature of the application, the user can load two images from different time periods of the same area by pressing the 'Waterline changes' button. When the images load finishes, the two estimated waterlines are shown in the same figure, thus the user is able to identify any possible changes (Fig. 8). Without georeferenced images, it is difficult to work with aerial images. This feature works better with google earth images.

Figure 8: The waterline differences between 2003 and 2010. The dashed line refers to 2003 image, while the solid line refers to 2010 image from Google Earth.

3 CONCLUSIONS

Our work focuses on the waterline extraction and the connection of the results with cadastral data. The waterline extraction is performed through advanced image processing techniques and the results are compared to the available cadastral data. A user can load the images of interest, perform coastline extraction, view the results and, finally, calculate useful parameters with distance or area metrics. Since the framework back-end structure is ready, as a next step we need to focus on the matching of the aerial images with the cadastral data in order to finalize the accuracy estimation of our methodology

As future work, our framework needs to be tested in more than one administrative region in order to explore the sensitivity and the performance of the proposed methods and how these two factors are affected by image parameters, like image resolution or image data complexity. We should also further explore the application's functionality regarding the cadastral data.

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