Todo list

Contents

It's the author job to make the reader's job easy - Joshua Schimel.

1 Introduction

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Begin the thesis by giving a general overview of the field you are conducting research in. Focus on work that has lead up to your project. Remember to cite. This could look something like: What a route planner is, maybe its definition. Then, move further on to what types of methods has been used in the field. In this case data-based and non-data based models. The middle part goes into a more specifics. Write about what you are investigating and why. Get help with referencing if needed. At the end of the introduction, simply state what the thesis aims to achieve.

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Before computers and computation, data was logged manually. While traveling across the worlds seas, logging wind and current information enabled ships to decrease their travel time (Lewis 1927).

Transportation on sea has become, and is still to this day one of the biggest businesses within the global trade. Maritime shipping amounts to 90 % of the world's trade transportation method (https://business.un.org/en/entities/13). Route planning is a comprehensive guide developed and used by a group of people to determine the most favorable route, raise awareness of potential problems or ensure the vessel's safe passage. Constructing a route depends on either knowledge of past voyages or surroundings of route.

AIS-data has been used for prediction and estimation in the maritime industry. The approaches and methods used in research base their predictions on previous voyages (see chapter 2: literature review). This is one of the research areas in the maritime industry (Meijer 2017). AIS-data used in various applications such as streamline cargo transfer at harbors, avoiding collisions at sea with real-time data of speed and position of vessels within a region and helping companies to take better decisions.

Before the invention of AIS-data, conducting voyages was done based on maps. Algorithms search through a space given start and end points. The goal is to maneuver through this space and create a route without colliding with obstacles i.e land (Hvamb 2015). The algorithms vary from applications in sciences such as informatics, mathematics and physics (Hvamb 2015), (Besse et al. 2015), (Peder-

sen and Fossen 2012). The latter has motivated and will be a basis for the research done in this thesis.
In this thesis, a framework for creating and predicting routes for marine vessels will be made. A data-based model is provided, more specifically, a AIS-data driven one. In addition, an approach based on principles and theory in the field of fluid mechanics. More specifically, potential theory. Setting up an environment given a map in which the route shall be produced by calculating streamlines will provide routes from a given starting and end point. The area of interest will be Geirangerfjorden located in Sunnmøre, Norway.

Remember to cite!

1.1 A brief history of navigation at sea

One of the first tools used in navigation was a magnetic compass. This created some confusion and inconsistent measures at sea due to unawareness of magnetic variance (difference between magnetic north and geographic north). Before the compass celestial navigation was done by knowing the distance between particular stars.
Modern navigation tools. The twentieth century brought important advances to marine navigation, with radio beacons, radar, the gyroscopic compass, and the global positioning system (GPS). Commonly known as electronic navigation. Most oceangoing vessels keep a sextant onboard only in the case of an emergency
Gyroscopic compass always pointing at true north
Radar(short for ”radio detection and ranging”) system was produced in 1935. It was used to locate objects beyond range of vision by projecting radio waves against them. This was, and still is, very useful on ships to locate other ships and land when visibility is reduced.
The U.S. navigation system known as Long Range Navigation (Loran) was developed between 1940 and 1943, and uses pulsed radio transmissions from so-called ”master” and ”slave” stations to determine a ship’s position. The accuracy of Loran is measured in hundreds of meters, but only has limited coverage.
In the late twentieth century, the global positioning system (GPS) largely replaced the Loran. GPS uses the same principle of time difference from separate signals as Loran, but the signals come from satellites. As of 2002, the system consisted of 24 satellites, and gave the mariner a position with accuracy of 9 meters (30 feet) or less.

1.2 Problem statement

Objectives:
- Cleaning data
- Create a map-based algorithm
- AIS-data based algorithm

The objective of this thesis is easy to comprehend. To put it in layman's terms, how to create a route from a to b for marine vessels to traverse. A straight line between two points will not be satisfactory. Some information is required to use as input when making a model. This could of course vary and combined in order to make a model more robust or improve accuracy. Historical AIS-data (Automatic Identification System) has been and is still used to make predictions based on vessels location. This approach is a very realistic one as the data is based on real locations, so the safety and accuracy aspect of the route leads to well defined and trustworthy predictions.

1.2.1 AIS-data driven

Given two points, how is it possible to construct a route between these two points. These points could represent ports or way points.

1.2.2 Fluid mechanics approach

make a vector field given a map and construct a route with flow theory from fluid mechanics. Each potential represents different objects in the map. The necessary representations of a map will be objects which needs to be avoided and start and end points.

1.3 Constraints

2 Literature review

In this section an overview of the research done in the path-planning field is presented. An attempt to present the methods systematically beginning with methods with applied mathematics, physics and finishing with AIS-based models. Lastly, a table listing the pros and cons of each presented method is done.

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Try to present the route prediction method as a problem of many solutions. Each method with its own limitation. By combining AIS and none-AIS approaches the predictions made will hopefully be stronger and more robust. Weight the contribution to route planning, not patterns nor collision avoidance, motion patterns, anomaly detection. important factors, but not of interest in review section

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Depending on method some sort of input to model is required. The input often leads to an output of certain character. Here, mainly inputs will have the type of start and end points or AIS-data. The models dependent on start and end-point

(Hvamb 2015) presents three approaches for route planners. These methods requires a map. The first one using a Voronoi diagram. Making connecting lines between vertices of polygons or points describing obstacles e.g islands. Then, perpendicular lines at their half distance are drawn and connected creating Voronoi lines. Each line not intersecting the obstacles are suggested routes.

The next method is based on Rapidly-exploring Random Trees (RRT). Searching an area by sampling points a graph is produced. A bias toward to the goal makes the model possible for convergence.

The final method presented in (Hvamb 2015) is applies a Probabilistic roadmap and uses this for planning routes for marine vessels.

(Pedersen and Fossen 2012) makes the first route planner by applying potential flow theory on marine vessels. Setting up potentials with different flow characteristics, a flow pattern emerges. From this, following certain streamlines lead to the desired goal. In addition, a vessel guidance scheme is derived making sure the vessel gets to its destination.

(Besse et al. 2015) analyzes taxi-drivers' patterns in San Francisco with GPS-data. Predicting the destination of the taxi's by their choice of route with a method derived from (Besse et al. 2015) a Symmetrized Segment-Path Distance (SSPD).

(Pallotta, Vespe, and Bryan 2013) implements a unsupervised learning scheme (Traffic Route Extraction and Anomaly Detection) to predict routes in different locations. By clustering AIS-data into waypoints for certain areas in a route. Vessels are then classified with state when entering a waypoint.

Method	**Author**	**Pros**	**Cons**
Voronoi diagram	Hvamb 2015	• Based on map i.e need polygons to describe obstacles • No need for AIS data (may be useful if wanting to straighten out route)	• Initial route may not be realistic • Must apply additional algorithm for getting e.g shortest route • Computational heavy to generate
RRT	Hvamb 2015	• Able to provide several routes from same or different starting points • Several trees can be initiated at once • No need for AIS data • possible to optimize w.r.t other metrics • A bias parameter can decrease number of calculations	• Struggles in finding paths in narrow passages • Exploration method is symmetric which causes unecessary computations
PRM	Hvamb 2015	• Does not requires AIS data • Based on map • Can compute multiple routes • Can implement a straightening out technique for shorter routes	• Finding the shortest route, which is often the case, requires an additional algorithm • Computing multiple routes comes at a higher computational cost

Potential flow	Pedersen and Fossen 2012	• No need for AIS-data • Not computational heavy • Produces multiple routes by visualizing streamlines	• Must adjust strength-parameters for optimal map representation • Streamlines could be very close to objects and must therefore be selected carefully • If flow is non-uniform around a vessel leads to deviation from the streamline
SSPD	Besse et al. 2015	• Does not requires labeled data • Implementation able with cython for optimal computation speed	• Not easy to verify how much data is required for a good model
TREAD	Pallotta, Vespe, and Bryan 2013	• No prior information needed • Amount of data is huge • Model able to predict anomalies	• Not a good model for traffic with a low density of vessels • Certain amount of pre-processing is necessary for good and precise motion patterns to be made

3 Theory

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Worth mentioning what the criterias are for setting up a potential. From Navier stokes equation and conservation of mass to streamfunction. No curl $->$ Potentialflow

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In this section the mathematics used in the thesis is presented. The theory will mostly be from the field of fluid mechanics. A brief introduction to the equation which governs the properties and motion of fluids will be given, namely Navier-Stokes equations. From the general Navier-Stokes equations, some characteristics of fluid will be assumed (the fluids viscosity) and yield new equation which will be the main equations used in this thesis. These equations are part of fluid mechanics named potential theory.
Visualization is a key component the research on which we will conduct. Therefore, tools for using vector fields and plotting are a necessity. A more detailed description can be found in (Gjevik 2019) and (Acheson 2003). The data used will also be described in this section.

3.1 Vector

A vector is used to describe a quantity with direction and magnitude. From a point of reference this can be represented in a coordinate system. Mathematically this can be written as:

$$\vec{r} = [x, y, z]$$

The arrow indicates that r is of the type vector. The first component moves along the x-axis, second along the y-axis and the third along the z-axis. The three components indicate that the vector $\vec{r}$ exists in a three-dimensional space. This can visualized as seen in the figure below:

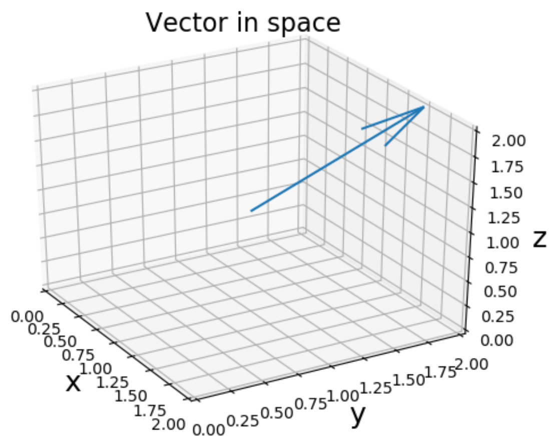

Figure 1: shows a typical vector representation. The arrow shows a vectors direction, it's length represents it's magnitude.

3.2 Vector field

Vector fields are useful when wanting to describe velocities, forces or accelerations within a domain. The field are represented with vectors which are functions of spacial coordiantes and time. Mathematically this is written as:

$$\vec{F} = \vec{F}(x, y, z, t)$$

This can written out more as:

$$\vec{F}(x, y, z, t) = (F_x(x, y, z, t), F_y(x, y, z, t), F_z(x, y, z, t))$$

F_x, F_y, F_z are scalar fields. The field is called stationary if it is independent of time.

3.3 Navier-Stokes equation

The Navier-Stokes equations are derived using the laws of several quantities which are conserved. The quantities include mass, momentum and energy.
The continuity equation arise from the law of conservation of mass which says that mass can not be created or disappear. The general equation of continuity is

stated below:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$$

ρ is the fluid density, $\nabla = [\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}]$ the gradient and $\vec{u}$ the velocity. We will assume that the properties of fluids looked are incompressible. This means the fluid's density is constant. The continuity equation for incompressible fluid states:

$$\nabla \cdot \vec{u} = 0$$

Where both density terms are excluded first by statement above and dividing by the density ρ.

This leads up to the next equation, the momentum equation. It states that a fluid's density times acceleration is proportional to the forces acting upon the fluid. Since we are only worried about incompressible fluids the momentum equation for such a fluid is:

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u} = -\frac{\nabla p}{\rho} + \mu \nabla^2 \vec{u} + f_v$$

This is the Navier-Stokes equation for an incompressible fluid. The left side hand states the inertia term. The terms $\frac{\partial \vec{u}}{\partial t}$ and $(\vec{u} \cdot \nabla)\vec{u}$ are the local and convective acceleration respectively. The right hand side is pressure gradient $\frac{\nabla p}{\rho}$, viscous forces $\mu \nabla^2 \vec{u}$ and external forces f_v. As for the continuity equation we will make some assumption which in turn will produce equation which will be used here. The fluid which will be focused on are stationary and inviscous $\mu = 0$. These assumptions leads further to potential flow theory which will be covered next. This section will be the main focus the physical base model of the thesis.

3.4 Potential flow

Streamlines, also called field lines is useful to visualize the flow in a fluid. This is represented as a vector field. By assuming that the flow of the fluid is steady, that is, the velocity does not change with time at a fixed point in space, it is possible to find these streamlines. Mathematically the velocity can be written as:

$$\vec{u} = \frac{d\vec{x}}{ds} \tag{1}$$

Where $\vec{u} = [u(x,y,z), v(x,y,z), w(x,y,z)]$, $d\vec{x} = [dx, dy, dz]$ and ds is a small change in the curve s. Streamline curves are defined as having same direction as the velocity vector at each point. Then the cross product between the velocity vector and curve s is zero:

$$\vec{u} \times d\vec{x} = 0 \tag{2}$$

Writing out the components gives:

$$(vdz - wdy)\vec{i} = 0$$

$$(wdx - udz)\vec{j} = 0$$

$$(udy - vdx)\vec{k} = 0$$

This gives the equations:

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w} = ds \tag{3}$$

For a 2-dimensional description the equation for an incompressible flow is :

$$\nabla \cdot \vec{u} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{4}$$

$\vec{u}$ is the velocity vector is a function of u and v, $\vec{u} = [u, v]$. u and v are the velocity components in x and-y direction, respectively. $\nabla = [\frac{\partial}{\partial x}, \frac{\partial}{\partial y}]$ is the differential operator nabla. We can relate the velocity vector to the stream functions as:

$$u = \frac{\partial \psi}{\partial y} \tag{5}$$

$$v = -\frac{\partial \psi}{\partial x} \tag{6}$$

ψ is the stream function. Putting (5) and 6) into (4) yields:

$$\nabla \cdot \vec{u} = \frac{\partial^2 \psi}{\partial x \partial y} - \frac{\partial^2 \psi}{\partial x \partial y} = 0 \tag{7}$$

By also assuming that the field is irrotational $\nabla \times \vec{u}$, the laplace equation is obtained:

$$\nabla \times \vec{u} = \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial x^2} = \nabla^2 \psi = 0 \tag{8}$$

Where eq (5) and eq (6) are substituted in as expressions for the velocity components. The laplacian has some important properties which will be used here. The laplacian operator is a linear operator which says that if two different stream functions are solutions to eq (8) then the sum is also a solution. This is known as the superposition principle .

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Equation (1) is satisfied. Furthermore, eq (2) can give us the conditions on what the stream function must look like in order for this to be true. Putting eq (5) and eq (6) into eq (2) and assuming this is for a 2 dimensional flow the stream function yields:

is this correct?

$$udy - vdx = \frac{\partial\psi}{\partial y}dy + \frac{\partial\psi}{\partial x}dx - = 0 \tag{9}$$

$$\partial\psi = 0 \tag{10}$$

$$\psi = Constant \tag{11}$$

ψ is constant along the streamline. All stream functions satisfying eq (7) are valid choices for ψ. Solutions of ψ are: sinks, sources, doublets. The velocity components represented in polar coordinates are:

$$v_r = -\frac{1}{r}\frac{\partial\psi}{\partial\theta} \tag{12}$$

$$v_\theta = \frac{\partial\psi}{\partial r} \tag{13}$$

and the laplacian in polar coordinates:

$$\nabla^2\psi = \frac{\partial^2\psi}{\partial r^2} + \frac{1}{r}\frac{\partial\psi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\psi}{\partial\theta^2} = 0 \tag{14}$$

$r = \sqrt{x^2 + y^2}$ is the radius and θ is the angle from origo.

Include Dipol, sink, source and uniform flow equation and derivation

3.4.1 Uniform

A uniform flow has constant velocity components u and v in x and y direction respectively. By the relation from eq(5) and eq(6) this satisfies eq(7) and is therefore a solution

3.4.2 Sink and source

Consider a source flowing radially outwards with a steady rate. By finding how much is flowing outwards we can find the velocity components of this type of flow. By integrating the flow over a circle with radius r this yields:

$$Q = \int_0^{2\pi} v_r r d\theta = 2\pi r v_r \tag{15}$$

Derive flowrate equation?

Q is the flow strength. A flow which emits fluid isotropically i.e is uniform in all directions. This type of flow has the characteristics of a source and has the stream function:

$$\psi_{source} = \frac{Q}{2\pi}\theta \tag{16}$$

Needless to say, this is also a solution of the laplacian. The corresponding velocity components take the form:

$$u_{source} = \frac{Qx}{2\pi(x^2+y^2)} \tag{17}$$

$$v_{source} = \frac{Qy}{2\pi(x^2+y^2)} \tag{18}$$

Where eq(12) is equated with eq (15) for the radial velocity. The stream function satisfies the laplace equation eq(8). A flow which absorbs fluid isotropically is called a sink and has the same stream function as a source but with a positive sign:

$$\psi_{sink} = -\frac{Q}{2\pi}\theta \tag{19}$$

The velocity components share the same form as the source but with opposite sign which is expected.

$$u_{sink} = -\frac{Qx}{2\pi(x^2+y^2)} \tag{20}$$

$$v_{sink} = -\frac{Qy}{2\pi(x^2+y^2)} \tag{21}$$

3.4.3 Doublets

Here we derive the stream function equation for a doublet. This is where a sink and source coincide at the same point. By placing a sink in a point, a is small

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distance, (a, 0) with angle θ_2 and a source in (-a,0) with angle θ_1. This gives the stream function using the superposition principle:

$$\psi = -\frac{Q}{2\pi}(\theta_1 - \theta_2) \tag{22}$$

Now, take the tangent on each side:

$$\tan\Big(-\frac{2\pi\psi}{Q}\Big) = \tan(\theta_1 - \theta_2) = \frac{\tan(\theta_1) - \tan(\theta_2)}{1 + \tan(\theta_1)\tan(\theta_2)} \tag{23}$$

Further we rewrite $\tan(\theta_1)$ as $\frac{y}{x-a}$ together with $\tan(\theta_1)$ as $\frac{y}{x+a}$ and insert this into eq (19).

$$\tan\Big(-\frac{2\pi\psi}{Q}\Big) = \frac{\frac{y}{x-a} - \frac{y}{x+a}}{1 + \frac{y^2}{(x^2-a^2)}} \tag{24}$$

After cleaning up the equation reads:

$$\tan\Big(-\frac{2\pi\psi}{Q}\Big) = \frac{2ya}{x^2 + y^2 - a^2} \tag{25}$$

Taking the inverse tangent on both sides of and remembering that a is small distance gives small values in the argument of arctan. For small values of a gives:

$$-\frac{2\pi\psi}{Q} = \arctan\Big(\frac{2ya}{x^2 + y^2 - a^2}\Big) \approx \frac{2ya}{x^2 + y^2 - a^2} \tag{26}$$

Solving for the stream function yields:

$$\psi = -\frac{Qay}{\pi(x^2 + y^2 - a^2)} \tag{27}$$

Now, as a tends toward 0, Q will tend to infinity. In this case, let a $->$ 0 and Q $->$ ∞ so that there product is constant. This can be written as:

$$\lim_{\substack{a\to 0\\ Q\to\infty}} -\frac{Qay}{\pi(x^2 + y^2 - a^2)} = -\frac{ky}{\pi(x^2 + y^2)} \tag{28}$$

k is the strength of the doublet.
The stream function equation for a doublet reads finally:

$$\psi_{doublet} = -\frac{ky}{\pi(x^2 + y^2)} \tag{29}$$

The velocity components for a doublet is found from eq (5) and eq (6):

$$u = \frac{k(y^2 - x^2)}{(x^2 + y^2)^2} \tag{30}$$

$$v = -\frac{kyx}{(x^2 + y^2)^2} \tag{31}$$

Below are figures visualizing different streamline behaviors.

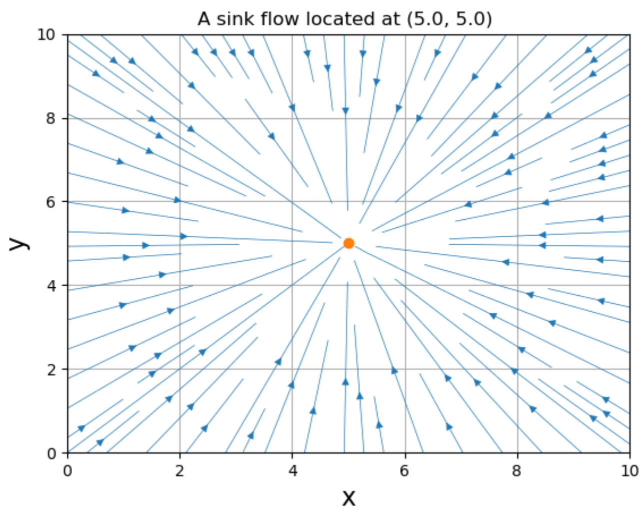

Figure 2: A solution of the laplace equation produces streamlines directed radially inward to it's origin (orange point). The velocity decreases inversely proportional from it's distance from the origin. This flow characteristic is called a sink flow. This flow is useful when representing end point of routes.

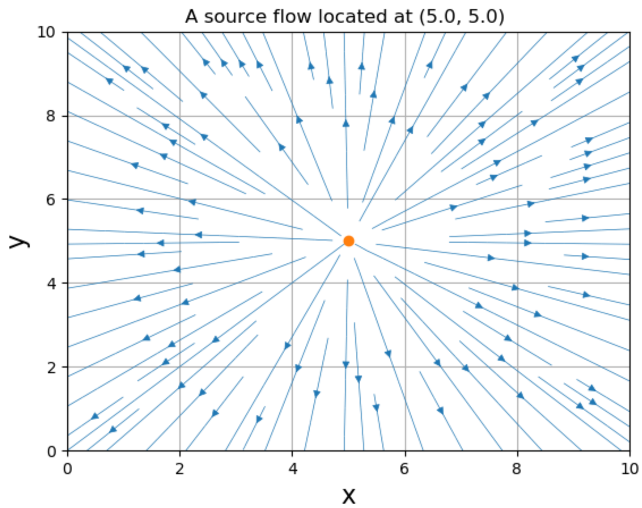

Figure 3: This flow characteristic is called a source flow. The velocity is points outward from it's origin (orange point). This flow is useful in starting points

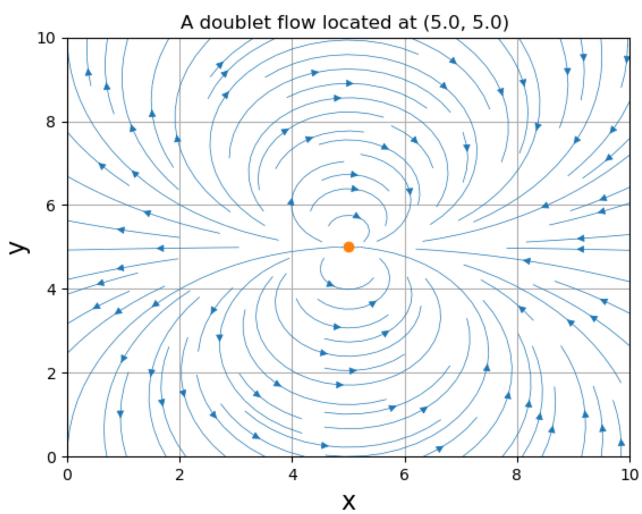

Figure 4: A doublet emerges from a sink and source coinciding in the point. A doublet represents objects i.e islands and land.

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