

A DNA ALGORITHM FOR THE BATIMETRIC MAPPING IN THE LAGOON OF VENICE USING QUICKBIRD MULTISPECTRAL DATA

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ABSTRACT:

During the last decade, several studies have focused on the use of passive multispectral remote sensing to derive the bathymetry in coastal zone. In particular, data acquired with the SPOT and the Landsat TM/ETM+ sensors have been used to derive models of bathymetry at medium scales. Until now, the successful application of passive remote sensing techniques to bathymetry mapping was restricted to costal zones with clear water and small changes in the seabed, but with the availability of the high resolution satellites (IKONOS, Eros-A1, QuickBird, SPOT-5), researchers have a new powerful tools to study environmental phenomenon at large scale. This paper focus on the use of high resolution imagery to estimate water depths in a lagoon environment. Starting from the depth of penetration zone method proposed by Jupp for costal bathymetry mapping, a new genetic algorithm was developed for lagoon bathymetry mapping. The potential use of the QuickBird multispectral data, together with the new algorithm developed, was tested in a complex environment such as the lagoon of Venice (Italy). Several tests have been performed into five different test sites (S.Erasmo littoral, Treporti canal, S. Felice canal, Canesa canal and Bari canal), where 18 radiometric transects were traced to study the lagoon bathymetry. The accuracy of the batimetric measures was assessed by using other known soundings depth points within the test area. An interesting correlation between the real and the computed bathymetry was found. The limit of a such analysis lies in the correct calibration of the model, that, for the complex lagoon ecosystem, is not a simple task.

1. INTRODUCTION

The bathymetry is that branch of the oceanography that deals with the measure of the depths of the sea and studies its configuration and evolution over the time. Nowadays, bathymetric surveys are generally carried out using ships equipped with sonar instruments or, in the case of coastal zones, by Airborne Laser Bathymetry (ALB) from aerial platform. The implementation, but especially the updating, of the bathymetric maps using the traditional techniques shows high costs and long time to realize the survey and process all the data collected (Abduallah *et al.*, 1991), for this reason researches have become interested in use of remote sensing (RS) techniques to find a fast and low-cost mapping tool.

In the course of the last decade, several studies have shown the possibility to use the multispectral data acquired with the SPOT and Landsat satellites to derive the bathymetry in coastal zone (Jupp, 1988; Nordman *et al.*, 1990; Hengel and Spitzer, 1991), but frequently with precisions not suitable to the editing of charting for the navigation. Until now, the successful application of passive RS techniques to bathymetry mapping was restricted to shallow and clear water, with small changes in the seabed (Gordon and McCluney, 1975; Lyzenga, 1986; Bierwrth *et al.* 1992).

This paper focus on the use of satellite's high resolution images (HRI) to estimate water depths in a lagoon environment. The small pixel size of such sensors (<5 m), in respect to Landsat TM/ETM+ (30 m) and SPOT HRV (20 m), could be a key factor to obtain accurate batimetric computations. In particular, the potential use of the QuickBird multispectral data was tested

in the lagoon of Venice (Italy) using a new algorithm developed (Gianinetto *et al.*, 2003).

2. BATHYMETRY MAPPING ALGORITHM

2.1 Jupp DOP model

Electromagnetic radiation that cross a water column suffer an attenuation due to the joint action of diffusion and absorption of the medium. Considering a bundle of monochromatic light, the relative loss of radiant flux is proportional to the size of the path, to less of a coefficient of proportionality (extinction coefficient). A model that finds large employment in literature to reconstruct the bathymetry in coastal zones from RS multispectral data, is the depth of penetration zone (DOP) method proposed by Jupp (Jupp, 1988)

$$L_c = \left(e^{-2kz} \right) L_b + \left(1 - e^{-2kz} \right) L_w \quad (1)$$

where L_c = measured at-sensor radiance
 L_b = emergent radiance from the seabed
 L_w = emergent radiance from the different layers
 z = depth
 k = coefficient of absorption

Hypothesizing negligible the term of L_w , directly related to quality of the water (suspended sediments), and for small changes in seabed, then, among the depth of the water column and the logarithm of the measured at-sensor radiance there is a linear correspondence. Under this conditions, rearranging Eq.

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(1) lead to the classical DOP equation for the water depth determination

$$z = \sum_{i=1}^N \frac{\ln(L_e)_i}{-2k_i N} - \sum_{i=1}^N \frac{\ln(L_b)_i}{-2k_i N} \quad (2)$$

where N = number of spectral bands

In practice, to guarantee homogeneity the DOP model assumes constant coefficients of absorption, and, as will be discussed later, this is the main cause of the failure of the DOP algorithm in the lagoon of Venice, where the spatial lack of homogeneity is very high.

2.2 A new stratified genetic algorithm for bathymetric measures in the lagoon

The high spatial variability of the seabed and the presence of suspended sediments in the water is the principal causes that make inapplicable the DOP model in the lagoon of Venice. The high variability of which the coefficients of absorption assume in the lagoon of Venice can be interpreted as a lack of homogeneity in the water column, circumstance that does come less one of the conditions imposed to the Jupp bathymetry mapping model. Since the condition of uniformity of the seabed in the lagoon of Venice is not verified, the Jupp model has been modified in order to compute an accurate description of the real bathymetry into a complex environment such as the lagoon of Venice. Looking at Eq. (2), the term

$$\sum_{i=1}^N \frac{\ln(L_b)_i}{-2k_i N} \quad (3)$$

is interpretable as a corrective term that normalizes the geometric media of L_b . It can be noticed that Eq. (2) doesn't perform a complete regression on the radiometric input data, but uses only the deriving information from the coefficient of absorption (the slope) to achieve a first bathymetric estimation, and, subsequently, compensates the error by esteeming separately the term (3) in shallow water areas. In our new model, called stratified genetic algorithm (SGA), the term (3) has been eliminated from Eq. (2) and a new parameter (Y_j) has been introduced to perform a complete regression on the multispectral dataset.

$$z = \sum_{j=1}^m \frac{\ln(L_e)_j - Y_j}{-2k_j} \quad (4)$$

where m = number of layers

The new algorithm proposed uses Eq. (4) to build a stratified genetic algorithm. Exploiting the different penetration of the electromagnetic radiation in the water, Eq. (4) is computed for intervals of increasing depths. The SGA algorithm divides the water column into elementary volumes of increasing depth, and for each of them computes the coefficients of absorption (k_j), the parameters (Y_j) and the estimated bathymetry (z). This

procedure is repeated for every spectral bands available, until all the image is processed. In practise, for every elementary water volume built, the SGA computes a bathymetric estimation for every spectral band available and puts in competition results. Only those outputs (coefficients of absorption, coefficients of regression and the estimated bathymetry) with the highest correlation coefficient are assumed as representative for the whole elementary water volume. The final bathymetry map is built incrementally, using for every step the best correlated parameters found.

3. BATHYMETRY MAPPING IN THE LAGOON OF VENICE

3.1 Study area

The lagoon of Venice is a particularly complex territory, where land and water intersect to form systems and subsystems regulated by delicate equilibriums and where ecosystems of incomparable beauty coexist with a considerable industrial and agricultural activity. The lagoon of Venice is extended on a surface of about 550 km², among the terminal course of the Brenta river (mouth of Brondolo) and the final flow of the Sile river to north (mouth of old Piave). From the hydrographical point of view, the lagoon is divided into three portions: the mouth of Chioggia, the mouth of Malamocco and the mouth of Lido. These subtend and determine real lagoon basins, that are clearly identifiable and have easily recognizable limits. The 78% of the lagoon surface is characterized by wide expanses of water crossed by a dense net of canals with different depth. The communication of the lagoon with the sea determines its brackish character, that guarantees the survival of the peculiar biological characteristics, and the daily sea ingression-regression across the mouths constantly models the physical conformation of the lagoon.

3.2 Dataset

The SGA algorithm proposed has been used to evaluate the bathymetry in the lagoon of Venice, using the multispectral data acquired with the QuickBird sensor on May 16, 2002 (10:05:40 GMT). Figure 1 show the study area (from 45°33'28" N and 12°17'10" E to from 45°23'53" N and 12°30'33" E). The spectral and spatial characteristics of the QuickBird images are:

Pancromatic band with a GSD of 0.64:

- 0.450-0.900 μm spectral range.

Multispectral bands with a GSD of 2.56 m:

- Blue (0.450-0.520 μm);
- Green (0.520-0.600 μm);
- Red (0.630-0.690 μm);
- Near infrared (760 -900 μm).

QuickBird data have been converted to at-sensor radiance and atmospherically corrected using the 6S (Second Simulation of the Satellite Signal in the Solar Spectrum) radiative transfer code (Vermote *et al.*, 1997) and the optical thickness obtained from the Aeronet network (<http://www.aeronet.gsfc.nasa.gov>). Satellite data was subsequently geometrically corrected and georeferenced.

A sounding bathymetry chart of the entire lagoon at scale 1:5,000 was used as bathymetric reference data. Depth sounding points were extracted from the chart and they have been interpolated and resampled with a TIN (Triangular Irregular Network) algorithm, in order to obtain a regular sampled raster

image of the water depth at the same resolution of the QuickBird data. Several tests have been performed into five different test sites (S.Erasmo littoral, Treporti canal, S. Felice canal, Canesa canal and Bari canal), where 18 radiometric transects were traced to study the lagoon bathymetry. For every testing site, depths points (DP) were estimated from the QuickBird data using the SGA algorithm described in (2.2). A final bathymetry estimation was obtained interpolating all the DPs extracted.

Data on suspended sediment concentration and bottom composition materials were not available for reference.



Figure 1. QuickBird multispectral image of the Lagoon of Venice (May 16, 2002; 10:05:40 GMT). RGB composition.

4. RESULTS

4.1 S. Erasmo littoral

Three radiometric transects (transects nr.1, 2 and nr.3) were traced at S. Erasmo littoral (Figure 2). For transects nr.1 and nr.2 the correlation between the real bathymetry (derived from the sounding points) and the computed bathymetry with the SGA algorithm showed a very high correlation ($R^2=0.96$ for transect nr.1 and $R^2=0.94$ for transect nr.2), while for the transect nr.3 a correlation of 0.89 was obtained. Figures 3, 4 and 5 show results.

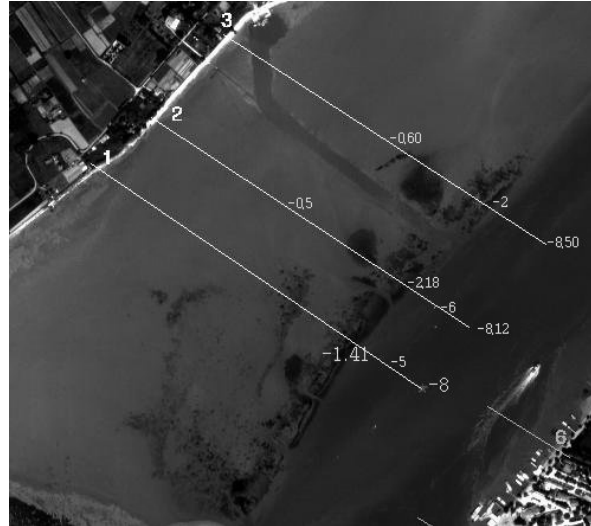


Figure 2. Radiometric transects at S. Erasmo littoral with lagoon depths overlaid.

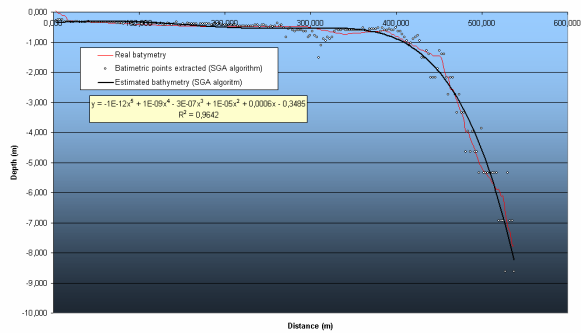


Figure 3. Bathymetry estimation at S. Erasmo littoral (radiometric transect nr.1). $R^2=0.96$

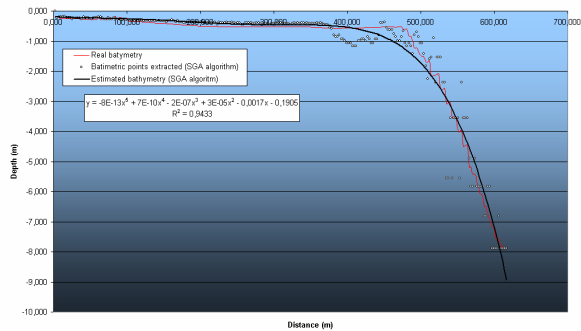


Figure 4. Bathymetry estimation at S. Erasmo littoral (radiometric transect nr.2). $R^2=0.94$

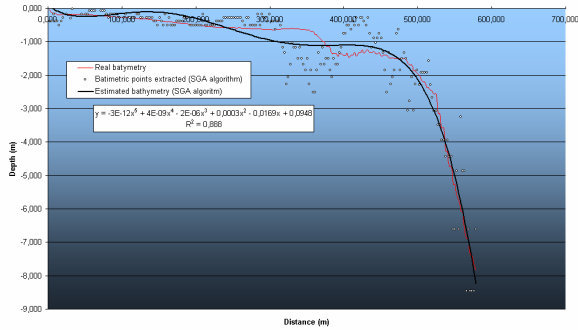


Figure 5. Bathymetry estimation at S. Erasmo littoral (radiometric transect nr.3). $R^2=0.89$

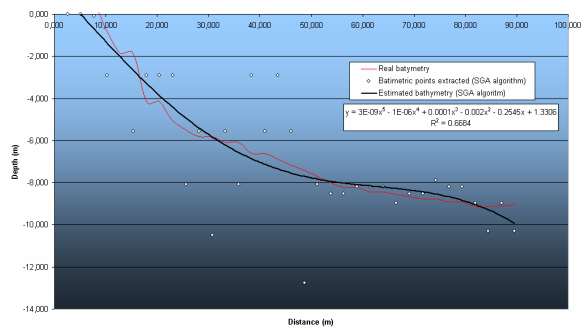


Figure 8. Bathymetry estimation at Treporti canal (radiometric transect nr.7). $R^2=0.67$

4.2 Treporti canal

Four radiometric transects (transects nr.4, 5, 6 and nr.7) were traced at Treporti canal (Figure 6). Correlations between the real bathymetry and the computed bathymetry are between 0.92 for the transect nr.5 and 0.67 for the transect nr.7. Figures 7 and 8 show results.



Figure 6. Radiometric transects at Treporti canal with lagoon depths overlaid.



Figure 9. Radiometric transects at S. Felice canal with lagoon depths overlaid.

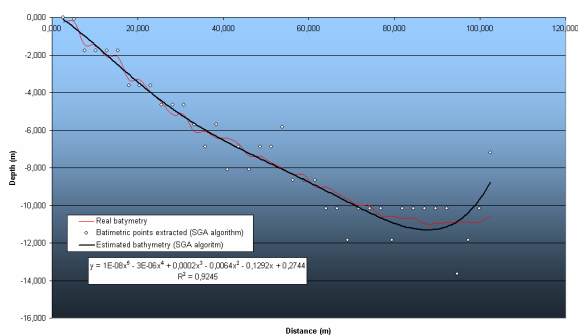


Figure 7. Bathymetry estimation at Treporti canal (radiometric transect nr.5). $R^2=0.92$.

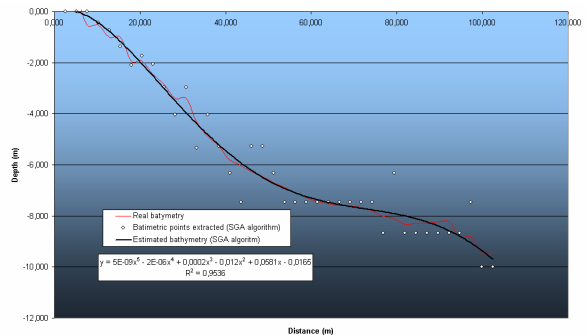


Figure 10. Bathymetry estimation at S. Felice canal (radiometric transect nr.8). $R^2=0.95$.

4.3 S. Felice canal

Four radiometric transects (transects nr.8, 9, 10 and nr.11) were traced at S. Felice canal (Figure 9). All transects showed high correlations between the real bathymetry and the computed bathymetry ($R^2>0.85$) except for the transect nr.10 ($R^2=0.45$). Figure 10 show results.

4.4 Bari canal

Four radiometric transects (transects nr.12, 13, 14 and nr.15) were traced at Bari canal (Figure 11). Transects nr.12, 13 and nr.14 showed correlations greater than 0.72 (transect nr.12 $R^2=0.86$, transect nr.13 $R^2=0.72$, transect nr.14 $R^2=0.96$). Figure 12 show results.



Figure 11. Radiometric transects at Bari canal with lagoon depths overlaid.

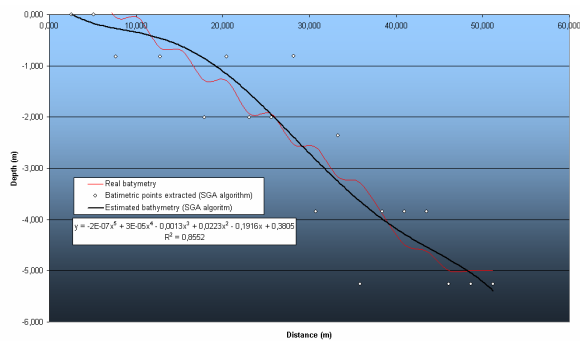


Figure 12. Bathymetry estimation at Bari canal (radiometric transect nr.12). $R^2=0.86$.

4.5 Canesa canal

Two radiometric transects (transects nr.16 and nr.17) were traced at Canesa canal (Figure 13). The best correlation was found in deeper water (transect nr.16) with an $R^2=0.91$. Figure 14 show results.



Figure 13. Radiometric transects at Canesa canal with lagoon depths overlaid.

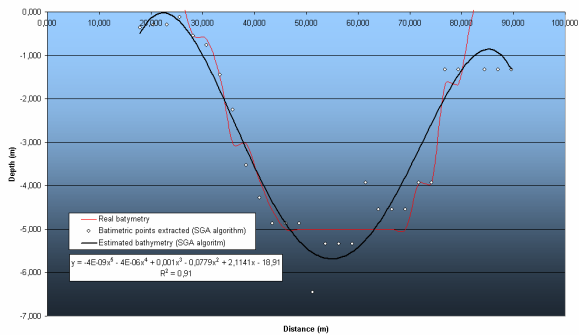


Figure 14. Bathymetry estimation at Canesa canal (radiometric transect nr.16). $R^2=0.91$.

5. ALGORITHM COMPARISON AND PERFORMANCES

Because of a high spatial variability of the seabed and the presence of suspended sediments in lagoon of Venice, the Jupp DOP model couldn't successfully determine the coefficients of absorption. Moreover, the DOP model computes a single set of coefficients of absorption for the entire radiometric transect. On the other hand, the SGA methodology presented computes a set of coefficients of absorption for every layer (step) into which is divided the water column. This lead to a more precise estimation of the algorithm parameters, and finally, produces better bathymetric mapping. For algorithm comparison, Figures 13 and 14 presents punctual bathymetry estimation at S. Erasmo littoral testing site using the DOP model (Figure 13) and the stratified genetic algorithm developed (Figure 14).

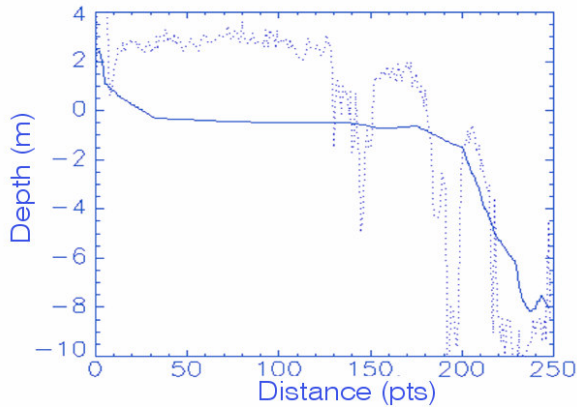


Figure 13. S. Erasmo littoral. Bathymetry estimation using Jupp's model (dotted line) vs. real bathymetry (plain line).

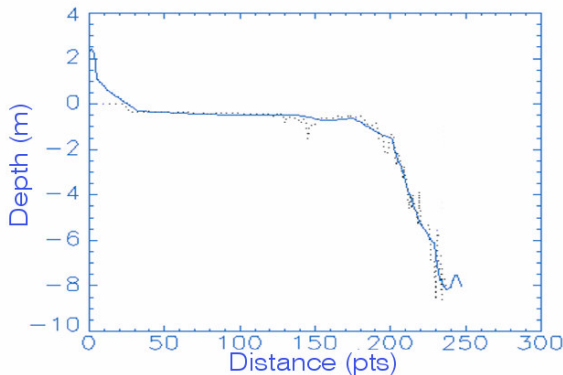


Figure 14. S. Erasmo littoral. Bathymetry estimation using SGA algorithm (dotted line) vs. real bathymetry (plain line).

6. CONCLUSIONS

The great attention that is given to the lagoon of Venice and to his environmental problems is justified by the value of the ecosystems and for the wealth of the artistic patrimony that it contains. The erosion phenomenon subtracts sand and sediments to the lagoon with a dynamics that provokes the lowering and the levelling of the depth contour, and the disappearance of the physical typical designs of the lagoon environment. Nowadays, the discharge of sediments from the lagoon of Venice is esteemed in about 1.100.000 m³ per year, so emerge the problem of developed a fast and cheap monitoring technique of the bathymetry in the lagoon.

The methodology proposed in this paper is an evolution of the Jupp's DOP model that holds account of the complex environmental conditions of the lagoon. Tests in the lagoon of Venice shows a good correlation between the real bathymetry derived from the sounding points, used as reference data, and the computed bathymetry with the stratified genetic algorithm developed.

As like as the original Jupp model, even the new SGA algorithm needs to be calibrated to correctly esteem the coefficients of absorption. The limit of a such analysis lies in the correct computation of these coefficients for a spatial generalization, that, for the lagoon of Venice, are very variable. This problem, however, is to be attribute to the very complex lagoon ecosystem and should be deeper studied.

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