Remote Sensing of Environment 159 (2015) 102–116

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Retrieval of nearshore bathymetry from Landsat 8 images: A tool for coastal monitoring in shallow waters

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ARTICLE INFO

Article history:
Received 3 September 2014
Received in revised form 12 November 2014
Accepted 8 December 2014
Available online 29 December 2014

Keywords:
Satellite-derived bathymetry
Landsat
LiDAR
Linear transform algorithm
Coastal monitoring
Ria Formosa

ABSTRACT

Nearshore bathymetry is likely to be the coastal variable that most limits the investigation of coastal processes and the accuracy of numerical models in coastal areas, as acquiring medium spatial resolution data in the nearshore is highly demanding and costly. As such, the ability to derive bathymetry using remote sensing techniques is a topic of increasing interest in coastal monitoring and research. This contribution focuses on the application of the linear transform algorithm to obtain satellite-derived bathymetry (SDB) maps of the nearshore, at medium resolution (30 m), from freely available and easily accessible Landsat 8 imagery. The algorithm was tuned with available bathymetric Light Detection and Ranging (LiDAR) data for a 60-km-long nearshore stretch of a highly complex coastal system that includes barrier islands, exposed sandy beaches, and tidal inlets (Ria Formosa, Portugal). A comparison of the retrieved depths is presented, enabling the configuration of nearshore profiles and extracted isobaths to be explored and compared with traditional topographic/bathymetric techniques (e.g., high- and medium-resolution LiDAR data and survey-grade echo-sounding combined with high-precision positioning systems). The results demonstrate that the linear algorithm is efficient for retrieving bathymetry from multi-spectral satellite data for shallow water depths (0 to 12 m), showing a mean bias of −0.2 m, a median difference of −0.1 m, and a root mean square error of 0.89 m. Accuracy is shown to be depth dependent, an inherent limitation of passive optical detection systems. Accuracy further decreases in areas where turbidity is likely to be higher, such as locations adjacent to tidal inlets. The SDB maps provide reliable estimations of the shoreline position and of nearshore isobaths for different cases along the complex coastline analysed. The use of freely available satellite imagery proved to be a quick and reliable method for acquiring updated medium-resolution, high-frequency (days and weeks), low-cost bathymetric information for large areas and depths of up to 12 m in clear waters without wave breaking, allowing almost constant monitoring of the submerged beach and the shoreface.

1. Introduction

Updated and detailed coastal topography and bathymetry are increasingly being required for a wide variety of purposes including research, management, and marine spatial planning. With the expansion of coastal and marine economic activities, there is a growing need to develop fast and accurate measurements of nearshore regions, as well as to describe the physical features of the sea bottom and adjoining coastal areas, particularly for the purposes of modelling and monitoring. Coastal observation systems continue to be developed for measuring parameters of and processes related to water quality, hydrodynamics, meteorology, and ecology, as well as submarine geomorphology (analysed using bathymetric data).

Accurate bathymetries are the most essential data for driving coastal modelling and monitoring. Currently, two of the most widely used techniques for acquiring bathymetric data rely on single- or multi-beam echo-sounding and airborne Light Detection and Ranging (LiDAR). However, the cost and logistical difficulties of obtaining nearshore bathymetry using these methods makes survey updates rare or allows them to be conducted only on sites of special interest. As such, the ability to derive continuous bathymetry from satellite images has become a topic of increased interest for coastal monitoring. Such an approach exploits the fact that different wavelengths of the light spectrum are attenuated by water to varying degrees. Initially, these approaches could not be used for marine mapping applications owing to the unique optical properties of water and to highly variable parameters such as turbidity. However, advances in the optical sensors on board remote sensing satellite platforms have improved the ability to detect the spectral properties of aquatic targets such as bottom reflectance, which can then be inverted to yield direct estimates of depth (Mobley et al., 2005).

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http://dx.doi.org/10.1016/j.rse.2014.12.004

The present work explores the retrieval of satellite-derived bathymetry (SDB) for shallow coastal areas, aiming to provide a straightforward and inexpensive method for obtaining and updating bathymetric data relevant to coastal research and management. The study takes advantage of several improvements introduced in the latest generation of Landsat imagery that were included in the Landsat 8 mission launched in early 2013. Furthermore, the Landsat 8 satellite images the entire Earth at approximately fortnightly intervals (every 16 days) and the data collected by the instruments onboard the satellite are available to download at no charge. This paper details the processing of the satellite images required to derive bathymetric maps using the water radiance of three bands (coastal aerosol: 433–453 nm; blue: 450–515 nm; and green: 525–600 nm). The processing steps include the radiometric rescaling of the images, the application of adapted Lyzenga's (1985) depth-retrieval algorithm that uses existing bathymetric data for tuning the image-to-depth conversion, and an averaged and depth-dedicated error analysis. The SDB maps generated have medium resolution (~30 m) and are used to provide cost-effective, frequent, high-density data in raster map format.

2. Study area

The nearshore coastal waters adjacent to the Ria Formosa system in southern Portugal were chosen as the test case in which to derive satellite bathymetric maps (Fig. 1A) because of the complexity and variability of this coastal environment. The Ria Formosa is a coastal lagoon bordered by a multi-inlet barrier island system, and the adjacent coastal areas have several different morphologies such as tidal inlets, alongshore bars, crescentic bars, shoals, and ebb channels. The total length of the system is 60 km, presently comprising five islands and two peninsulas separated by six tidal inlets. The inlets comprise three artificially opened or relocated inlets (Ancão, Fuseta, and Lacém), two artificially stabilised inlets (Faro–Olhão and Tavira), and one natural inlet (Armona). Tides in the area are semi-diurnal, with average ranges of 2.8 m and 1.3 m for spring and neap tides, respectively. Maximum ranges of 3.5 m can be reached during spring tides. Wave energy is moderate with an average annual offshore significant wave height (H_s) of 1.0 m and an average peak period (T_p) of 8.2 s. Dominant incident waves are from the W–SW, representing 71% of occurrences, although E–SE conditions represent 23% of the observations (Costa, Silva, & Vitorino, 2001). Net littoral drift and alongshore currents are typically from west to east. The cuspate shape of this coastal area induces two behaviours in terms of exposure to wave action: the west coast is more energetic, being under the direct influence of the dominant wave conditions (W–SW), whereas the east coast is directly exposed only to the E–SE waves. The nearshore morphology also reflects this cuspate shape, with the bathymetry being generally shore parallel, although incorporating complex areas such as shoals, ebb deltas, alongshore and swash bars, and ridge and runnel systems (Pacheco, Williams, Ferreira, Garel, & Reynolds, 2011).

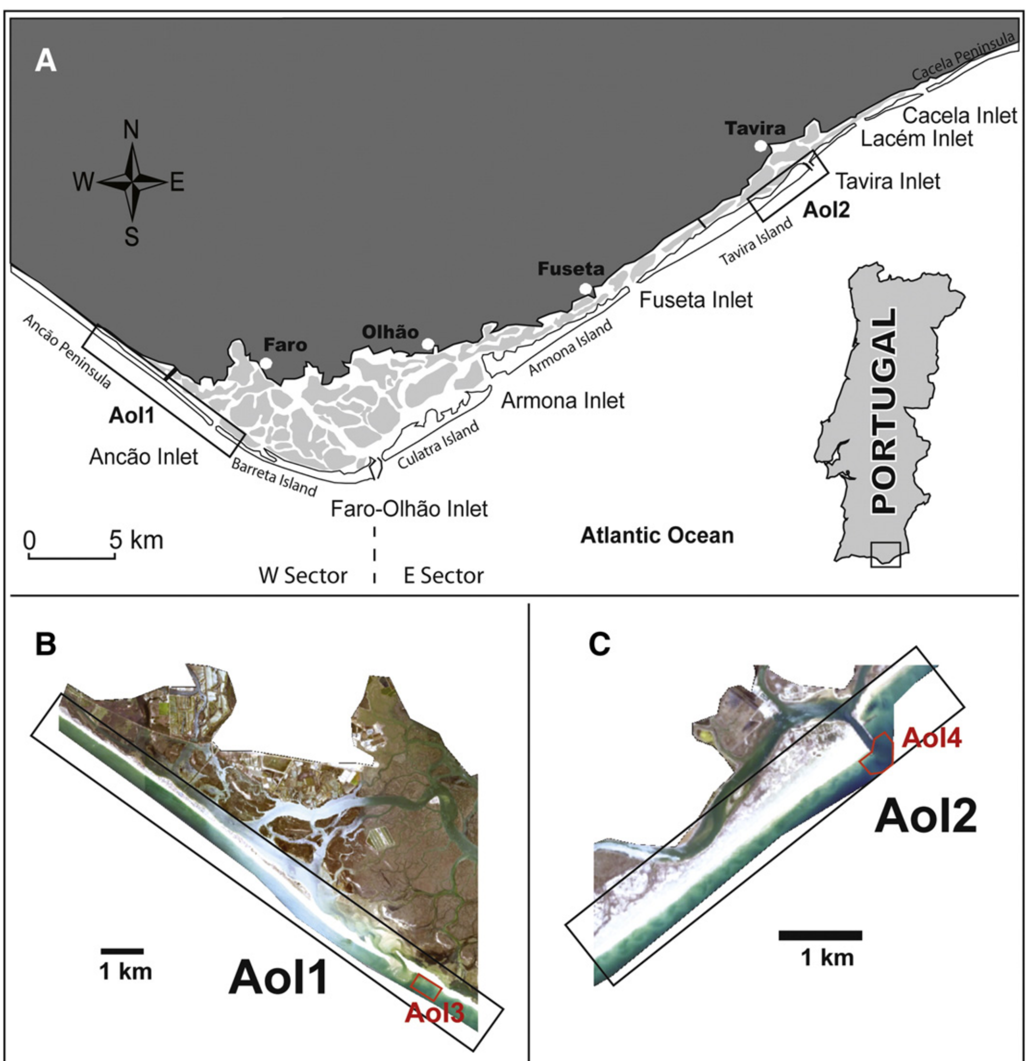

Fig. 1. (A) Ria Formosa multi-inlet system (southern Portugal). Areas of interest AoI1 and AoI3 (B) and AoI2 and AoI4 (C) are represented by aerial photography images to a depth limit of ~12 m.