

# Shoreline Detection by Digital Image Processing of Aerial Photography

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## ABSTRACT

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Digital image processing techniques applied to digitized (scanned) aerial photography allow significant improvements in the process of shoreline detection. Those improvements can be achieved in two areas: firstly, the area of objective and consistent shoreline recognition and secondly in the area of accurate georeferencing of the detected line. From the possible lines, the High Water Line (HWL) is most clearly represented in the photographs by a line of high brightness gradient. Three different enhancement and filtering techniques were utilized for the detection of the HWL. A combination of two of the methods provided an optimal detection methodology. The improvement in the area of georeferencing was achieved by mainly the increase in the number and accuracy of the control points relative to manual methods.

**ADDITIONAL INDEX WORDS:** *Aerial photography, image processing, shoreline change.*

## INTRODUCTION

Long-term coastline variations are important indicators of changes in global climate and in regional depositional or erosional processes. Reliable analysis of those variations must be based on historical records. Infrared photography provides an optimal tool for this purpose as a result of the high absorption of the infrared radiation by water. However, most historical photos are black and white in the shortwave spectrum. Both high resolution and wide coverage are important advantages of photography relative to other sources of information. A large number of works utilized aerial photography for the detection of historical changes in shoreline (see for example: SMITH and ZARILLO, 1990; STAFFORD and LANGFELDER, 1968), however, these works are mainly based on human interpretation and therefore lead to some level of subjectivity and inconsistency in the detection process.

The coastline as a transition zone between land and sea forms a complex system of brightness variation in the panchromatic spectrum. High brightness values are registered (many times with saturation) for both dry sand areas and areas of foam formed by breaking waves. Medium level of brightness is registered from areas of wet sand,

coarse material or shallow water. Low brightness is reflected from deep water or from beach shrubs and seaweeds. All these variations and similarities in the brightness system are further complicated by the dynamic nature of this environment which results in both large temporal and spatial variation.

Ideally, one would search for the water line at the instantaneous moment of the photography. This line may be presented by the edge of the dark water body or foam or by a line of specular reflection from the edge of the dark water body. However, in reality there are two characteristic problems with regard to identification of the real water line: first, the fact that the foam line does not always represent the forefront water line and, second, the fact that the spatial and radiometric resolution of the photographs many times masks the contrast along the edge of the water body.

Examination of few alternative lines (DOLAN *et al.*, 1978): line of inshore bars, mean low water, bottom of swash zone, mid-swash zone, swash terminus, mean sea level, high water line, high tide line and berm line shows that the high water line provides the optimal line in two aspects: detectability and stability. The HWL "appears as a tonal change on the beach face due to differences in water content of the sand" (SMITH and ZARILLO, 1990) and the stable nature is a result of the rel-

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 REMOTE SENSING AND GIS LABORATORY

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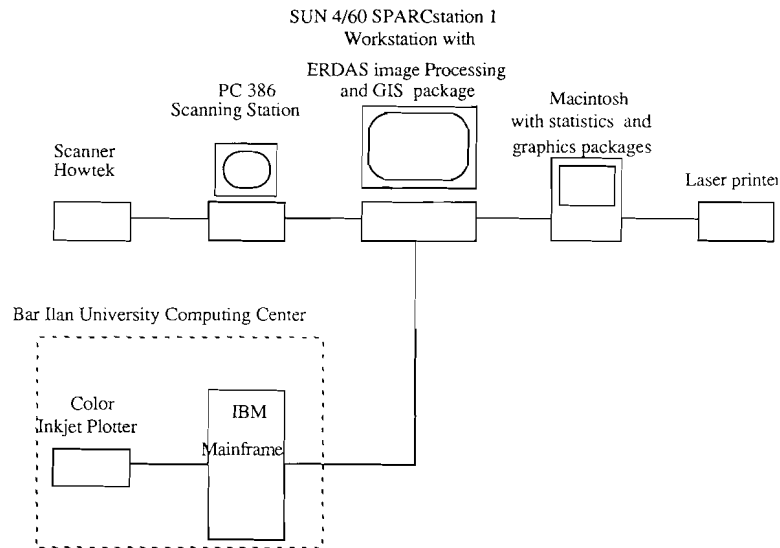


Figure 1. The Remote Sensing Laboratory configuration used for the shoreline detection project.

ative slow rate of sand drying. This stability of the HWL is related to specific sea conditions, mainly wave height and average sea level according to the lunar period. Furthermore, the detectability of the HWL depends on the sand wetness above it, thus, in rain conditions or during storms there could be no contrast of brightness above and below the HWL. Analysis of longterm changes in the shoreline position must be then based on comparable sea conditions and season, preferably it should be conducted with photographs taken during the same month of dry summer conditions and low sea waves.

Attention is given in the literature to two typical interrelated sources of error in determining the shoreline from aerial photography: errors due to the photographic process, including the change of scale from the center to the margins, relief displacement, lens distortion, camera tilt, and film development; and errors due to the geometrical adjustment between the photograph and the base map (including map accuracy limitations). Problems concerning the recognition of the HWL in the image are not discussed. In few cases the HWL

was not recognizable (see SMITH and ZARILLO, 1990, for example) and other lines replaced it (from the list of alternative lines listed above); however, one must consider the fact that the alternative lines present higher inaccuracies relative to those related to the HWL.

Digital image processing techniques may help in solving a few of the problems concerned with the detection of shorelines. First, enhancement and edge detection techniques may help in the shoreline recognition process and, second, image rectification and registration techniques may help in solving some of the geometrical problems including change of scale and image distortion. Furthermore, those techniques add a crucial aspect of objectivity and consistency to the process.

It is the objective of this paper to describe the application of digital image processing techniques to the problem of HWL detection. This work is based on experience gathered in a project to detect shoreline changes in the eastern basin of the Mediterranean Sea (DEGANI and GOLICK, 1990). The system used for the analysis is based on ERDAS image processing package running of SUN

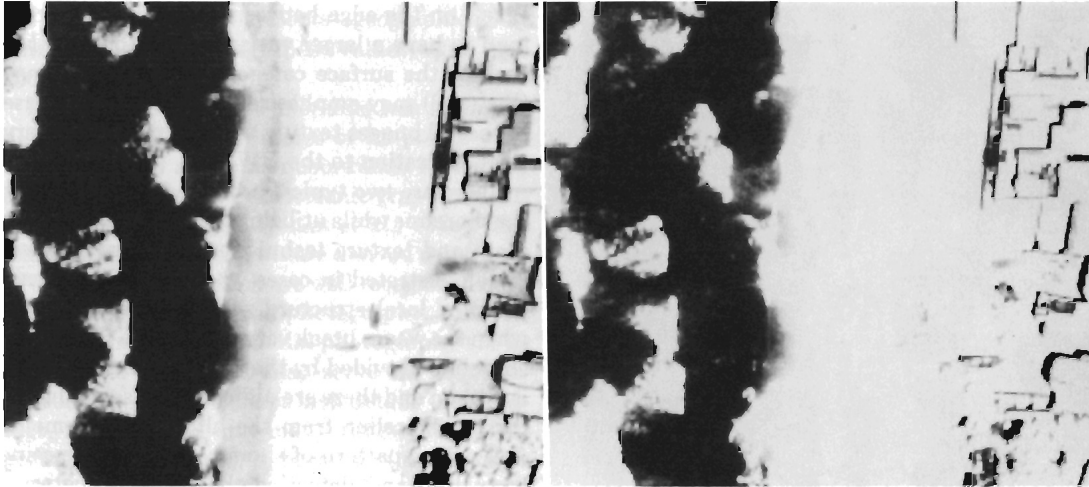


Figure 2. The effect of contrast enhancement on the detectability of the shoreline: (a) contrast factor of 3.0; (b) contrast factor of 5.0. (Left direction is west.)

Sparcstation 1 workstation. A Howteck optical scanner was used for converting the data from analog to digital format (Figure 1).

#### SHORELINE RECOGNITION USING IMAGE ENHANCEMENT TECHNIQUES

The aim of this part of work is to examine different methods for recognizing the shoreline. Three different types of techniques are assessed: contrast enhancement, high pass filtering and texture. The methods represent significant differences in terms of computation and are expected to produce the same shoreline if this line represents real physical phenomena. Those methods are described as follows:

(1) Image spectral enhancement techniques are utilized for increasing the contrast between image features of different brightness, thus allowing the visual discrimination between features of only a slight difference in brightness and emphasizing edges of high brightness gradient. The enhancement is done by applying lookup tables (function memories) of different characteristics to the original digital data before displaying it as an image on the system display unit. Linear contrast stretch is gained by, for example, changing the slope and bias of the function memory. It was anticipated that by utilizing linear stretching it would be possible to discriminate between areas of different

brightness properties. The edges between those areas are hypothetical shorelines. One can expect to find different definitions of those edges with changing the lookup table parameters. However, a significant edge is one which does not change while varying those parameters within a certain range (Figure 2). The decision of the final contrast stretch parameters within this range will not affect the determination of the hypothetical shoreline. Because aerial photographs vary in their average brightness following differences in illumination conditions, type of film and film processing procedures, it is not possible to suggest common stretching parameters. Therefore, it is the role of the interpreter to make a decision of the final parameters. This might be seen as a constraint of the enhancement technique. On the other hand, such combination of human visual judgment based on interactive work with the computer might be regarded by many other researchers as an optimal solution for the detection of shorelines.

(2) Image filtering techniques. As mentioned before, the shoreline may be represented by a border between areas of different brightness properties. Those borders are detected as edges of high brightness gradient using 'high pass' filters. The ERDAS system utilizes a convolution kernel containing an array of weights (coefficients) assigned to the pixels within the specified neighborhood of the modified pixel. A high pass filter is charac-

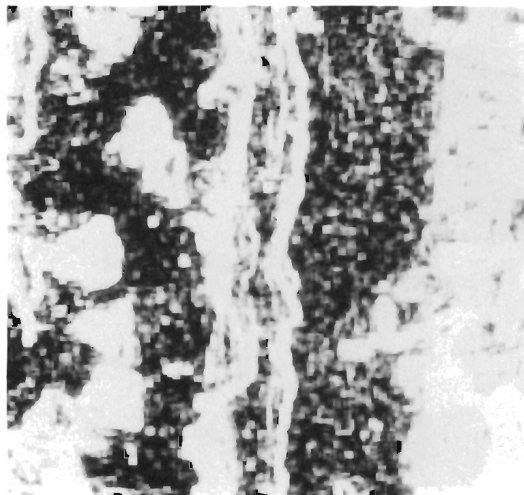


Figure 3. Texture image of the shore. (Left direction is west.)

terized by a high weight given to the central pixel (to be modified) relative to its neighboring pixels. Thus, after applying the filter to all the image pixels a new image is formed emphasizing pixels with distinctly different brightness values from their neighboring ones. When the pixel is on the border between water and land areas its modified value depends on whether it is a 'land' pixel or 'water' pixel. In the first case its brightness will be further increased while in the second it will be decreased considerably. Running several high pass filters on coastal images reveals that the most enhanced image features are the foam areas. However, they create a very 'patchy' pattern of bright areas in contrast to the relative brightness homogeneity of the sandy areas. Between the two distinctive spatial brightness patterns many times it was difficult to detect the shoreline and it was necessary to enhance the contrast of the filtered image to allow its accurate digitization. Since this procedure does not allow always the detection of the shoreline it is not recommended for use.

(3) Image texture techniques. The term 'image texture' relates to "the repetition or quasi repetition of fundamental image elements" (HE *et al.*, 1987) where the elements are pixel neighborhoods of characteristic grey tone variation. There are numerous texture classifiers which are based on the statistics of this variation (ROAN *et al.*, 1987). In this work the variance of the brightness values within a specified neighborhood around every im-

age pixel was regarded as a measure of texture. Pixels on the edge between soil and water areas tend to have a larger variance than those within each of the surface categories. A texture image (Figure 3) may emphasize edges, and in the case of coastal images texture analysis provides a very clear indication to the HWL.

There are two typical problems with detecting the shoreline while utilizing the contrast enhancement and texture techniques. The first problem is demonstrated in cases where the beach has a complex local structure with pools and bars or when the waves break very close to the HWL. The shoreline provided by the texture technique then is broken and there are difficulties in selecting the correct shoreline from the alternative segments (between a pattern of short parallel and crossing segments) and detecting the shoreline between successive segments. The second problem concerns the selection of appropriate contrast stretch parameters. Both problems can be solved by combining the two techniques: it is possible to increase the contrast stretch parameters as long as the bright areas do not 'overflow' over the exiting edges defined by the texture (thus solving the second problem). This process is done by combining the brightness and texture information to form an image (Figure 4) in which the bright white areas represent edges and waves, the gray tones represent the sand areas (light gray: dry sand; dark gray: wet sand) and the black zone is water. The first problem is then solved by following the most western segments of the edge (bright patches) adjacent to the light gray areas and the western margin of the light gray area as the HWL between the segments (along the coastline).

#### GEOGRAPHIC REFERENCING OF THE SHORELINE USING REGISTRATION AND RECTIFICATION TECHNIQUES

The fact that the paragraph describing the shoreline detection precedes the one describing the geographic referencing represents the right working order. The registration and rectification of an image involve a process called resampling by which the brightness values of the new rectified image pixels are interpolated from the brightness values of their neighboring pixels (from the original image). This step is necessary as the grid of pixels of the new image does not exactly fit geographically with the original grid. Since there is some loss of information following the interpo-

lation process it would be preferable to first detect the shoreline (which represents a geographical line entity rather than brightness values) and then georeference it.

In previous works the shoreline was manually digitized and the coordinates of its points were transformed to a common coordinate system by a computer program or electronic graphic calculator (see for example: DOLAN *et al.*, 1978). The transformation coefficients are derived using a set of common points which are well recognized both in the base map and the photography. Analysis of maps and historical aerial photography shows that only a few points may serve the transformation process: first, maps lack details (of buildings, for example) and many times their point accuracy is poor; second, because of the changes in the environment there are only a few points which appear on all of the data sources (maps and photos). Consequently it was found preferable to accomplish full registration and rectification of one of the sets of the aerial photography using detailed base map and local ancillary data and then to register the other sets of aerial photography to the first one. The ancillary data of height points and accurately measured coordinates for road junctions and public buildings and infrastructure (bridges, water channels and sewage systems, for example) may be provided by the National Mapping Agency or the local government in digital form or derived from accurate geodetic maps. The accuracy of the determination of the corresponding control points in the images is well enhanced by the image display and processing capabilities. It is possible to zoom in and out to sharpen edges which are blurred in the image and enhance contrast. The registration and rectification of the aerial photography with a large number of control points which are well spread within the photographed area using complex polynomial transformation functions may result in an almost complete correction for any of the geometrical errors described above. If the control points are regarded as ground truth then the resulting accuracy is a function of the image resolution and the photograph scale. For example, if an aerial photograph (of the scale of 1:5,000) is scanned at a density of 300 dots per inch, the resulting resolution element is of size of 0.43 m. In many cases it is possible to identify a point such as a building corner with an accuracy of one pixel. One must consider the fact that along the beach itself and in the sea there will be only a few

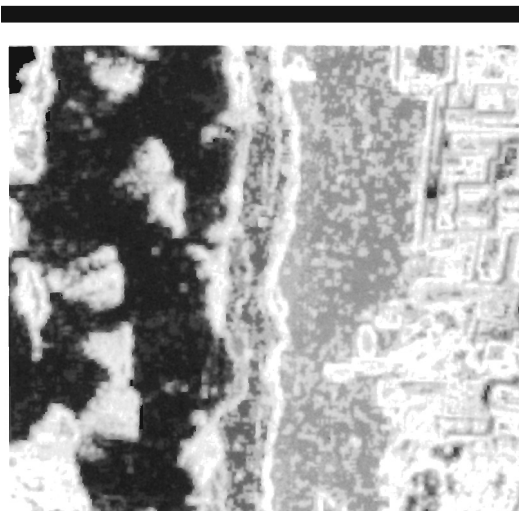


Figure 4. Image as the combination of brightness (red channel) and texture (green channel). (Left direction is west.)

control points (if any), thus, the accuracy in determining the HWL depends largely on the distance between the beach and the close control points. If the beach is within a distance of few tens of meters from the control points and the photography flight is parallel to the beach (to ensure the same tilt effect), then it might be expected that the same type of inaccuracy will affect all the shoreline points. Once a set of photographs (of one flight) is registered it is possible to register other sets to the base one using many control points including points at the shoreline and within the sea (beach rock, for example). This procedure ensures that the detection of temporal shoreline variations will be affected only minimally by geometrical inaccuracies.

#### CONCLUSIONS

While new remote sensing systems are advancing rapidly and producing new data with increasing spatial and spectral resolution, it will be always necessary to analyze historical images from previous systems such as the old photographic cameras. The experience gathered on the utilization of digital image processing techniques in various areas of the earth sciences showed that those techniques provide solutions for problems of detection, classification and quantification of features from digitized photographic (analog) data and digital images. Problems of shoreline detection are complex because of the dynamic nature

of the beach zone and consequently the spatial and temporal variation in reflectance (brightness) as recorded in remote sensing images. This paper has shown that the shoreline as represented by the High Water Line may be almost fully automatically detected using different image processing techniques. Future research of applications of techniques based on texture analysis may provide a tool for classifying the various beach zones which will help the study of the beach processes.

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#### □ RÉSUMÉ □

Les techniques d'analyse digitale des images appliquées à la digitalisation de photographies aériennes permet d'améliorer significativement la détection des processus littoraux. Ce, dans deux domaines: 1— celui de la reconnaissance objective et consistante de la ligne rivage; 2— celui de la géoréférence des lignes de rivage ainsi détectées. La ligne des hautes eaux est la plus clairement représentée sur les photographies (ligne de fort gradient de brillance). Elle a été mise en évidence par 3 techniques de filtrage. La combinaison de deux méthodes permettent un détection optimale. L'amélioration de la géo-référence consiste surtout en une augmentation et une plus grande exactitude des points de contrôle, par rapport aux méthodes manuelles.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*

#### □ ZUSAMMENFASSUNG □

Digitale Bildverarbeitungstechniken wurden auf digitale Luftbilder angewandt. Sie erlauben bedeutende Verbesserungen bei der Entdeckung von Küstenlinien, die auf zwei Gebieten erreicht werden können: bei der objektiven Dokumentation von Küstenlinien und bei der exakten geographischen Erfassung der entdeckten Linien. Von allen möglichen Linien ist die Hochwasserlinie in den Photographien am deutlichsten als eine Linie mit hohem Helligkeitsgradienten wiedergegeben. Drei verschiedene Vergrößerungs- und Filtertechniken wurden zur Identifizierung der Hochwasserlinie benutzt. Eine Kombination von zweien dieser Methoden gewährleistete die bestmögliche Erfassung. Die Verbesserung auf dem Gebiet der geographischen Dokumentation wurde im Vergleich zu manuellen Methoden hauptsächlich durch die höhere Anzahl und Genauigkeit der Kontrollpunkte erreicht.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, Germany.*

#### □ RESUMEN □

La utilización de técnicas de proceso digital de imagen aplicadas a fotografías aéreas permite significantes mejoras en la detección de la línea costera. Esas mejoras pueden ser obtenidas en dos áreas: La primera en el reconocimiento objetivo y consistente de la línea de costa y la segunda en la localización precisa de la línea detectada. Entre las posibles líneas, la correspondiente a marea alta es la más claramente visible de las representadas en las fotografías por medio de un gradiente de brillo. Para la detección de la línea de marea alta fueron utilizadas tres diferentes técnicas de realce y filtrado de imágenes. Una combinación de dos de las técnicas mencionadas produce una metodología óptima para la detección. La mejora en la localización fue obtenida, fundamentalmente, por el incremento en el número de puntos de control respecto a otras metodologías.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*