Ai-MAST 2015

International Conference of Advanced Intelligent Maritime Safety and Technology

Original article

On the Maritime Spatial Planning (MSP)

to Enhance Safety and Security at Sea

Michele FIORINI [1][†], *Andrea CAPATA* [2], *Domenico D. BLOISI* [3]

[1][†] *The Institution of Engineering and Technology (IET), Italy Network, Rome, Italy, mfiorini@theiet.org, Corresponding Author*
[2] *Meetatnine Srls, Rome, Italy, andrea@meetatnine.com*
[3] *Dept. of Computer, Control, and Management Engineering, Sapienza University of Rome, Rome, Italy, bloisi@dis.uniroma1.it*

Abstract

Maritime Spatial Planning (MSP) is the process of public developing a plan for allocating the spatial and temporal distribution of human activities in marine areas. The constant increase in marine traffic and the simultaneous growth of the demand for installing offshore wind power plants require an adequate planning strategy and effective monitoring and surveillance solutions for managing the traffic volume as well as to consent to improve the wind energy capacity. The adoption of the e-Navigation is a possible solution for improving safety and security at sea by integrating maritime information onboard and ashore. AIS traffic data represent a fundamental source of information, since the analysis of AIS data can highlight the presence of congested areas as well as of illegal actions, such as smuggling, pollution, and unauthorized phishing in protected areas. Indeed, those activities are often characterized by abnormal maneuvers that can be recognized by analyzing the routes of the vessels. In this paper, we present a complete pipeline for displaying and analysing publicly available AIS data, in order to carry out an AIS-based route analysis. An example is described using only open-source software.

Keywords: e-Navigation, AIS data, maritime safety, maritime piracy, clean mobility, intelligent transport systems

I. Introduction

Global shipping and the movement of goods by sea have seen substantial changes during the last decade, in terms of both sheer number and dimensions of ships. Maritime transport grows at an average rate of over 8.5 percent every year: Over 90% of world's trade is carried by sea for a total of 23 million tonnes of cargo and 55,000 cruise passengers travelling by ship every day (IMO, 2015). Cruise alone has tripled its size between 1999 and 2009, carrying over 6,000 passengers on ultra-large cruise ships. On March 2012, Ms Maria Damanaki, European Commissioner for maritime affairs and fisheries, starts her keynote speech at the European Commission in Brussels with the following sentences: "Today the oceans and seas around the European Union are shrinking. They are not becoming smaller, but more and more users are racing to develop their activities there, and to compete with those

who are already there" (Damanaki, 2012). Together with marine traffic, also the installation of offshore wind turbines is becoming an important factor to be considered in the process of Maritime Spatial Planning (MSP), defined by UNESCO as the public development of a plan for allocating the spatial and temporal distribution of human activities in marine areas (MSP Forum, 2015). Indeed, abundant offshore wind resources have the potential to supply immense quantities of renewable energy to major U.S. coastal cities, such as New York City and Boston (BOEM, 2015). Offshore wind energy is still growing from the 4 GW capacity in 2012 to the 150 GW expected in 2030, i.e., a 4,000 percent increase! (Fiorini and Chang, 2012).

The interconnected global economy and the ever-raising public demand for adequate monitoring and surveillance of sea traffic requires higher efficiency in managing the traffic volume as well as low emissions. On one hand, 'green' initiatives, such as switching to renewable energy collected in power plants off-shore as well as temporary or permanent marine nature reserves, have gained priority allocations in certain quarters of the sea by the process of Maritime Spatial Planning (MSP). The 'message' of this is that people living ashore make it clear, by means of their laws and regulations, that they are not prepared to accept just any environmental risk or damage or even 'only' certain environmental side-effects of the current way of living any longer, as in the case of energy supply. They are also not prepared to accept replacement of nuclear energy with fossil energy resources to any degree because of its negative side effects on the world climate. Hence, the acceptance of the usage of offshore sea areas for the construction and operation of offshore renewable energy sources.

On the other hand, people living ashore want to reap the benefits of the current way of living: This results in the following value derivation chain: the current way of living necessitates and incurs (global) trade which in turn creates (overseas) maritime transport which again prompts maritime traffic. Maritime traffic can again be construed as consisting of the 'berth-to-berth navigation' of many vessels which immediately prompts the most relevant attributes of vessel navigation and vessel traffic, namely, safety, efficiency, security and environmental friendliness or 'greenness', amongst others (Fiorini and Lin, 2015).

In such a context, the International Maritime Organisation (IMO) launched their e-Navigation strategy in 2008 by a decision of their Maritime Safety Committee (MSC), with the goal of harmonising marine navigation systems to improve safety and security at sea by integrating maritime information onboard and ashore (IMO, 2009). E-Navigation is conceived to improve the traditional traffic management instruments and measures by enhancing berth to berth navigation and related services for safety and security at sea and protection of the marine environment. The e-Navigation prerequisites can be summarised as follows:

- Electronic Navigation Charts (ENC): worldwide coverage required;
- Electronic Positioning System: a robust fail-safe (with redundancy);
- Ship-Shore link: an agreed communication infrastructure.

The expected e-Navigation outcomes are:

1. Ship based systems: integration of ship's own sensors; electronic positioning; Electronic Navigational Charts (ENC); decision support capability to reduce human error;
2. Shore based systems: management of vessel traffic and related services from ashore;
3. Communications infrastructure: authorised information transfer onboard ship, ship-to-ship, ship-to-shore and shore-to shore.

From the above considerations, it derives that, to achieve the expected e-Navigation goals, having a clear defined model of the maritime scenario, generated from the Maritime Spatial Planning (MSP) process, is even more that a prerequisite in order to manage properly all the maritime stakeholders assets.

The main contribution of this paper is a step-by-step description of a procedure for displaying Automated Identification System (AIS) data coming from vessels navigating across large geographical areas. AIS traffic data represent a fundamental source of information, since the analysis of AIS data can highlight 1) the "traffic level" in specific areas and 2) the presence of illegal actions, such as smuggling, pollution, and unauthorized phishing in protected areas. Indeed, those activities are often characterized by abnormal maneuvers that can be recognized by analyzing the routes of the vessels: Machine learning techniques can be used to recognize abnormal behaviors, in order to prevent illegal and dangerous activities especially in crowded areas. We present a complete pipeline for displaying and analysing publicly available AIS data, in order to carry out an AIS-based route analysis: An example using only open-source software is described in detail.

The remainder of this paper is organized as follows. Section II presents a brief overview of wide area surveillance analysis techniques, i.e., methods for the statistical analysis of vessel trajectories. Section III describes a step-by-step procedure for visualizing AIS data. Only open sources software are used to process the data. Conclusions are drawn in Section IV.

II. Statistical Analysis of Vessel Trajectories

The application of statistical methodologies to derive motion patterns from a collection of trajectories is a largely studied topic. However, the number of papers dealing specifically with the problem of trajectory analysis in the maritime domain is rather low, mainly due to the difficulties in obtaining real data.

Two surveys about maritime anomaly detection can be found in (Martineau and Roy, 2011) and (Pallotta et al., 2013). From the analysis of the literature, existing methods dealing with maritime data can be grouped according to two main categories (Pallotta et al., 2013):
- Grid-based approaches;
- Vectorial representation of traffic.

In Grid-based approaches the area to be monitored is divided into cells to create a spatial grid. The cells are characterized by the motion properties of the crossing vessels. (Vespe et al., 2008) presents a system for suspect vessel detection and track propagation, including (i) knowledge-based filtering and tracking, (ii) model-based track prediction, (iii) data correlation, and (iv) Neural-Network (NN) based data characterization. The navigational and geographical knowledge is exploited for the data association, while the vessel motion features and the scenario influence is used for the estimation of the degree of confidence of correlation.

(Bomberger et al., 2006) describe a learning-based maritime domain awareness system to produce predictions of future vessel location on the basis of current vessel behavior. The work uses AIS data recorded from the Miami Harbor area. (George et al., 2011) presents an anomaly detection scheme, which utilizes a context-aided tracker to perform situation/threat refinement and assessment by means of a hypothesis generator. A test case scenario is developed considering Hampton Roads Bay, Virginia. The area of interest is divided into a 15×20 grid-field and a trafficability value is assigned to each cell based on the target vessel type and the individual contextual data.

As pointed out in (Pallotta et al., 2013), grid-based methods are effective when the surveilled area is small, while their effectiveness decreases when the size of the monitored area is big. Indeed, the main limitations of the grid-based approach resides in the required computational burden and in the need of performing an *a priori* selection of the optimal cell size.

In the approaches that exploit a vectorial representation of traffic, trajectories are modelled as a set of connected waypoints. In a such away, vessel motions in large areas (i.e., global scale) can be modelled thanks to the high compactness of the waypoint representation. In (Nevell, 2009) a node-sparse network is used to model the ocean traffic, where each landmass in the world is represented by a closed polygon and Great Circle Branches are generated between pairs of nodes that are not impeded by any intervening landmass. A Bayesian approach is adopted for estimating the likelihoods for a range of journey destinations. A similar representation is used also in (Lane et al. 2010), where the nodes represents waypoints near land masses, and Great Circle routes are formed to represent ocean journeys. (Vespe et al. 2012) introduce the concept of intermediate nodes to increase the precision level in the description of the routes. This is useful especially in areas with high traffic. An important drawback of the methods based on a vectorial representation is the difficulty in being effective when unregulated areas are monitored, where the behavior of vessels is much more difficult to categorize (Pallotta et al., 2013).

An approach using automated statistical analysis to prevent subject matter experts from being diverted from their duty and to make it possible to automatically detect new unseen behaviours is presented in (Ma et al., 2009). The paper report a use case about the heavy and complex traffic in the port of Singapore.

Usually, existing approaches assume that AIS data have already been processed and patterns have been extracted, e.g., (Ristic et al., 2008). In the next section, we present a step-by-step procedure for processing AIS data in order to allow for extracting vessel trajectories. Only open source and freely available software is used to compute AIS trajectory visualization from real data.

III. AIS Data Visualization

A good AIS data visualization is crucial in having a good understanding of the maritime traffic situation for shipping safety. In this section, we describe a procedure for processing ship routes to create a density map. The data used throughout this discussion have been extracted from a sample shapefile containing AIS data Sample of vessels over a section of Europe for August 2013 and they have been downloaded from the Internet (ExactEarth, 2015).

The complete visualization process is made of two main parts:

1. Map construction;
2. Interactive map visualization.

In the first part of the process, a visible map layer of density points is created by describing the ship routes along a time interval of one month. In the second part, such a route density map layer is visualized by means of a web client: The aim is to obtain a map that is *(i)* easily readable, through the use of an underlying background geographical map, and *(ii)* interactive, i.e., queryable through simple clicks on it.
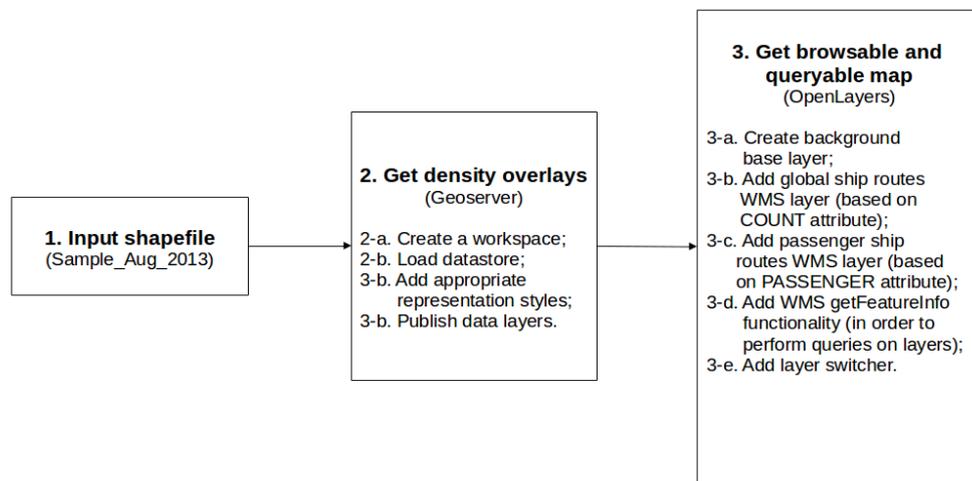
1. Input shapefile
(Sample_Aug_2013)

2. Get density overlays
(Geoserver)

2-a. Create a workspace;
2-b. Load datastore;
3-b. Add appropriate
        representation styles;
3-b. Publish data layers.

**3. Get browsable and
queryable map**
(OpenLayers)

3-a. Create background
        base layer;
3-b. Add global ship routes
        WMS layer (based on
        COUNT attribute);
3-c. Add passenger ship
        routes WMS layer (based
        on PASSENGER attribute);
3-d. Add WMS getFeatureInfo
        functionality (in order to
        perform queries on layers);
3-e. Add layer switcher.

Figure 1: Overall scheme of the visualization process

Fig. 1 shows the overall scheme of the proposed AIS data visualization procedure. First of all, we need to choose an instrument able to take charge of the interpretation of the shapefiles by converting them into a more standard format, easily reachable over the web by a client, without the need to download the shapefile itself each time.

We have chosen Web Feature Service (WMS) as the way to share the information with the web clients, since the layer map in use consists of a set of pixels having different colors according to specific properties. WMS is an Open Geospatial Consortium (OGC) standard protocol, designed to allow retrieving over the web map images generated by map servers and extracted from databases of geo-spatial data.

In our mapping process, the role of database of spatial data is played by the shapefile (in our case, Sample_Aug_2013) downloaded from the exactEarth company website (ExactEarth, 2015). As a map server, we used Geoserver, because it is offers a certified OGC compliant implementation of a number of open standards such as Web Feature Service (WFS), Web Coverage Service (WCS) and Web Map Service (WMS), which is the on of interest for us.

III.I. Map Construction

The first step of the map construction process concerns the creation of a reference workspace for the data to be extracted, transformed, and exported. We called it "ship_routes" and enabled the use of the OGC standards on its data. The GeoServer screenshot is shown in Fig. 2.
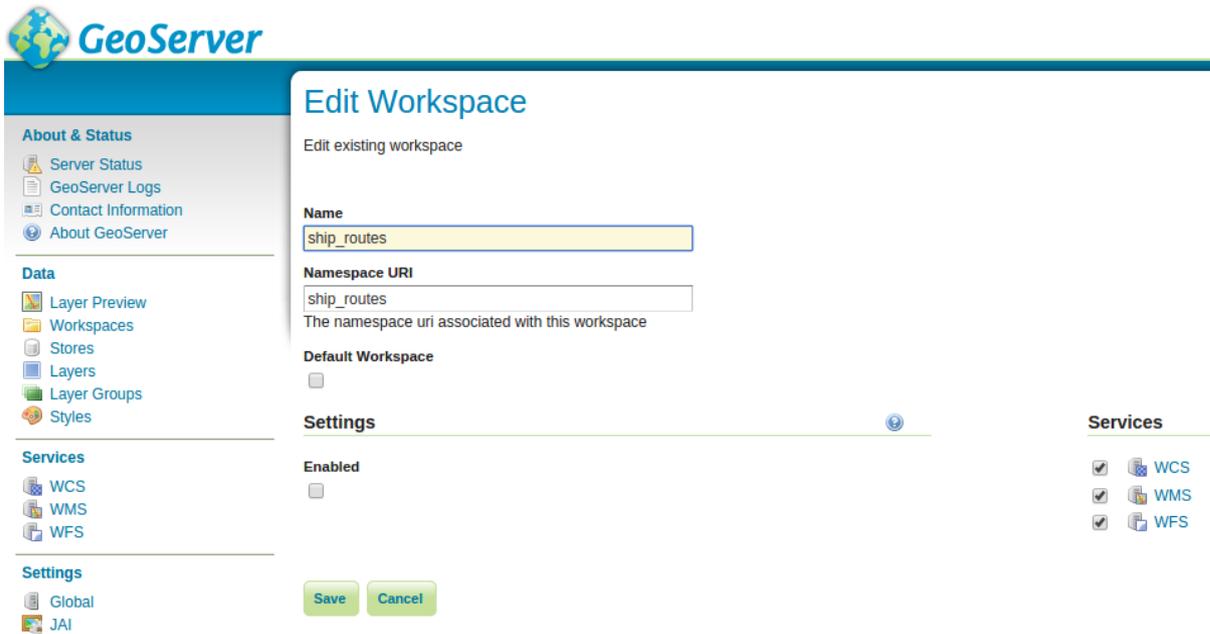
Figure 2: Workspace creation

Then we need to define the datastore in Geoserver, i.e., the source of our data. Providing the path of the sample shapefile, Geoserver can import the data and make it available for client requests, according to the several available OGC standards (WMS in our case). We called it "ship_routes_datastore" as well and associated it to the ship_routes workspace. The GeoServer screenshot is shown in Fig. 3.
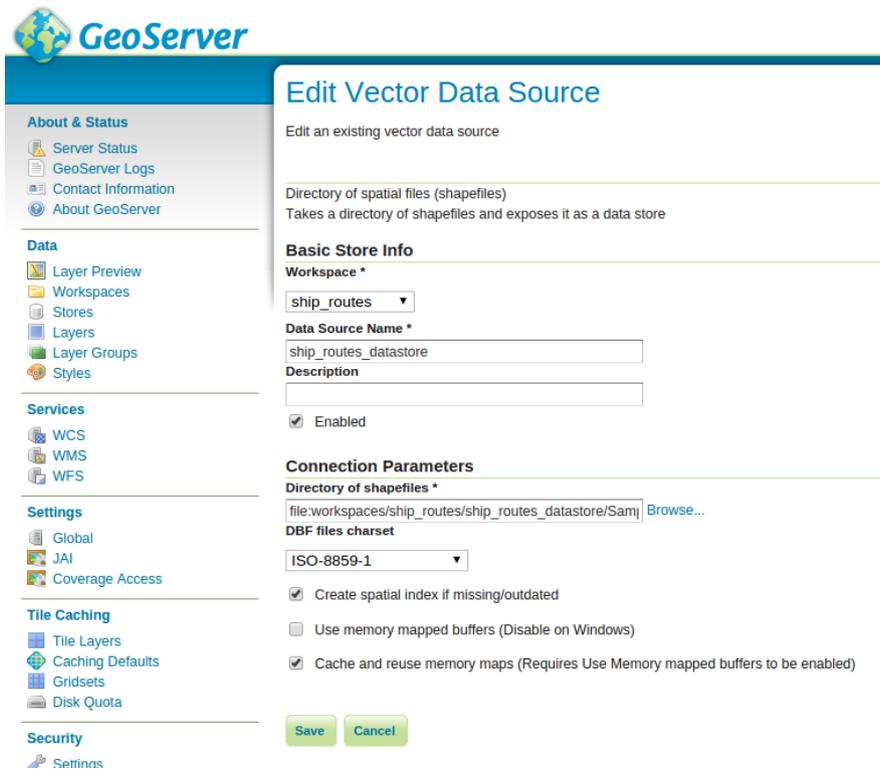

Figure 3: Importing data in Geoserver

As final step, we want to create the effective layers to be visualized by the requesting clients. In order to achieve such a result, we need to choose the ship_routes_datastore within the ship_routes workspace (ship_routes:ship_routes_datastore) as the data source for our new layers and define the desired projection. It is worth noting that the original one was in WGS84, but we need a reprojection to EPSG:3857 instead. The GeoServer screenshot is shown in Fig. 4.

Figure 4: Reprojection to EPSG:3857

To have an appropriate representation of the data types, we created new visualization styles, defining the variation of the color of a pixel according to a particular value of one or more attributes of that pixel. We created two styles, each one taking into account the variation of one particular attribute: COUNT and PASSENGER. According to these styles, we generated two layers: ship_routes_layer and ship_routes_layer-passenger.

The attributes of this layer, present in each pixel in this density map, were automatically relieved by Geoserver according to the available feature types shown in Table 1. They refer to the number (per type) of ships present in the zone represented by that particular pixel during the sample period (August 2013). The attribute COUNT represent the sum of all the kind ships passed through that point along the sample period.

Table 1: Feature types available

Feature Type Details

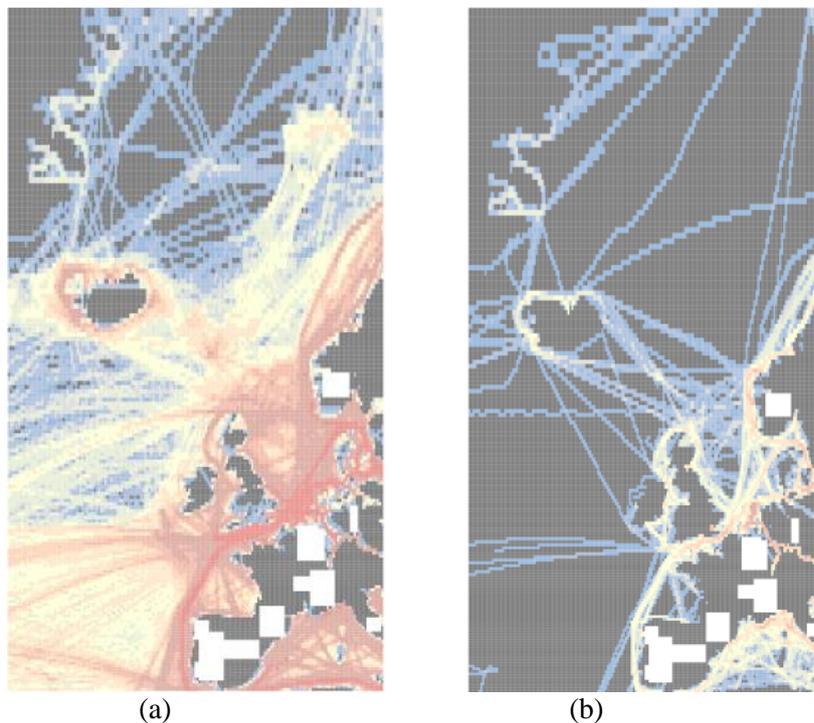| Property	Type	Nillable	Min/Max Occurences
the_geom	MultiPolygon	true	0/1
COUNT	Long	true	0/1
FISHING	Long	true	0/1
PASSENGER	Long	true	0/1
CARGO	Long	true	0/1
TANKER	Long	true	0/1
START_DATE	Date	true	0/1
END_DATE	Date	true	0/1

(a)　　　　　　　　　　　　　　　　(b)

Figure 5: Map visualization. (a) COUNT attribute based visualization. (b) PASSENGER attribute based visualization.
Scale: 1:70m.

So we created two layers containing density maps of ship routes, with pixel colors based on the attribute COUNT (the sum of all the ships, per type, in that point over the sample period) and PASSENGER (the number of all the passenger ships in that point over the sample period).

III.2. Interactive Map Visualization

To make those layers accessible, easily visualizable and queryable through WMS requests, we then realized a web page using OpenLayers3, an open source JavaScript library to display maps on web browsers. OpenLayers allows to interact with web servers providing data interchange based on standard protocols, such as WMS.

The following JavaScript code represents the OpenLayers3 implementation of the two layers of interest (plus a background one) and of the whole density map:

```
var routesLayer = new ol.layer.Tile({
            title: 'All ship routes',
            type: 'base',
            source: new ol.source.TileWMS({
                    url: 'http://localhost:8080/geoserver/ship_routes/wms',
                    params: {
                            'FORMAT': 'image/png',
                            'VERSION': '1.1.1',
                            LAYERS: 'ship_routes:ship_routes_layer',
                                tiled: true,
                                STYLES: ''
                        }
        })
});

var passengerRoutesLayer = new ol.layer.Tile({
            title: 'Passenger ship routes',
            type: 'base',
            visible: false,
            source: new ol.source.TileWMS({
                    url: 'http://localhost:8080/geoserver/ship_routes/wms',
                    params: {
                            'FORMAT': 'image/png',
                            'VERSION': '1.1.1',
                            LAYERS:'ship_routes:ship_routes_layer-passenger',
                            tiled: true,
                            STYLES: ''
                        }
            })
});

var backgroundLayer = new ol.layer.Tile(
            {source: new ol.source.MapQuest({layer: 'osm'})
});

var map = new ol.Map({
            target: 'map',
            layers: [
                    backgroundLayer,
                    new ol.layer.Group({
                            title: 'Overlays',
                            layers: [
                                    routesLayer,
                                    passengerRoutesLayer
                                ]
                        })
            ],
            overlays: [popupOverlay],
              view: new ol.View({
                    center:ol.proj.transform([-8.79,62.11],'EPSG:4326', 'EPSG:3857'),
                    zoom: 3
            })
});
```

The result is a fully browsable and queryable (through the use of WMS getFeatureInfo service, as shown in the code below) map, in which we can observe and analyze the density data of ship traffic for all the types of ships, or in particular only for passenger ships, over all the sample period, i.e., August 2013. Fig. 6 contains the final results that is obtained following all the above described steps.

```
map.on( 'singleclick',
        function(evt) {
                var coordinate = evt.coordinate;
                var view = map.getView();
                var url = routesLayer.getSource().getGetFeatureInfoUrl(
                                        evt.coordinate,
                                        view.getResolution(),
                                        view.getProjection(),
                                        {
                                          'INFO_FORMAT': 'text/html',
                                          'FEATURE_COUNT': 50
                                        }
                                );
                if(url){
                        content.innerHTML='<iframe seamless src="'+ url + '"></iframe>';
                }
                popupOverlay.setPosition(coordinate);
        }
);
```
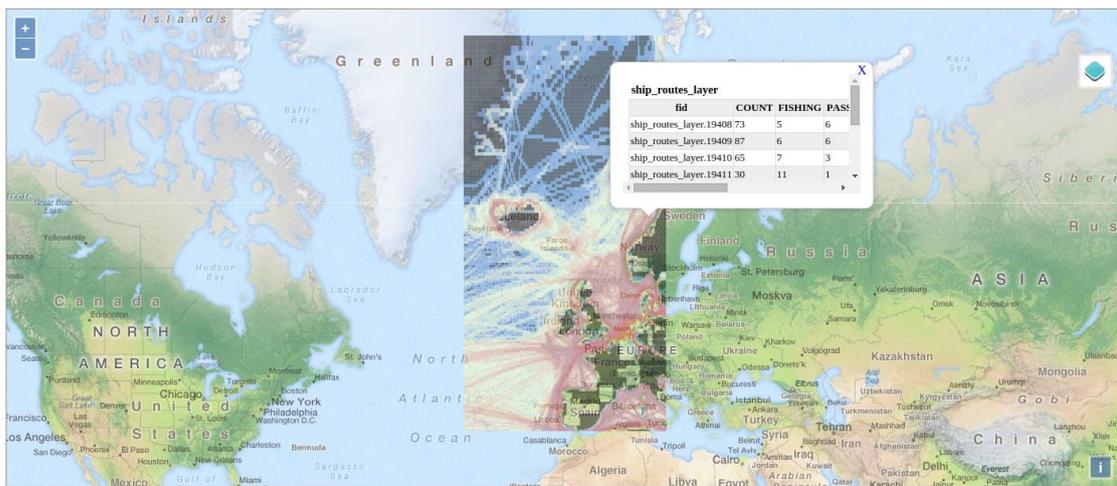

(a)
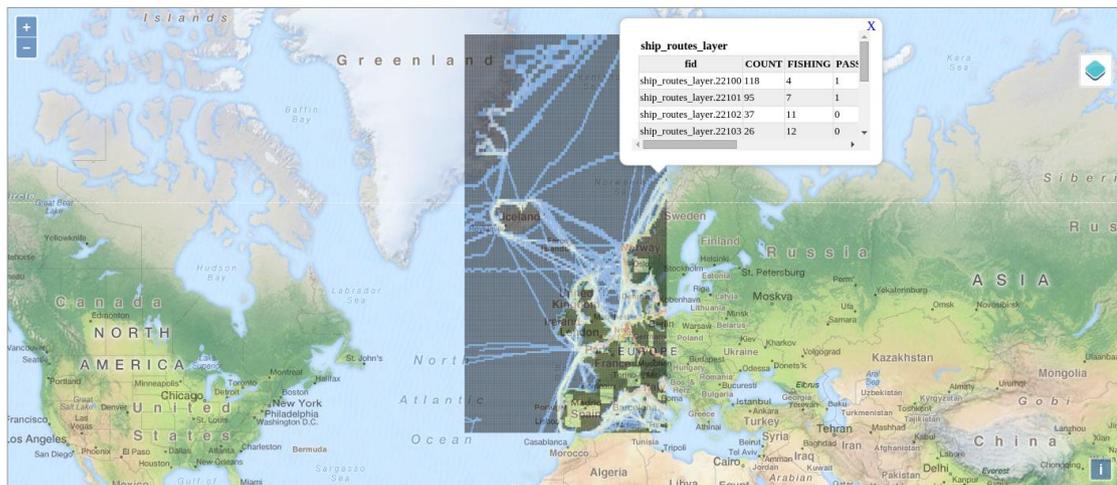
(b)

Figure 6: a) COUNT attribute based map projection. b) PASSENGER attribute based map projection.

IV. Summary and Conclusions

In this paper, we have described a procedure for displaying Automated Identification System (AIS) data coming from vessels navigating across large geographical areas. The proposed visualization scheme can be used as a first stage towards the development of automatic AIS data management systems to extract the "traffic level" in specific areas and to highlight the presence of illegal actions (e.g., smuggling, pollution, and unauthorized phishing in protected areas). A review of existing statistical techniques to be used for recognizing abnormal behaviors has been provided.

References

IMO (International Maritime Organization)'s website: https://business.un.org/en/entities/13, last accessed October 2015.

Fiorini, M. and Chang, S. J. (2012), Vessel route analysis by in situ measurements. A prerequisite for Maritime Spatial Planning, In: Proc. 12th International Conference on Intelligent Transport Systems and Telecommunications, ITST2012, pp. 423-427.

Damanaki, M. (2012), Maritime spatial planning: the right answer to secure and support Blue growth for the European Union. In: EU International Conference The case for Maritime Spatial Planning: efficient resource management for sustainable growth, speech 12/224, pp. 1–3.

Fiorini, M. and Lin, J-C (2015), Clean Mobility and Intelligent Transport Systems, IET Transportation Series 1, London 2015, pp 464.

IMO (International Maritime Organization) Maritime Safety Committee (2009), Strategy for the Development and Implementation of e-navigation, In: IMO/MSC. Report of the Maritime Safety Committee on its Eighty-Fifths Session. MSC85/26. Add. 1, Annex 20.

Bostwick, D., Goldstein, J., Stephenson, T., Stromsten, S., Tierno, J., Torrelli, M., & White, J. (2009). PARSEC, an application of probabilistic case based reasoning to maritime surveillance. In Proceedings of the IEEE Conference on Technologies for Homeland Security. Boston, MA: IEEE Press.

The Nautical Institute's MSP Forum website: http://www.nautinst.org/en/forums/msp, last accessed October 2015.

BOEM (Bureau of Ocean Energy Management)'s website:
www.boem.gov/renewable-energy-program/renewable-energy-guide/offshore-wind-energy.aspx, last accessed October 2015.

Ma, K.-T., Ng, G.-W., Wang, X., and Grimson, W.E.L. (2009), Anomaly detection for Maritime Security, NATO Workshop on Data Fusion and Anomaly Detection for Maritime Situational Awareness (NATO MSA 2009), NATO Undersea Research Centre (NURC).

Ristic, B., La Scala, B., Morelande, M., and Gordon, N. (2008), Statistical Analysis of Motion Patterns in AIS Data - Anomaly Detection and Motion Prediction, In: Proceedings of The 11th International Conference on Information Fusion (Fusion 2008).

Martineau, E. and Roy, J. (2011), Maritime Anomaly Detection: Domain Introduction and Review of Selected Literature, Defence R&D Canada – Valcartier Technical Memorandum, DRDC Valcartier TM 2010-460.

Pallotta, G. Vespe, M. and Bryan, K. (2013), Vessel Pattern Knowledge Discovery from AIS Data: A Framework for Anomaly Detection and Route Prediction, Entropy 2013, 15(6), pp. 2218-2245.

Vespe, M., Sciotti, M., Burro, F., Battistello, G., and Sorge, S. (2008), Maritime multi-sensor data association based on geographic and navigational knowledge, In: Proceedings of IEEE Radar Conference RADAR 08, pp. 1–6.

Hu, W., Xiao, X., Fu, Z., Xie, D., Tan, T., and Maybank, S. (2006), A system for learning statistical motion patterns, IEEE Trans. Pattern Anal. Mach. Intell., 28, pp. 1450–1464.

Bomberger, N.A., Rhodes, B.J., Seibert, M., and Waxman, A.M. (2006), Associative learning of vessel motion patterns for maritime situation awareness, In: Proceedings of 9th International Conference on Information Fusion, pp. 1–8.

George, J., Crassidis, J., Singh, T., and Fosbury, A.M. (2011), Anomaly detection using context-aided target tracking. J. Adv. Inf. Fusion 2011, 6, pp. 39–56.

Nevell, D. (2009), Anomaly detection in white shipping, In: Proceedings of 2nd IMA Conference on Mathematics in Defence, pp. 1–7.

Lane, R. O., Nevell, D. A., Hayward, S. D., and Beaney, T. W. (2010), Maritime anomaly detection and threat assessment, In: Proceedings of 13th Conference on Information Fusion, pp. 1–8.

ExactEarth, AIS data Sample of vessels over a section of Europe for August 2013 downloaded from http://main.exactearth.com, last accessed October 2015.