An Algorithm for Coastline Extraction from Satellite Imagery

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Abstract: Monitoring of coastline areas facilitates landscape development, sea transport, sea-level rise, changes in coastal areas and other important activities so it is very important that coastline extraction is quick and precise. In the past coastline extraction consisted of two stages: high-resolution images were captured from airplane and then coastline was drawn based on these images. This operation was slow compared to today's modern techniques such as satellite images and image processing. In this paper we proposed a new technique for coastline extracting from satellite images. The proposed procedure is based on algorithms for image processing and edge detection. Experimental results showed that the proposed method was fast and accurate.

Key–Words: Coastline extraction, histogram matching, Gaussian filter, locally adaptive thresholding, Canny edge detector.

1 Introduction

Coastline extraction is technique based on analyzing satellite images. These images are stored in a digital format. Each digital image is made up of a series of pixels, and the pixels have attributes such as color, brightness and position. Using computer algorithms that can analyze the image pixels and their mutual relations we can establish some rules for the further coastline extracting. The application of these algorithms on digital image is called digital image processing techniques. Satellite images are a valuable source of information, and, when comes to coastline extraction, could be used for several purposes.

In the last 100 years human race activity heavily influenced and threatened the Earth's ecosystem. This has led to various problems for our environment. Nowadays, vegetation mapping is much easier because of capability of hyperspectral sensor to distinguish vegetation compared to other types of terrain. Information on vegetation and wetlands can provide a significant information about changes in hydrology and insight into impact of this changes on plant and animal world [1].

Satellite images analysis and information about composition of soil and climatic condition are useful tool for agricultural crop yield prediction. These predictions are very important because they provide the insight into the possible shortage of some agricultural crops which could affect national food security. In the past, this assessment was based on visual assessment and samples taken directly from the fields, but this method was very slow and expensive and is usually was used on smaller areas [2].

Coastline is an important basis for the measurement of water and land resources. This means that the fast and accurate coastline mapping is very important for the development of a country, urban planning and safe navigation [3].

Coastline extraction techniques can be classified into three categories: image rectification and restoration, image enhancement, information extraction. Image rectification is the process of correcting image geometry so it can be displayed on a flat surface. Image enhancement techniques should improve the quality of image to the level that alow necessary information to be easily discerned in relation to the sum. There are many different image enhancement techniques. In the computer era, these techniques are mainly digital and algorithms are executed by computers. These digital techniques are much more precise and give much better results than previously used image processing techniques.

For coastline extraction many different image processing algorithms are combined. Numerous

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adjustments and combinations were proposed in the past several years. Some of the techniques that are used are thresholding [4], contrast enhancement [5] usually by histogram equalization [6] and many others. The objective of the information extraction operations is to replace visual analysis of the image data with quantitative techniques for automating the identification of features in a scene. Aim of coastline extraction is to classify all the pixels into the two groups, water or land, usually by using some of the classification methods [7]. Some of classifier that were used for classification in applications for coastline extraction are support vector machine [8], Gaussian process [9], etc.

Another common task in applications for coastline extraction is edge detection. One of the successful method for edge detection is by using fuzzy logic. Fuzzy image processing is consists of all those approaches that understand, represent and process the images, their segments and features as fuzzy sets. The representation and processing depend on the selected fuzzy technique and on the problem to be solved [10].

This paper describes the basic technological aspects of coastline extraction using satellite images. The rest of this paper is organized as follows. In Section 2 we will discuss articles about coastline extraction, image processing and edge detection using satellite images. In Section 3 our proposed algorithm is presented. In Section 4 experimental results were showed and at the end in Section 5 a conclusion is given.

2 Literature Review

In [3], coastline detection methods were implemented to detect changes coastline of the Pearl River delta area in Guangdong province. One of the biggest problems is caused by changes in coastal lines in the Pearl River Estuary is narrowing of the river which led to flooding in the top part of the river bed. Their study provides an analysis of river Gorge using satellite images of Pearl River deltaic area in Guangdong Province, China. Methodology consists of the following steps: a) data collection, b) image data processing and 3) visual and digital analysis of the coastline changes in time. It was concluded that the better results can be obtained when an image separates into smaller parts, especially where wetlands are. All satellite images must be with no clouds otherwise it will not be able to do correct extraction of the coastline. Based on the analysis of images each pixel has been distributed to some of the following classes: water, forest, plantation and bare land.

In [4], an automated detection shoreline method using histogram equalization and adaptive thresholding techniques is developed. Their study adopted Modified Self-Adaptive Histogram Equalization with Plateau Method threshold (Modified Sapha-M), a clipped histogram equalization based contrast enhancement method to enhance coastal features. Modified Sapha-M, is a modified method of Self-Adaptive Histogram Equalization Plateau (Sapho) proposed by Wang et al., 2006, to enhance the main objects and suppress the background for infrared images. Modified Sapha-M, which consists of five steps (Raju et al., 2013b); 1. Smoothen the input image histogram with 3-neighbor Median filter 2. Fond the maximum local and global maximum values 3. Selected the optimal mean plateau value 4. Modified the histogram according to mean plateau value and equalize the 5. Normalized histogram the image brightness was applied. Thresholding operation was adopted where pixels are coded with 0 (land pixels) and with 1 (water pixels). Grouping of the region was done using 'Grass fire' method. This method works by taking first pixel on Picture as the beginning of the spread of fire, as the fire spread by one grouped the pixels of the same type by making one continuous area. For edge detection Roberts edge operator by Thieler et al. and outlined shorelines were converted to vector maps.

In [9], and method of extraction on coastline remote sensing image is presented. This method uses a Gaussian process classification for grouping land and water, and then extracting coastline from the obtained results. The results showed that the use of Gaussian process classification overcomes a series of public problems about coastline extraction that over-learning and the limitations of poor generalization ability and small sample exist and Artificial Neural Network and hyper-parameters are difficult to choose for Support Vector Machine. This method is currently very popular in the field of satellite analysis images and extracting data.

In [11], a coastline extraction method is presented. It consist of a sequence of image processing algorithms, in which the key component is image segmentation based on a locally adaptive thresholding technique. Several technical innovations have been made to improve the accuracy and efficiency for determining the land/water boundaries. They use of the Levenberg-Marquardt method and the Canny edge detector to speed up the convergence of iterative Gaussian curve fitting process and improve the accuracy of the bimodal Gaussian parameters. The result is increased reliability of local thresholds for image segmentation. A series of further image processing steps are applied to the segmented images. Particularly, grouping and labeling contiguous image regions into individual image objects enables them to utilize human heuristic knowledge about the size and continuity of the land and ocean masses to discriminate the true coastline from other object boundaries. The final product of their processing chain is a vector based line coverage of the coastline, which can be readily incorporated into a GIS database. Their coastline extraction method consists of three groups of image processing algorithms: pre-segmentation, segmentation and post-segmentation. The pre-segmentation processing algorithms aim to suppress image noise and enhance edge elements.

In [12] an approach is proposed based on fuzzy connectivity concepts and takes into account the coherence measure extracted from an InSAR (Interferometric Synthetic Aperture Radar) couple. The approach proposed is a semi-interactive segmentation based on a seed-growing process. User is choosing where to plant a seed and then a seed-growing algorithm occupies neighbours land areas. The final result is a large land area which has all their pixels connected to the area where seed growing originally started.

A [13] presents a novel approach for coastline extraction from SAR images. This method is using the combination of modified K-means method and adaptive object-based region-merging mechanism (MKAORM). For noise and speckle removing a regular and six offset Gaussian filters are applied. Along with Gaussian a 8x8 median filter is also used. Finally a modified K-means method is used to prepare an image to land-water classification. For merging multiple land areas in one big area, a seed technique is used. Seed algorithm starts with planting a seed in one area selected by user and then allowing it to grow across the land using seed algorithm. The results showed that 93 percent of detected coastline are in 2 pixels range from each other.

In [14] a new methodology for automatic extraction of the coastline using aerial images was presented. This is a combination of four step algorithm that is used to extract coastline. First a noise reduction filter is applied for the preparation of image for the next image processing step. Then image is separated into land and water regions using threshold technique which supply a binary image as a result. After that image is manually processed in order to remove small objects and other irregularities so that at the end of the process only land and water pixel remains. Finally an edge detection technique is applied.

In [6] a procedure based on classifying the land and water components by applying a spectral band ratios method is proposed. First step is land-water classification based on the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). Second step is binary conversion of the image by assigning 0 or 1 values to land or water pixels. Third step is edge detection using Sobel edge operator which is using a pair of (3x3) kernels. Finally given edges are converted to vector list. Experimental results shows that the given algorithm is very fast and is very little CPU consuming, and it is also very precise. Final results revealed the changes on Dubai coastline which are mostly due to urbanization for touristic purposes.

In [15] an automated object-based region growing integrating edge detection (OBRGIE) for the extraction of coastline was presented. Aquaculture coast is special type of complex artificial coast. It is formed by the farming of aquatic organisms on tidal flats. In recent years there is a rapid growth of coastal aquaculture, especially in some developing countries. It has been estimated that aquaculture coasts constitute about 30 percent of all coastlines in mainland China. This is an enormous area that needs management and planning. So the first step is coastline and aquaculture mapping. OBRGIE method was proved itself as a robust when it is applied on small and large areas. This method is very fast and cheap for coastline mapping using satellite images. OBRGIE method consists of four main steps. First step splits image to segments using multi resolution segmentation algorithm. This algorithm is very popular in many applications. Smaller images allows us to easier detect edges. Second step applies Canny edge detection algorithm. This algorithm is applied on a near-infrared (NIR) bands (band-3 for SPOT-5 and band-5 for TM) as the edges of land and water are sharp in these bands. Final step is post-processing which is removing unwanted objects and anomalies. Unwanted objects can be ships or lakes which is detected as water areas (but if they are surrounded by the land they will be automatically replaced with land pixels). Resulting edge is usually jagged so the special algorithm is applied for smoothing the edges and to get a natural look of coastline. Finally coastline is converted to vector list using Douglas-Peucker algorithm. OBRGIE method has successfully captured land-water border, even on places where coastline is complex shape. Also OBRGIE method shows that it is not dependable on image scaling, so it is successfully applied on small and large areas. But on extremely large and small areas OBRGIE method is not usable.

3 The Proposed Algorithm

The aim of this paper is to develop a method to effectively detect coastline. This approach produces vector files of the coastline which can be utilized to estimate rates of change over relatively long time period. In this study, various image processing and edge detection techniques were carried. It consists of five main steps:

1. Image Extraction
2. Histogram Matching
3. Gaussian Blur Filter
4. Locally Adaptive Threshold
5. Canny Edge Detection

3.1 Image Extraction

The first step is to select a desired area and extract it from satellite images. The dataset used in the present work for the extraction of the coastline is composed of SAR images acquired by Envisat, ERS, Landsat, IKONOS, DMC, ALOS, SPOT, Kompsat, Proba, IRS, SCISAT. All images are then scaled to proper resolution and converted to format needed for our program to start extracting coastline. Because the images from different satellite sources differs in illumination, contrast and type of day and weather conditions while taking this images, different parameters and techniques are used in preparation the images for the coastline extraction.

3.2 Histogram Matching

The next step is to apply histogram matching technique. Histogram equalization represents image processing technique is contrast based enhancement method and it is used to enhance coastal features but it is also used in other applications [16], [17]. By applying histogram equalization in most cases it will increase image details, especially in places where edge detection algorithm will be used. Instead of using standard histogram equalization a histogram matching method is used. Standard histogram equalization is method where histogram is uniformly distributed. Histogram matching technique produces more details in coastline area, thus increasing the accuracy of coastline detection.

3.3 Gaussian Blur Filter

Third step is to apply Gaussian blur filter. Gaussian blur filter (also known as Gaussian smoothing) is the result of using Gaussian function to create blur effect on image. It is a very popular effect mostly used in graphics software, typically to reduce noise and speckle on images and to reduce detail. The result of this technique is a smooth blur. Gaussian smoothing is also used as a pre-processing stage in computer vision algorithms in order to enhance image structures at different scales. In our experiment Gaussian filter is used for noise and speckle removal, without blurring the major edge features. Gaussian function is 2D version of normal distribution (which is one dimensional).

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

By applying normal distribution in 2 dimensions (x and y) we can calculate the weight matrix (Gaussian kernel also called Gaussian mask). There are two standard sizes of the kernel: 3x3 and 5x5 pixels. The 5x5 size creates more blur effect thus more noise is removed. Then we must choose sigma, usually the greater sigma removes more noise, in our case we used sigma with value 6. After calculating Gaussian mask, it is then applied to pixel values.

3.4 Locally Adaptive Threshold

Fourth step is to apply threshold technique. Thresholding is common technique for image segmentation and many different algorithms were proposed for optimal threshold value determination [18], [19], [20], [21]. Instead of applying threshold on a whole image, a locally adaptive thresholding algorithm is used for image segmentation. By using this technique we can increase coastline detection by increasing edge visibility on areas in the image with low contrast. This technique will dynamically set the threshold according to the local characteristics of neighbours pixels. The purpose of threshold is to separate image into two main homogeneous regions water and land. Then the border between land and water regions can be delineated as the coastlines. In standard threshold technique applied on images with strong illumination gradient poor results are produces. The larger image, the poorer results are produced. We were using locally adaptive threshold on smaller portions of the images from 7x7 pixels size to 20x20 pixels size. Also by using median instead of mean the results were even better.

3.5 Canny Edge Detection

Edge detection using Canny algorithm. This very popular algorithm is simple but reliable edge detection

Figure 1: Coastline extraction when histogram matching was turned off (left) and with histogram (right)

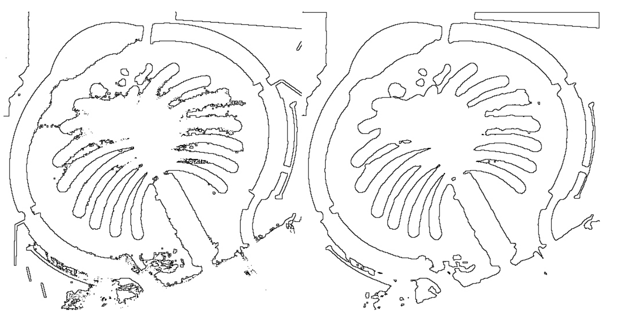

Figure 2: Coastline extraction with difference in noise level: without blur (left) and with applied blur (right)

technique. Canny edge detection is a technique to extract edges between different vision objects. It has been widely applied as satellite image edge detection technique. Before using Canny edge detection, it is mandatory to apply Gaussian filter and thresholding technique. Depending on what parameters are used in these techniques it will greatly affect the Canny edge results.

4 Experimental Results

The proposed method has been tested with 2 satellite images representing different artificial islands of Dubai coastline, Palm Jebel and Palm Jumeirah. In Figure 4. you can see the image transformation when the techniques are applied. Images in first row are original images extracted from satellite imagery. In second row Histogram matching technique is applied. Image contrast and color are affected by this technique. Edges between land and water are now more pronounced. Sometimes applying histogram will degrade results (Figure 1.), it all depends on what is the quality of the satellite images and were they already preprocessed sing some technique or filter.

In the third row are the images with applied Gaussian blur filter. After applying this filter there are much less noise and speckles on the images (Figure 2.). Increasing the kernel size and sigma will increase the blur effect on images. We must be careful not to exceed the blur, because we can loose fine details on the image.

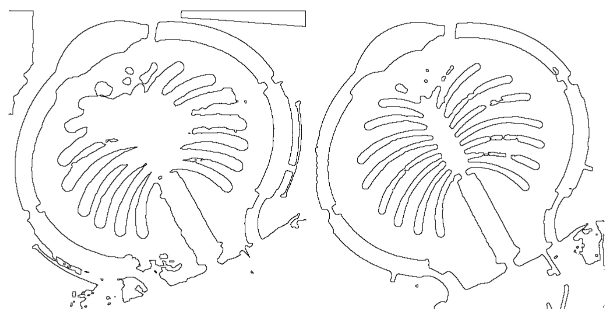

Figure 3: Coastline extraction by different threshold values

In forth row are the images with applied Locally Adaptive Threshold. Threshold is an operation that will greatly affect the end results, so applying the right threshold value is critical. Higher threshold values will recognize shallow waters as the land area thus increase the land, but reducing the threshold value too much will increase the water area on the expense of the land (Figure 3.).

Finally, a Canny Edge detection algorithm is applied which successfully detects coastline. Resulting coastline from Canny edge detection we can convert to a vector list where coordinates of pixels became vector coordinates. Although these images are very complex, obtained results are very good and accurate.

5 Conclusion

Although the coastline mapping seems to be a simple operation, in practice an automated extraction of the land/water is more difficult than one would expect. Because the land/water boundaries on satellite images lack of sufficient intensity contrast and the complications of distinguishing coastline from other object like buildings etc, the process of coastline mapping is challenging even for todays modern computers and algorithms. So there is a need for the better edge detection algorithms and image processing techniques in the future. Despite the successful results of our method on satellite images, it should be noted that the success rate of coastline mapping is heavily dependent from good quality satellite images. Satellite images must be without clouds or it will greatly affect the final results. Using satellite images with different bands greatly increase the edge detection success rate, and

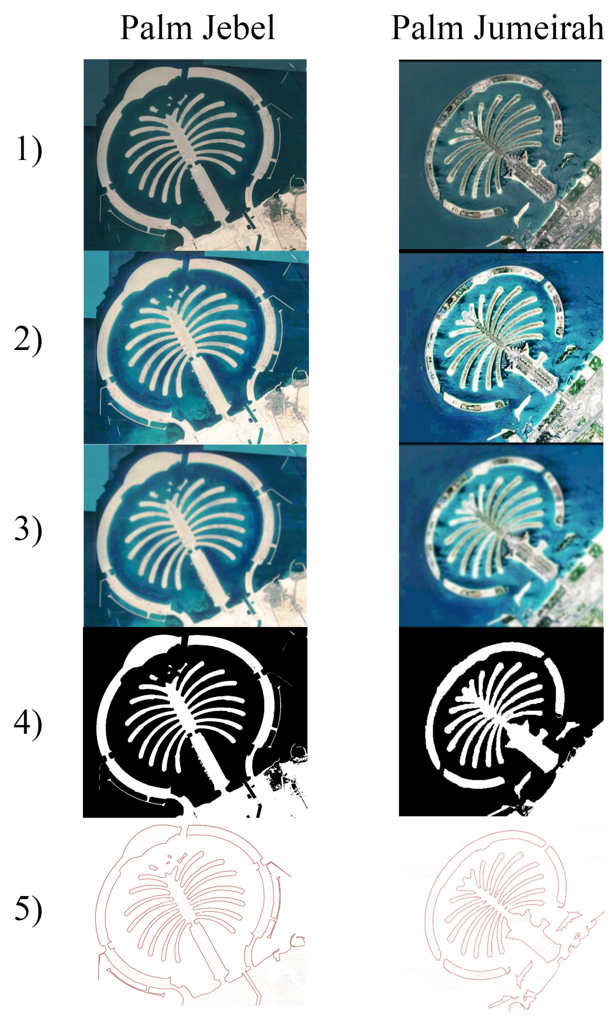

Figure 4: Coastline extraction by our proposed algorithm step by step

combining different bands on one area is a winning combination. During processing satellite images we detected some delineation errors. These errors can be easily corrected by deleting or inserting parts of an image using graphic editing tools. In future research we recommend to develop an algorithm which automatically detect image properties like contrast, brightness and color levels, and adjust them for creating better results. For developing this algorithm, we propose machine learning method which would learn itself using hundreds or even thousands images of the same location. This method will learn the machine to adapt itself not to depend on quality of the image or what type of day or weather condition are affecting the results. For the best results we recommend a cross comparison method, where two different coastline extraction algorithms will be developed. They will be using images in different bands, and then use a cross-checking to find the difference in the results.

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