Algorithm to support the definition of Portugal's continental shelf delineation

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Abstract

In recent years, aiming at the extension of their maritime boundaries, coastal states are addressing the task of delineating the continental shelf beyond 200 nautical miles, i.e. beyond its exclusive economic zone (EEZ). This work proposes an algorithm and its implementation in order to assist and automate part of Portugal's continental shelf delineation process. It aims at the maximization of the area enclosed by the final computed limit, which must satisfy legal requirements and is based on information retrieved and processed for this purpose. The proposed algorithm is based on the swinging arm algorithm for determining the footprint that best defines the region occupied by a set of points, adapted to work in a geodesic surface. A prototype of the implementation is outlined in the paper.

1 Introduction

For more than a decade, since 2009, coastal states are addressing the task of delineating the continental shelf beyond 200 nautical miles, i.e. beyond its exclusive economic zone (EEZ), aiming at the extension of their maritime boundaries. The limit is defined according to legal concepts, auxiliated by the constant collection of scientific data. The delineation aims at the maximization of the area of the polygon enclosed by the limit, as it strictly relates to the expansion of Portugal's territory, within a set of restrictive constraints, whilst all the computation is to be done over a geodesic surface.

As described in article 76 of UNCLOS documentation [?], the outer edge of the continental margin beyond 200 nautical miles, i.e. beyond its exclusive economic zone, is defined by the outermost of two formula lines, denoted as permissive conditions which allow the extension of the continental shelf. Restrictive conditions are implemented, also comprised of the outermost line of a pair of

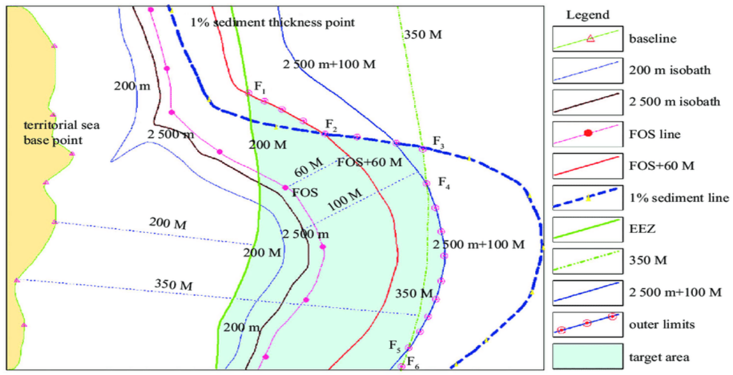

Figure 1: Limit delineation (adapted from [**?**])

rules. The final limit is computed by connecting the previous fixed points by lines that do not exceed **60 nautical miles** in length.

Figure **??** represents the process of the continental shelf delineation beyond the **EEZ**, 200 nautical mile mark. The limit of the continental shelf can extend to the outermost of **Gardiner** (1 pc sediment line) and **Hedberg** (FOS+60M) line. The outermost of the constraints **350M** and **2500m(depth)+100M** restrict the limit. The goal is to find an algorithmic approach that allows the maximization of the highlighted area respecting the previous conditions.

Goal. Portugal's delineation process is currently executed by professionals at *Estrutura de Missão para a Extensão da Plataforma Continental* (EMEPC), organization responsible for the analysis of the data retrieved from the seabed for continental shelf expansion purposes. Geocap is currently the software that the organization uses to aid the delineation, and as it still requires human intervention it is both time consuming and prone to error as the delineation may not result in the optimal solution, the one that would maximize the area of the final limit. In this work, we present an algorithm to automate the process.

2 Related Work

Convex Hull. As presented in [**?**], the work introducing Chan's algorithm, throughout the years several algorithms were developed in order to compute the convex hull of a set of points, the smallest convex polygon that bounds the corresponding set.

Jarvis March, also known as gift wrapping algorithm, begins with the identification of the point with the lowest x-coordinate. Iteratively add the point that is further counterclockwise, representing the largest interior polar angle to the previous edge, not exceeding 180º. The next iteration starts from the recently added edge and the algorithm terminates upon reaching the starting point. Figure **??** illustrates the process.

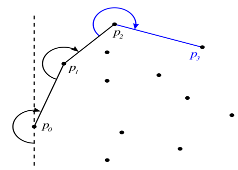

Figure 2: Jarvis March (adapted from [**?**])

Non-convex algorithms. Convex hull may not be the most appropriate approach to define the shape approximation of a set of points due to concavities or the presence of holes. Thus, in order to more accurately define what is denoted as the footprint [**?**, **?**] of a set of points, i.e the shape that best defines it, alpha shapes [**?**], concave hull [**?**] concepts and variations are addressed.

Convex hull fails to define the footprint of a set of points [**?**]. The approach used to produce non-convex results lies in modifying Jarvis March. Analogously, the proposed method starts at the point with the lowest y-coordinate, swinging a half-line L pivoting it throughout the points, thus reaching the next vertex of the hull, iteratively continuing the process from the new vertex. The proposed algorithm is denoted **Swinging Arm** and presented in [**?**].

The authors in [**?**], aimed at the automation of boundary creation in a geographic area defined by a set of points in the geographic space. Therefore, they developed **Concave Hull**, following a **k** nearest neighbours approach supported by an implementation of the **Jarvis March algorithm**. An adjustment was applied such that the angle is arbitrary and in each iteration only the **k** nearest neighbours were candidates to become the next vertex of the hull.

3 Approach

Algorithm. The algorithm that we propose to apply, defined in Algorithm **??**, is inspired in the related work discussed in the Introduction. Considering a set of points **P** (**Hedberg** and **Gardiner**), defined in a ellipsoidal surface, it computes the line **FL** that bounds the **P** such that area is maximized, while not exceeding the restrictive line **RL**. A 60 mile radius neighbour search is performed, as to satisfy the distance constraint, followed by the selection of the lowest clockwise angle between the last defined edge and the new possible one, to guarantee the delineation of **P** resulting in a boundary **H**. At last, **H** is restricted by **RL**, resulting in the solution **FL**.

Prototype and Evaluation. The implementation is comprised of three different stages and is written in Python. The first being the input preparation, in order to model the problem, using the osgeo.ogr module from the **gdal** python library. In the second phase, the algorithm discussed in the proposed approach section is applied to the Gardiner and Hedberg points. Finally, the restrictive limit is applied to the boundary of the set of points which is computed in the

Algorithm 1: Limit definition

Input: Set **P** and restrictive limit **RL**
Result: Boundary/Final limit **FL**

- **Computing the boundary of the set of points**

  1. Select the point with the lowest longitude value **A** storing it in **H**.
     (a) Anchoring on the point selected, compute the clockwise angle θ to those who dist 60 nautical miles from it.
     (b) Select the one with the lowest θ value clockwise.
     (c) Add the point **B** to **H**.
  2. Selecting **B**, repeat the inner loop until reaching **A**:

  The computational complexity of the search is $O(nh)$, **n** represents the size of **P** and **h** the size of **H** .

- **Applying the restrictive limit**

  – The polygon represented by **H** can not exceed the restrictive lines, **RL**. The intersection calculation of the areas enclosed by **H** and **RL** results in a restricted polygon ant its boundary represents **FL**.

second phase. The result is then a delineation which maximizes its area whilst respecting specific requirements.

Concerning the evaluation of the correctness of the proposed algorithm, solutions created by EMEPC in previous limit submissions will be used, as they provide ground truth to compare with the results obtained by the algorithm. It is expected that the value of the area of the final delineation is at least equal or greater than EMEPC results. Examples of tests performed with the prototype can be seen in the supplementary material [1].

4 Conclusion and Future Work

We have proposed a tool for assisting in continental shelf delineation, based on an algorithm that generates the non convex hull of a set of points whilst aiming for area maximization, in an iterative approach. The method is based on concepts of convex hull and footprint generation. Data structures more suited for nearest neighbour search are currently being considered for the implementation, aiming to take advantage of geographic proximity data to improve the search for points that satisfy the distance constraint.

[1] `https://github.com/BrunoDias98/jarvisemepc`