Finding Optimal Ship Travel Paths by Utilizing Ocean and Wind Data Through Level Set Method

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Abstract

Ships has been the ultimate mode of transportation throughout the history of civilizations in our world. As of now, with an increasing demand in energy resources, the utilization of fuel for this purpose also demands efficiency. This entails the optimal path the ship should pursue in order to achieve the most efficient fuel use, and also the shortest path should be taken. In this paper we will show how level-set method and line search method applied to finding the optimal for a ship to take, due to the constraints of wind data in a vector field format.

1. Introduction

The notion of reasons to choose the ship's path to travel, how to choose that path, and how to acquire the data, are concerns which needs significant considerations.

1.1. Why choose ship travel path?

Ship transport has been an important, though generally invisible, aspect of our life. Massive numbers of people, large quantities of oil and gas/energy, and innumerable consumer goods are being shipped throughout the world at all time. Environmental and military concerns also fall within this arena, as do oceanographic and biological research done with ships.

Nowadays, as the demand and cost of energy is increasing, it is necessary to be able to manage ship's fuel efficiency. The shortest physical distance is not always the least-cost distance in terms of energy usage. Determining how ships of all types could optimize their travel paths as they move through the globally complex vectors of wind and water currents is presently impossible for ship captains or companies. However, because the air and water currents can be determined via satellite imagery multiple times a day, the data exist by which determinations could be made given appropriate computational means, to help solve this problem. This could result in significant research papers, research funding, and long-term connection to major companies.

Three processes that have significant effects on the ship's travel path are:

- ocean currents
- wind currents
- the locations of the nearby ships and their travel relationship to another ship (drafting behind another ship)

If a ship can determine those three factors accurately, the fuel utilization could be optimized in the most efficient way possible. The accurate determination of these factors can assist in then exploiting the satellite and wind data to provide meaningful answers to real users.

In this paper, we will only describe the use of wind current data for finding optimal path.

1.2. How to choose ship travel path? (use level-set method)

The process of choosing the optimal travel path can be done by the help of wind data visualization, where arrows reveals wind directions in each coordinate-grid seen, which are generated by vector fields. These vector fields can be utilized in order to apply the level-set method, which uses the Hamilton-Jacobi equation to perform simulation which involve the deformation of an initial surface by the vector fields. This deformation can be minimize by a simple optimization algorithm, the steepest descent method, and the points of which the steepest descent method yields reveals the coordinate-grid that can be used as guide by the ship to perform the most efficient path.

1.3. How to get the data?

Data acquisition can play a very important role on helping the ship's captain to make a noble decision on choosing its path. One of the popular satellite that incorporate the acquisition of the wind current data is the QuikSCAT satellite, which provieds near-surface ocean wind speed and direction. The QuikSCAT satellite uses the SeaWinds instrument to perform such things.

PODAAC, which stands for Physical Oceanography Distributed Active Archive Center, provides these SeaWinds QuikSCAT ocean wind data.

On another hand, the one major technical difficultiy occurs on this data acquisition is the fact that PODAAC can provide monthly up-to-date data, but no a day-to-day basis. However, the development of our algorithm is also in need to be carefully address, and thus to prepare us for the moment where acquisition technology for these data improve significantly. This paper is in hope to contribute to the future of ocean transportation.

2. Preliminary study of the level-set method

For one object to perform a travel from one point to another, within a selected region, there are obstacles in that region which would need to be considered in order for the object to travel efficiently. Here, we define "efficient" as the shortest time possible.

Two important aspect are in need on finding this efficient path:

- Level-Set Method

- Optimization Algorithm

In this project, we will use the Hamilton-Jacobi equation to apply the level-set method.

$$\phi_t + \left(\vec{w} + a \frac{\nabla\phi}{|\nabla\phi|} \right) \cdot \nabla\phi = 0$$

Eq. 1

On the equation above, we shall define the “obstacles” in our chosen region as the vector field **w**, where each grid in that region (interpreting numerically) has a 2D vector. The region here is described as a plane.

Simplifying Eq. 1,

$$\phi_t + \vec{w} \cdot \nabla\phi + a\,|\nabla\phi| = 0$$

Eq. 2

Eq. 2 gives us a more clear picture of the phenomena of the level-set method, besides **w** as our vector field (vector in each grid), a will be the speed of the object.

And last but not least, numerical implementation requires us to discretize Eq. 2. Here, Euler method is applied, thus leads us to

$$\phi_{n+1} = \phi_n - \Delta t \left(\vec{w} \cdot \nabla\phi + a\,|\nabla\phi| \right)$$

Eq. 3

This equation reveals the sinking of our level-set surface by rate **a**, and the deformation of that surface by the vector field **w**. After the last iteration, will the final **phi** obtained, optimization will be performed by choosing the destination as the initial guess, and tracking all the points that the optimization algorithm goes through in order to efficiently reach the minima, which is take-off point.

2.1. Choosing cone as the initialization surface

Since this project deals applies optimization, it is necessary to choose an appropriate initialization that ease the finding of the minima of the deformed surface. One wise choice would be the cone, which involve smooth region everywhere and symmetricity of gradients on all grids pointing to the minima.

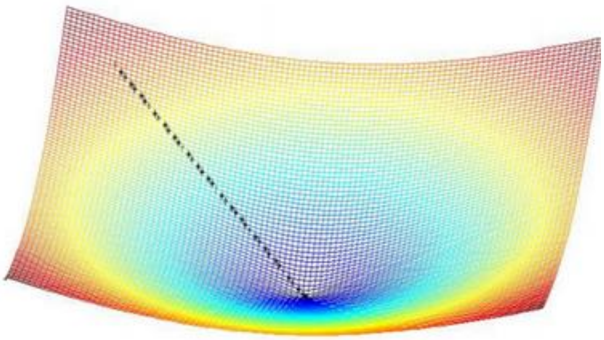

Fig. 1

2.2. Preliminary Study

Before we actually apply a real life vector field on the level-set surface, we shall study how the surface's behavior along n iterations. This study is important in order to understand how the surface deformed over time.

2.2.1. Natural contour growth

To obtain the natural contour growth of the surface, from Eq. 3, we can set the vector field w to zero, and set a to be a constant normal velocity of the contour (this case it will be a circle).

On this study we can see how the cone is sinked down to create a larger and larger concentric circles as collective contours, over time.

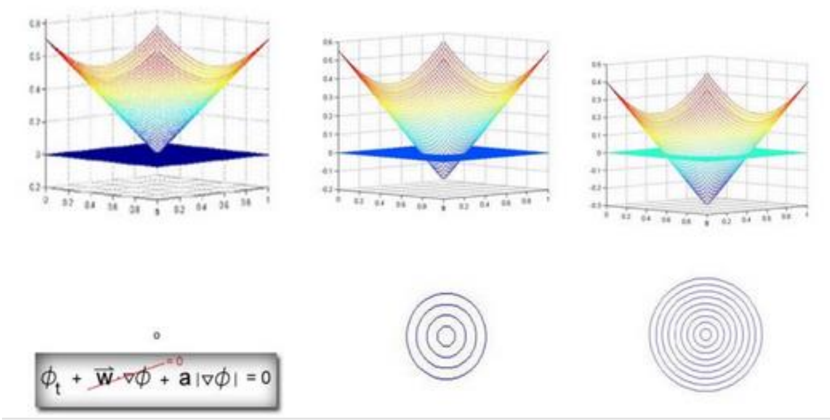

Fig. 2

2.2.2. Constant vector field example

Another preliminary study we can do is to see how constant vector field deform the conic level-set surface. Here we study for different cases, where each case involve a constant vector field on a single-axial direction, namely either x-axis or y-axis. The magnitude of constant vector field will be chosen as the same magnitude of the advection velocity **a**.

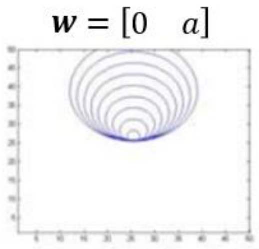

Fig. 3

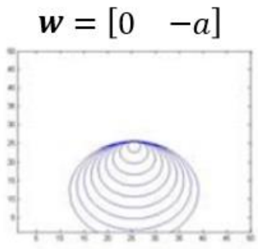

Fig. 4

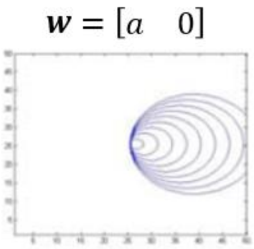

Fig. 5

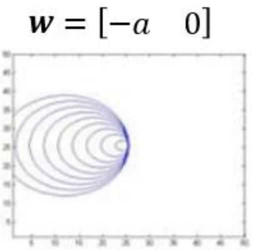

Fig. 6

3. Optimal travel path with level-set method

The path search, as noticed earlier, requires the minimization of the deformed surface. Here the deformed surface is optimized using the steepest descent method. To update the new coordinate in the steepest descent method, we simply use:

$$\overrightarrow{X_{n+1}} = \overrightarrow{X_n} + \alpha \cdot \overrightarrow{P_n}$$

Eq. 4

where,

$$\overrightarrow{P_n} = -B_n \cdot \nabla \cdot \Phi$$

$$B_n = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Eq. 5

Alpha is the step length, which in this project we used adequately small value. **P_n** is the steepest gradient at the specific point where the iteration lies. Below is one example where the optimization applied to a deform conic surface.

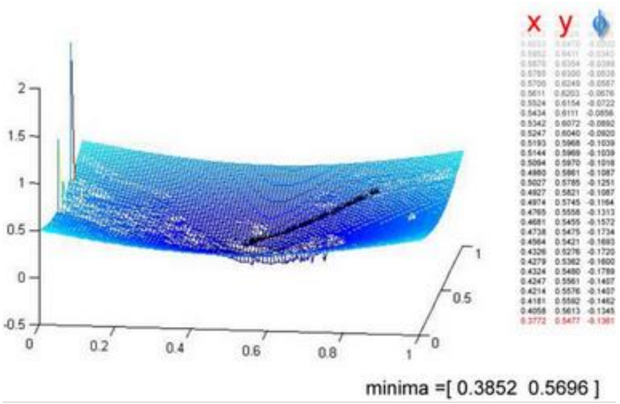

Fig. 7

Out of all, there are more challenges needs to be addressed. One issue would be the shift of the minima, where the deformed conic surface would take into account the original take-off point, instead the vector field applied shifts the minima onto another location. This needs some modification on the steepest descent algorithm.

Other challenges would be to address sharp corners in the deformed surface. Steepest descent might be easy to implement, but other method such as conjugate gradient would also deserves consideration.

Despites these challenges, the advantage of using a fix, normalised in a sense, domain. For example, on a given region, the sensors to acquire the data have limited capability; some can acquire more data in the region than others. But that should be fine with our algorithm, since we can always choose amount of grid on each axis, Nx and Ny, accordingly.

4. Conclusion

- Optimization algorithm needs to be modified to address issues such as sharp corners
- Optimization algorithm needs to be modified in order to address the shifted minima, thus leads to a more accurate optimal path.
- The step length alpha needs to be chosen accordingly, at each time step, to address the issue of rate of convergence within its neighbour.
- The convergence of the level-set method needs to be redefined, where if the contour at zero-level set touches the destination, iteration should be stopped. Last but not least, the algorithm works well with natural advection (without vector field) and with constant vector field.