Using polar diagrams to obtain the optimal course of a sailboat in an open water environment
by The UpWind Project

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Abstract

Motorboat navigation does't differ much from driving a car. Once defined a free space where moving safely the problem of finding the optimal route between two points is simplified to a basic geometry issue. When talking about sailboats, variable factors such as the wind direction and water streams must be taken into account when talking about finding the **optimal path**. These factors have been traditionally obviated by other software products. The project described in this paper handles with the problem sticking to the scientific approach that defines and characterizes the UpWind Project.

The purpose of the UpWindPolar project is to design and implement an algorithm able to consider variable factors such as weather conditions and sail configurations and obtaining in real time the optimal path between two given points. This calculations have as an output the number and exact location of each tack, suggesting the sailors when to change the direction to optimize the sailing.

Keywords: Polar diagram, wind direction, tacking time.

1 Introduction

The UpWind Project was created in 2006 with the objective of creating intelligent algorithms for optimal route planning. We try to help leisure sailors to minimize the errors when planning sailing routes and suggesting them the **optimal path** for a set of given variables; often those variables such weather conditions or sail configuration can vary on-the-fly, making necessary the recalculation of this path in *real time*. We have defined an equation which differentiates us from the rest of the available software packages available in the market and makes this project an interesting research area for many scientific purposes:

$$O_p = S_p * i + F_p * i + Ms_p * i \tag{1}$$

This equation completes the traditional approach when using *euclidean geometry* to solve routing problems by adding to the classical premise "The shortest path between two points located in the same plane is the straight line", factors such as the speed and the user preference. In the equation 1, the *Optimal Path* O_p is a scale that relates the classical *Shortest Path* S_p, the *Fastest Path* F_p, crucial when dealing with sailing boats where changing the leg inappropriately might suppose staying still for hours until the next wind blow come, and the *Most Suitable Path* Ms_p where factors such as the most safe or the user preference are included in the calculations. The result is not the shortest, not the fastest and not the nicest, but the **optimal** way to go from a given origin to a giving destinations. The advantage of using this equation system is that makes easier to determine which factor is the most important for a given situation and allows to the recalculation of the Path in real time as many times as required.

Heretofore, the UpWind project has centered its efforts on finding an appropriate definition of **free space**. Roughly, we define *free space* as a subarea defined inside of the provided scope area where we can assure safe sailing in any condition. This area is obtained by applying a two-phase algorithm to the original cartography. In the first phase we isolate the areas that will remain constant in any conditions (ie islands) and in the second phase, we will obtain in real time areas that because its nature can change depending in external factors, like sandbands or streams during storms. Using sailing terms, free space is the area that is left when isolating all the land areas and dangerous objects from a marine chart.

In this occasion, we have decided to change the area of study, creating for this purpose the project we present in this paper: **UpWindPolar**.

The objective of the UpWindPolar project is to assume the existence of a trusty free space and research in this area the effects of the wind on a sailboat with different combinations of sails and hulls. This is, the generation of an algorithm that **optimizes** the sailing for a given *polar diagram* and variable weather conditions by reducing the number of tacks that the boat should execute in order to accomplish a route between two given points.

2 Research

At the moment and as introduced above the UpWind project is developing in parallel several parts of a navigation system. Traditionally all these parts are being built in existing code, either improving it or adding new functionalities to the system. For this project and due schedule issues, the project managerial has decided to implement a completely separated project, that can be developed aside and started virtually from scratch. For that reason the previous research on the topic is at this time limited.

Polar diagrams have been used by sailors to determine which is the fastest achievable speed for a set of sail configurations and wind speeds. A polar plot presents a visual representation of boat speed in relation to True Wind Speed and True Wind Angle, and at times to a apparent wind angle. Graphically the behavior of the true wind angle (TWA) is asymptotic, as shown in the Figure 1.

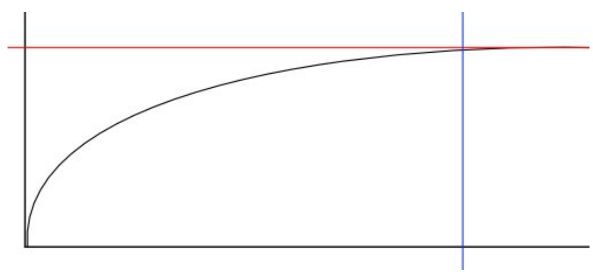

Figure 1: Relationship between boat speed (red), true wind speed (blue) for a specific TWA (graph)

For the full range of true wind angles, a **polar diagram** can be produced, where boat speed is measured in concentric circles. TWA are measured clockwise from the wind direction, and the plot of boat speed for specific true wind speeds.

In this project, team members should get familiar with these and other related concepts. Based on the data acquired from our test boat and the theoretical concepts learned during the research phase an algorithm should be designed and implemented, able to advise the sailor of the number and position of the different tacks to take in order to *optimize* the navigation between a given origin and destination.

3 Objectives

The objective of the UpWindPolar project is to create a test application, able to simulate the navigation of a sailboat under different changing wind conditions. For simplicity we will assume that the ship is navigating in an **open water** environment. In practice this means that the

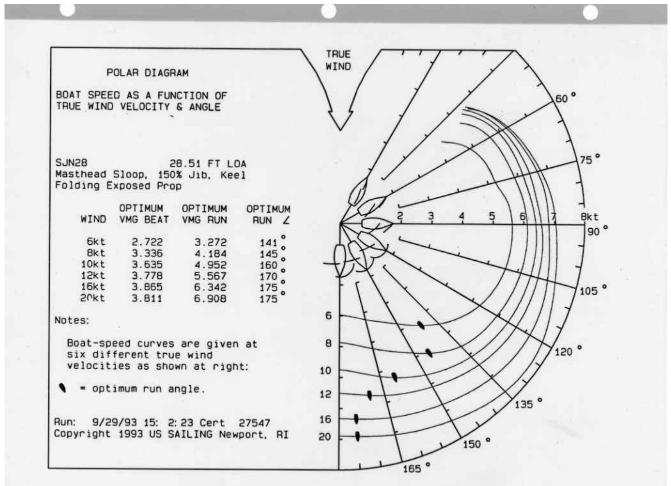

Figure 2: Classic polar diagram representation for a sailboat

sailboat is located into the **freespace** area obtained in previous research. The first objective is to create a polar diagram *standard*, able to create and load personalized polar plots for different sailboats. The algorithm will require from this data in order to obtain the results. I will describe each stage of the project with screenshot of an *hypothetical* program layout once the polars have been inputted.

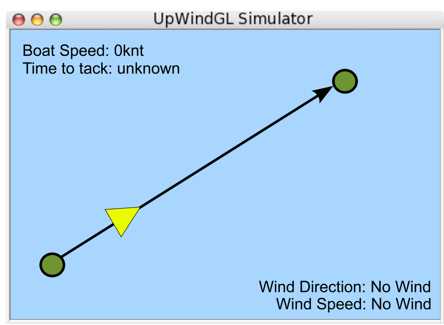

Figure 3: Base case, a route between two points without wind.

The figure above represents the first stage of the development. In green, an origin and a destination are displayed; the red triangle symbolizes the sailboat and the arrow represents the **optimal** route between the given origin and destination. Notice the absence of wind and the speed of the boat in the simulation. The next figures display a conjectural situation where the wind is changing.

Figure 4 presents typical sailing scenarios, when some wind is applied on the sailboat the program calculates, based on the polars which is the best route and the tacking points that the boat should follow in order to complete the route in the optimal way; meaning in the minimal time, obtaining the fastest speed before each tack and minimizing its number. For this simulation the wind speed and its direction are constant during the execution of the program and are hardcoded in the algorithm. The discontinuous line represents the basic course.
The final version of the simulator (Figure 5) allows the meteorological factors to change interactively. In the image we can appreciate the mouse pointer indicating the direction of the wind. In this case, the algorithm will recalculate the course in real time, proposing a track for set of wind direction and speed.

As a disclaimer, this screenshots are based on theoretical information, the final application layout and options can vary following the team needs. The possibility of including another

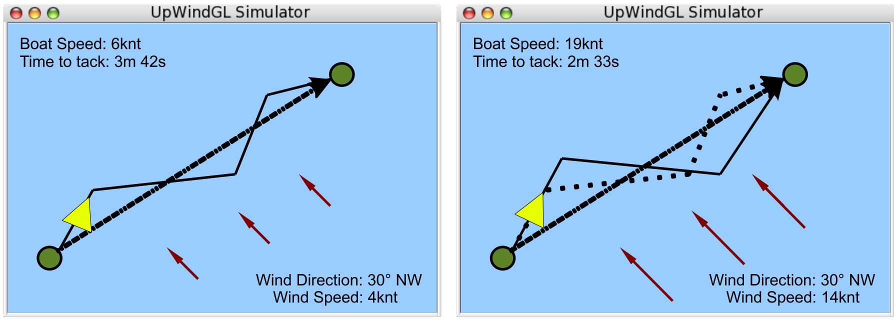

Figure 4: Simulations with variable wind speed.

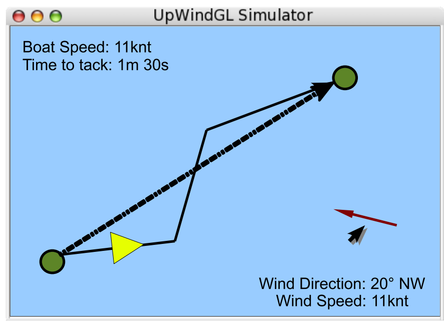

Figure 5: Base case, a route between two points without wind.

weather factors in the algorithm such as water streams and drifts.

4 Methods

The department demands a total of 300 hours per member. The project will be developed by a 3-4 member team that should be able to complete the objectives in a 20 week time frame. The team will have access to the research lab IT338 and several Windows/Linux/Macintosh machines for testing and development purposes. Typically the time frame contains four main control meetings (commonly named PSG[1]) and weekly meetings with the project supervisor. A project manager will be elected within the project members to control the workload and to make the environment to resemble as much as possible to a real industrial situation keeping it neat and **professional**. If none of the members wants to take the responsibility of the management, all the members will rotate as managers. The team will meet weekly with the supervisor and will inform briefly about the situation and the following steps. For the PSGs, a formal presentation and demos should be prepared in order to inform the meeting guests about the nature, status and future of the project.

A SVN server is available for the project, and also several charts corresponding several areas of the Finnish coast. The development will be done under Eclipse and Java will be the language of choice; external libraries are allowed, but its licensing system should be consulted before adding them to the code. LaTeX will be used for internal documentation and also for the final report. This server is maintained by Victor Arroyo, so any necessary software can be installed if required. This mainframe acts as a wireless access point as well, so connections can be established directly from the project member's laptops, either from the lab or from the radio range of the access point. The workstations located in the laboratory have also a wired network to the mainframe so SVN services can be used from any of them. At the moment the lab is

[1]Project Steering Group meetings

equipped with several Linux, Windows and Macintosh machines; those machines have installed all the software required for the project.

Keeping the nature of this project, the project supervisor will be open for any suggestions on the topic, methods and results. All the decisions will be taken during the weekly meetings and confirmed during the PSGs.

5 Results

The final result of the project will be the wind simulator with the exposed functionality:

- Definition for a personalized polar plot format.
- Option for using personalized polar diagrams.
- Possibility for running simulations using different, variable wind conditions.

Both objectives can be taken as separate problems, but with the appropriate strategies they both can be tackled together and achieved successfully as one. As exposed before, each member of the team should complete a total of 300 hours of work to get the course done. The project manager should take care that the work load is balanced project members and that they get tasks related with their area of expertise or preference (inside of the possibilities). There are several documents that should be presented before, during and after the development, briefly they are:

PSG Agenda Should be sent at least three days before the actual PSG meeting, should attach also all the documents to be presented during the meeting. i.e. project plan + project status, time schedule and a list of topics to be discussed in the session.

Project Plan Contains the list of tasks to be developed, the estimated time schedule, list of deliverables, glossary and any other information of the project.

Final Report Basically is a document that includes the final version of the project plan and the conclusions obtained during the development: lessons learnt, comparison between the planned objectives and the obtained results and a compendium of knowledge earned about the area of research.

Technical Report Technical description of the development, set of methods coded, short user manual and future of the development. This document should be an interface for the following projects.

Before the project is started the supervisor will give a complete description of each of them, detailing deeply their content and the time when they should be delivered. At the end of the UpWindGL project, a CD should be delivered with all the documentation and code developed during the time frame.