Geovisualization of fishing vessel movement patterns using hybrid fractal/velocity signatures

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Abstract—While much work has been done on representing vessel movements, little work has been devoted to understanding and representing what particular movement patterns are associated with specific activities. Using fractal dimension as a measure of activity complexity, and velocity as a measure of activity type, it is possible to develop signatures for particular activities or behaviours. These signatures can then be used within a geovisualization system to highlight areas or data points of interest to the user. Within the context of fisheries enforcement, officers could use such a system with real-time data to quickly ascertain whether a vessel is acting illegally and increase the odds of catching them when they return to port.

Index Terms—Fisheries, geovisualization, tracking systems, fractal dimension, filtering, virtual globe.

1 Introduction

Northwest Atlantic fisheries are regulated by the Northwest Atlantic Fisheries Organization (NAFO) in international waters (i.e., beyond 200 nautical miles from the coast), and by each country within its territorial waters. In those administrative regions, fisheries are bound by a set of rules which are aimed at preserving the resources or protecting specific environments of interest.

To help enforce these rules, most vessels fishing within Canadian or international waters are required to use a Vessel Monitoring System (VMS), an electronic device which records and transmits vessel positions at regular time intervals, generally on an hourly basis. This helps government fisheries enforcement officers verify, in quasi real-time, if vessels are complying with regulations, such as fishing within zones open for fishing and when the season is open.

Unfortunately, VMS only provides vessel positions at specific time intervals. These are often insufficient for demonstrating in court that an infraction has occurred, as nothing specifies when vessels are fishing during a given trip. In addition, the enforcement officers using VMS are overwhelmed by amount of VMS data made available every day and are seeking for better ways to make sense of these data.

This project presents a method for reducing the amount of VMS data presented to the user by dynamically excluding data that are not associated with fishing activities, such as steaming from a harbour to a fishing ground. It also explores how movement patterns occurring at different scales can be characterized based on VMS data. Using this, experts can gain knowledge about the movement patterns and perhaps gain insight into aspects of specific fishing activities.

Research done with movement data in ecology, such as optimal foraging theory [1, 2, 5], purports that the optimal path for animals to exhibit while foraging is a correlated random walk, a path of high fractal dimension. Moreover, it has been shown that different types of activities will exhibit distinct fractal signatures [7]. Measurement of fractal dimension, a measure of path complexity, can be applied to vessel movement paths. Using fractal dimension and velocity as parameters, it is possible to develop basic signatures which accurately discern between some movement patterns, such as cruising and fishing. Section 2 presents the approach which combines fractal and velocity measurements into a geovisualization environment and Section 3 presents specific aspects of the interactive interface that allows the user to dynamically adjust the filter parameters to highlight movement patterns of interest.

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2 Approach

All of the 2009 VMS data for the Atlantic Canada region were provided by Fisheries and Oceans Canada (DFO). Each record includes a randomly generated ID for each vessel, the latitude, longitude, and a time stamp of their position, recorded on an hourly basis. Fractal dimension and velocity estimations are based on the assumption that vessels follow a straight-line track between data points. While this is not generally true, it is a necessarily assumption due to the temporal resolution of the data.

2.1 Fractal Dimension

Fractality is a concept first introduced by Mandelbrot [4] which essentially states that complex structures have self-similar or repeating structures. Fractal dimension (*D*) is, essentially, a measure of fractality. Straight lines will have a fractal dimension of 1, while complex lines will tend towards 2. Fractal dimension can then be used to assess the complexity of fishing vessel movement paths.

For paths which are not mathematical functions, the fractal dimension cannot be calculated, only estimated. A number of methods exist for estimating the fractal dimension of arbitrary paths. Sevcik's method [6] is used in this work, where L is the total standardized path length and N is the number of points to consider (1). This method is essentially an improvement over Katz's method [3], allowing for a better estimation of D.

$$D_{Sevcik} = 1 + \frac{\log(L)}{\log(2N)} \tag{1}$$

The use of a variable window size for calculating the fractal dimensions of paths segments of various lengths allows for looking at the complexity of paths at different scales. This can be useful when trying to identify different types of patterns. For example, using a window size of 3 would identify rapid activities, such as dropping crab pots, but a window size of 15 might be more appropriate for activities such as trawling or steaming.

2.2 Velocity

Under the linear path assumption, vessel velocities were calculated as the distance between two data points over the duration covered. While this estimation is reasonable, it could be improved. Only having one-hour intervals, VMS data are a challenge this method must deal with. Using another interpolation technique, such as a spline, may help, at a cost in performance.

2.3 Interactive Filtering

Interactive filtering was implemented in a mapping interface through a set of sliders that allows users to filter for fractal dimension and for velocity. Both sliders support the selection of a minimum and a maximum bound. The window size *N* used in estimating the fractal dimension may also be selected using a slider. This slider only allows selection of one window size. While the analysis could be run on multiple window sizes, the computational costs would be large and is unlikely to be of benefit within the context of this research.

3. Geovisualization System

A geovisualization system which helps experts explore VMS data was developed, based on NASA WorldWind. The application allows for the display and interactive filtering of fishing vessel movement data. Figure 1 shows part of the interface displaying some of the data used in this project, filtered using a hybrid fractal/velocity signature roughly corresponding to fishing.

Paths are interpolated using a cubic Hermite spline that intersects each of the data points. Only those data points that match the fractal/velocity filter are show using a chevron glyph. With this representation, an enforcement officer can filter out data points that are uninteresting, and focus on those data points that represent a pattern of behaviour that is under investigation.

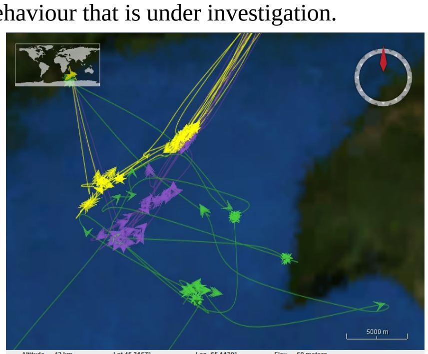

Fig. 1. The system showing movement paths of vessels and highlighting points which match the hybrid filter.

3.1 Selecting Filter Values

The most important aspect of being able to resolve a particular activity is the correct selection of filter values. Selecting filter values is a complex task which depends greatly on the type of data being inspected and the specifics of the activity being studied. Users can provide ranges of velocity and complexity values for different types of fishing (e.g., fishing for crab vs shrimp). Figure 2 shows examples of activity patterns corresponding to low and high velocity (x-axis), and low and high fractal dimension (y-axis).

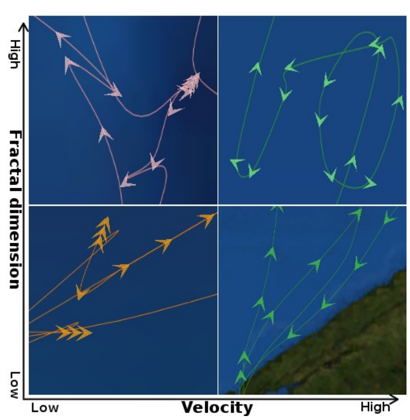

Fig. 2. Velocity vs. fractal dimension plot

3.2 Gaining insight

The primary goal of the geovisualization system is to help users into gaining some form of insight about the data being presented. The filtering mechanism only removes data points which do not pass the filter while retaining the original line, as can be seen in Figure 1. This allows users to focus on the important data while still retaining the contextual information of where the vessels came from or went after, which may help fisheries enforcement officers better understand the behaviours associated with specific fishing acitivities.

4 Conclusion

This paper presented a new interactive approach for supporting fisheries enforcement officers in identifying fishing activities for large VMS data sets. The method allows for filtering path sections using fractal dimension and velocity estimations. Fractal dimension indicates complexity, often related to specific fishing practices, while velocity allows the identification of low speed fishing from high speed movements between sites. The use of a variable window size on the fractal dimension calculation allows adapting the filtering algorithm to search for a number of different activity types. Incorporating this into a geovisualization system allows the user to iteratively refine the filtering parameters to select more appropriate subsets of data.

When dealing with a large amount of data in a geovisualization system, it is important to remove as much extraneous data as possible. The visual representations themselves have to be able to adapt and highlight important parts of data sets while downplaying unimportant sections. In the context of fishing, a large amount of time is spent cruising between the fishing grounds and ports. This is of limited interest to enforcement officers and can make it harder to see the interesting portions of the data (e.g., fishing activities).

Hybrid fractal/velocity filtering, combined with an interactive geovisualization system, should allow enforcement officers to perform their jobs more quickly and better deal with the very large volumes of data they must process on a daily basis. An informal validation of the system with a group of fisheries enforcement officers and fisheries scientists has confirmed the relevance of the approach. Further formal user evaluation will be conducted to assess the effectiveness of the visual representation and the usefulness of the interactive filtering features offered to the users.

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