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Optimisation of pipeline route in the presence of obstacles based on a least cost path algorithm and laplacian smoothing

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Abstract

Subsea pipeline route design is a crucial task for the offshore oil and gas industry, and the route selected can significantly affect the success or failure of an offshore project. Thus, it is essential to design pipeline routes to be eco-friendly, economical and safe. Obstacle avoidance is one of the main problems that affect pipeline route selection. In this study, we propose a technique for designing an automatic obstacle avoidance. The Laplacian smoothing algorithm was used to make automatically generated pipeline routes fairer. The algorithms were fast and the method was shown to be effective and easy to use in a simple set of case studies.

Keywords: Dijkstra's algorithm; Geographic information systems; Laplacian smoothing algorithm; Obstacle avoidance; Subsea pipeline

1. Introduction

Pipelines are essential for oil and gas projects, and represent a significant portion of infrastructure investment. It is essential, therefore, that their design should be cost-effective whilst meeting their operational requirements. There are many design parameters, including route selection, pipe sizing, material, coating, wall thickness, free span and cathodic protection (Chakrabarti, 2005). The design is affected by many factors too, such as flow rate, fluid properties, seabed terrain, on-bottom stability and thermal expansion. Several organisations provide design codes including the American Petroleum Institute, American Society of Mechanical Engineers, British Standards, Det Norske Veritas (DNV) and the International Organization for Standardization. Using these design codes, such as the DNV Offshore Standard and Recommended Practice (DNV, 2012, 2010a; 2011a, 2010;b 2006, 2011b; 2010c, 2010d), subsea pipeline designers can determine the pipe diameter and wall thickness, as well as numerically analysing the expansion, fatigue, on-bottom stability and span. Most of these tasks can be computerized, but pipeline route selection still requires much human intervention due to difficulties in automation. This work therefore requires skilled designers with good experience in the art of pipeline route selection. Consequently the process is time-consuming, and a prolonged pipeline route design process can create a bottleneck for an oil and gas project.

Many factors were considered by various authors when selecting the optimum route, including environmental, physical, societal, political, regulatory, technical and economic issues (e.g., Carpenter and Callen (1984), Ryder (1987), Feldman et al. (1995), Montemurro et al. (1998) and Feizlmayr and McKinnon (1999)). Recently, the rapid increases in speed and capability of computers have allowed engineers and researchers to use three-dimensional (3D) Geographic Information Systems (GIS) during the route selection process. Thus, a

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GIS-based system was used in a pipeline expansion project by Montemurro et al. (1998), while Feizlmayr and McKinnon (1999) performed various projects such as pipeline location selection and emergency response plans using a GIS-based pipeline information system. Matori and Lee (2009) prepared a GIS-generated subsea pipeline route based on the commercial program ArcGIS 3.2. These studies have contributed to technical advances in pipeline route design, but there is still no effective method for automatic pipeline route design with efficient obstacle avoidance algorithms.

In this study, we first investigate the use of the Least Cost Path (LCP) algorithm for pipeline route design, and then discuss smoothing algorithms to make the generated route fairer and show why the Laplacian smoothing algorithm is a better choice for this purpose. A computer program was written in C++ based on the algorithms and a series of case studies were conducted to show how the developed techniques can be used for pipeline route design in 3D seabed terrains with various obstacles.

2. LCP algorithm

Selecting an optimum pipeline route is the first major step during marine pipeline design and construction, and the criteria or conditions (terrain, obstacle, politics, etc.) that apply to the pipeline design are never the same in different offshore pipeline projects. The use of GIS to support the complex task of pipeline route selection process has been discussed extensively and some of the pertinent documents are open to the public. However, most are brief articles in magazines rather than detailed academic studies, and thus they do not provide sufficiently detailed technical information to be of practical use. In any case the industry practice still largely relies on manual process which requires much skill and experience.

In automating this crucial task, some form of optimisation scheme must be used and a most promising approach in this application is the LCP algorithm. The LCP algorithm is an algorithm for finding the least cost paths between two nodes. The least cost path would be the shortest path, the least time path, or minimum construction cost path depending on the user. This algorithm has been employed widely in many industries. For example, Berglund et al. (2003) and Yu et al. (2003) employed it for road planning, whereas Fraichard and Ahuactzin (2001) and Connors and Elkaim (2007a, 2007b) applied this algorithm to self-driving autonomous vehicles. Recently, the LCP algorithm has been used widely in video games. One of the classic LCP algorithms is Dijkstra's Algorithm (1959). Cui and Shi (2011) reviewed three frequently used techniques for path finding, where they focused on the A* path finding algorithm introduced by Hart et al. (1968) and is an extended form of Dijkstra's Algorithm.

In this study we investigated the use of the LCP algorithm based on Dijkstra's Algorithm in determining the optimum pipeline route. The technique was demonstrated by using a number of case studies in diverse obstacle situations based on a 3D seabed terrain.

Dijkstra's Algorithm and the A* Algorithm are classic graph search algorithms, which can find the LCP between any two nodes on a graph. The graph is a mathematical structure where the vertices or edges are associated with geometric objects, as shown in Fig. 1.

Before the development of A* Algorithm, Dijkstra's Algorithm was the only choice for path finding. Unlike Dijkstra's Algorithm where the entire graph must be searched, the A* uses a heuristic method to reduce the search area. The heuristics employed by the algorithm estimates the cost of the shortest (cheapest) path from the last node (n) on the path to the goal. By reducing the search range, the algorithm greatly reduces the time required to find LCPs. The acceleration of path finding is undoubtedly attractive for applications in video games and autonomous vehicles, and thus the A* Algorithm has become one of the most widely used algorithms for finding LCPs. However, this algorithm cannot guarantee finding the shortest route because it does not cover all of the possible nodes that the path can visit. Unlike video games or autonomous vehicles, real-time search is not important in pipeline route design, while optimum solutions are the key requirement. Therefore, in our current application Dijkstra's Algorithm was considered to be a better method. In fact, Dijkstra's algorithm can also obtain the solution almost immediately due to the speed and capacity of modern computers.

To find a shortest path (there may be more than one shortest paths), Dijkstra's Algorithm repeatedly examines the unvisited nodes neighbouring the current one and compares the previously assigned tentative values with the values that can be achieved by using the current node. For each node the tentative value (shortest distance to the node from the starting point so far determined) are then updated by assigning the lesser of the two values to the node. The node with the lowest value of the neighbouring set is then made the current node and the process is repeated until the target node is reached. If a cul-de-sac is reached, the nodes are retraced until progress can be made. Fig. 1 shows a simple graph problem where v1 is the starting node while v5 is the target node. The number on each edge denotes the cost (distance) between two nodes of the edge. It can be demonstrated that the LCP is (v1 → v2 → v4 → v3 → v5) and the cost of this route is seven (7).

Most digital display systems project images using fixed picture-element (pixel) arrays, and the pixels are normally

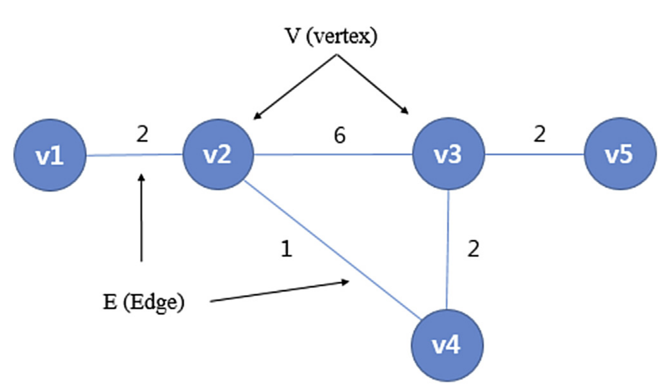

Fig. 1. An example graph.

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