Abstract - The origin of navigation is based on the development of sailing vessels. The art of capturing the force of the winds for navigation emerged independently in different parts of the world. During centuries, up to the present, sailing not only went from having maritime transport as the main objective, but also turned into a sport and a hobby.

Through technological evolution, nowadays, we have different devices and weather forecast to help safe navigation. The huge increase in mobile devices and their high usage led to the development of new navigation software that is accessible to everyone.

Although this development has brought many advantages to sailing, in particular the support that is given on high seas, small vessels experience difficulties in navigating estuaries with strong currents, strong winds, and navigation restrictions (channels, etc.). Thus, from the data provided by Maretec (IST) and MeteoTécnico, the BayNav application was developed. It represents the variables wind, current and the simulation of a route. We created a web application, using an iterative and incremental approach.

In the following two sections we will present some background about sailing basics and terms, and previous works similar to our solution. Additionally, we will present our solution, functionalities, development approach and evaluation of results. Lastly, we will draw conclusions about our work, and show our contributions and some examples of possible future work.

BACKGROUND

Before all else, it is important to understand sailing basics to summarize some important information and terms about sailing navigation.

Although design and construction of a vessel is one of the main focuses, everything is combined with highly sophisticated equipment that nowadays allow sailors to follow an optimal route to destination. From the astrolabe till now, with the evolution of technology, we can monitor every moment of the navigation through a simple mobile device. The Automatic Identification System (AIS) [2] [3] [4], is a short-range monitoring system used in ships and
vessels traffic. It is mainly used to avoid collisions between vessel and monitor vessel traffic. We also have Global Positioning System (GPS), MMSI, VHF radios (the radios commonly used at sea to communicate with ports), bridges, nautical charts, devices showing nautical charts, on-board computers or applications for mobile devices that can tell us not only the best route to follow but also the safest moments to navigate in the past, present and future, and for this work we need weather information and other variables such as currents all combined together [5][6][7]. It is also in this last point that our project is focused, because due to the evolution in the systems of weather forecast, it is nowadays possible to check meteorological and maritime information through different visualization techniques, although there are some problems with simultaneous visualization and problems with the visualization on mobile devices, our main goals.

**RELATED WORK**

We searched for previous related works, having in mind our main goals. We specifically searched for previous works related to sailing such as existing software, frameworks, map providers, different types of visualization of meteorological and maritime variables related to our project.

**I. Existing Software**

We identified three main softwares: Action Forecast\(^1\), Windy\(^2\) and Navionics Boating\(^3\). They are three different types of applications. Action Forecast is an online platform that presents meteorological and maritime information all over the globe. Windy is also a software that is focused on the presentation of meteorological and maritime information, whose main objective is to give the user a customizable interface and support both desktop and mobile devices. Finally, Navionics Boating, is an application focused on automatic route tracing and the display of nautical chart information. Analysis of these applications confirmed that one of the biggest problems of these softwares are screen size adaptation and the correct presentation of the meteorological and maritime information. We also identified that none of the softwares has the option to combine different variables simultaneously, one the objectives of our project. We aimed to combine all the advantages given in this three softwares and add some other features to support and solve problems for local domains such as the Tagus River Estuary navigation.

**II. Frameworks and Map providers**

The visualization of meteorological information was one of the main objectives of this work. The representation of the variables is superimposed on a map and it was necessary to analyze different map providers and different frameworks. The popularity of digital maps and the use of digital mapping frameworks has grown rapidly in recent years. While Google is still the market leader in map providers, there are now new companies in this sector and different ways to present and interact with a map. The map providers that we analyzed based on functionality and documentation were Google Maps\(^4\), Openstreetmaps\(^5\), CartoDB\(^6\) and Here\(^7\). As our project is also related to sailing, we analyzed map providers that can display nautical charts as Navionics\(^8\) and Transas Maps\(^9\). It was also important to study different frameworks that can display map information to visualize meteorological and maritime variables. The frameworks analyzed were Leaflet\(^10\), Mapbox\(^11\) and OpenLayers\(^12\).

**III. Wind and Currents Symbolic Representation**

Visualization of weather predictions is often done using color ranges that represent the expected variation around a value. Parameters represented by vectors such as wind, velocity and direction are usually fluctuating, and visualization methods may be limited. In our project we analyzed three wind and two water current representations.

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1. [www.actionforecast.com/](https://www.actionforecast.com/) (last access on 03/04/2019)
2. [https://www.windy.com](https://www.windy.com) (last access on 03/04/2019)
3. [https://www.navionics.com](https://www.navionics.com) (last access on 03/04/2019)
4. [https://www.google.pt/maps](https://www.google.pt/maps) (last access on 03/04/2019)
5. [https://www.openstreetmap.org](https://www.openstreetmap.org) (last access on 03/04/2019)
6. [https://carto.com/](https://carto.com/) (last access on 03/04/2019)
7. [https://wego.here.com](https://wego.here.com) (last access on 03/04/2019)
8. [https://www.navionics.com/fin](https://www.navionics.com/fin) (last access on 03/04/2019)
9. [https://www.transas.com/](https://www.transas.com/) (last access on 03/04/2019)
10. [https://leafletjs.com/](https://leafletjs.com/) (last access on 03/04/2019)
11. [https://mapbox.com/](https://mapbox.com/) (last access on 03/04/2019)
12. [https://openlayers.org/](https://openlayers.org/) (last access on 03/04/2019)
Synoptic and Isobar Representation of the wind

A line drawn on a weather map connecting points of equal pressure is an isobar. Isobars are generated from mean sea level pressure measurements. The pressure pattern is important because we can use it to know where the wind blows and how strong it is.

Wind Barbs

Wind barbs are a simple and convenient way to represent both wind speed and direction in a compact graphical form. Vectors also work to some degree, but it is more difficult to discern the magnitude when viewing vectors. For this reason, meteorologists prefer the use of wind barbs. Figure 2 shows how to read a wind barb. Meteorologists are also used to nautical miles per hour (knots) for magnitude.

Current Representation with arrows

The representation of currents by arrows is one of the possible solutions for the representation of currents. Its rationale is:

- The current direction is the direction shown on the map according to the current direction.
- The current velocity is represented by a pop-up rectangle when the cursor hovers over the arrow (velocity expressed in knots).
- The size of the arrow shows if the current is stronger or weaker. The larger the arrow, the strongest the current.

Current particles

Current particles are similar to Wind particles.

Summary

In this section, we mentioned and described several related works, map providers, wind and current representations. However, neither of them simultaneous accomplishes all our goals. In other words, we had to found out the best way possible to combine all the related works in our application. We secured the help of users that have some experience in sailing and often use different software or nautical charts for navigation. We combined different map providers and wind and currents representations together. After this we developed a solution.
**Solution**

The final result of this work was a web application, BayNav, capable of combining the representation of meteorological and maritime variables, wind and currents, so that it can be possible to visualize both simultaneously and individually, and also represent a route. BayNav was developed taking into account that the user interface must adapt to different screens and resolutions. To simplify and focus on our goals we started from the following assumptions:

- **Internet available** – we assume that the internet is available on all mobile devices when the user is sailing, because the application will be used in estuaries, rivers or lakes and the use of a mobile internet provider can be a viable option since the distance to land will not imply total loss of internet connection.

- **Covered area**: to simplify the project and given the estuaries, rivers, lakes and small bays in Portugal, we focused on the area of the Tagus River Estuary. This is the area that BayNav covers, with the data provided by Maretec (current) and MeteoTécnico (wind).

**Architecture**

The systematic view of the system architecture can be seen on Figure 5 where we can observe the components of the application.

From Maretec and MeteoTécnico Data Servers:

- The BayNav server shall extract and collect wind speed and direction data and current velocity and direction of the areas covered.

BayNav works as a client web application, so that it receives data and queries the Baynav Server. Once the Baynav server has collected the required data from Maretec and MeteoTécnico servers, it will be able to serve wind and current information in the target region of the application at any time and is able to answer requests from the application relative to a location, wind direction, with wind speed, current direction and current velocity.

Front-end displays the layout of the maps and commands for the interaction with the representation of wind and current and the simulation of routes.

As already mentioned, Baynav is a web application because this approach eases development for all mobile and desktop devices and reduces development time up to half. The framework chosen for the presentation of maps and on which the application is based, Leaflet, is a Javascript-based library that was designed for simplicity, performance and usability that is supported by most mobile platforms, as well as desktops, supporting also HTML5 and...
CSS3. Another reason for choosing Leaflet is that it allows the integration of various extensions and libraries such as Leaflet.windbarb\(^\text{13}\) and Leaflet.CanvasLayerField\(^\text{14}\) that can be extensible in a simple way as layers of image and "tiles". Leaflet’s overlapping visualizations, map interactions, data overlays, and integration with other third-party systems, fall within the frame of our project. In a first phase of the development of the application we took into account the general architecture of the application. Every day the simulators of Maretec (Mohid\(^\text{15}\)) and meteoTécnico produce files with forecasts of the following days. It was not our objective to check the existence and availability of such data. Maretec and meteoTécnico provided two distinct datasets from December 28, 2017, which we used to demonstrate our concept. With the data provided by Maretec and meteoTécnico we did data preprocessing (extracting and converting data) to integrate the data with Leaflet libraries Leaflet.windbarb and Leaflet.CanvasLayerField. The BayNav application was installed on a private server at hawking.tecnico.ulisboa.pt, at the public address http://hawking.tecnico.ulisboa.pt/BayNav

Baynav makes it possible to:
- Zoom in and zoom out the application display.
- Reset, the visualization to its default location.
- Show Fullscreen.
- Use a time picker, to change the current time of the day and display its data.
- Select different map providers.
- See wind and current information in any location of the Tagus River Estuary.

**CURRENT REPRESENTATION**

**Current Particles**
By default, the application will present current by the movement of particles.

**Current Color Velocity (Static)**
This option allows users to view the current through color variations. With this alternative view, the user will have a better perception of which areas of the Tagus River where there is a stronger or weaker current, based on the color scale shown in the bottom of the BayNav application.
**Current (with arrows)**
This option allows users to view the current by standard arrows, that show current direction.

**Wind particles**
The application shows current by moving particles.

**Current Particles with Colors**
This option allows visualizing the current through the movement of particles with the addition of colors to the particles depending on current velocity.

**Wind Color Velocity (Static)**
This option allows users to view the wind with a color scale. As for current, it is also possible to visualize its scalar field using a color scale.

**Wind (with arrows)**
This option allows users to view the wind through standard arrows that, like for current, allow the wind to be visualized through standard arrows that indicate the direction in which the wind blows.
ROUTE REPRESENTATION

For the representation of the route that a vessel should follow, a very sophisticated solution was not developed since the representation of the meteorological and maritime variables was the focus of our project. However, in our application it is possible to represent a fictitious optimal route. The blue route the application displays corresponds to the route recommended by the application and a vessel with a wind arrow, constantly updated, showing the vessel’s location (see Figure 15).

Figure 15 - BayNav Route

DEVELOPMENT

Our goal was to build an application with a graphical user interface that should be intuitive, easy to use and learn. In order to explore and compare different design alternatives in a short period of time, we followed an iterative and incremental design approach. We created storyboards of the main tasks in order to define the different states of our application, and then, incrementally, added more complexity, going form low-fidelity and non-functional prototypes to the final product. More specifically our steps where:
1. Define main tasks;
2. Create storyboards;
3. Create low-fidelity non-functional prototypes (paper prototypes);
4. Evaluated low-fidelity non-functional prototypes;
5. Create functional prototypes
6. Improve functional prototypes and consider the feedback from evaluation;
7. Evaluate functional prototypes.

The first step in our solution development process consisted of defining the main tasks and creating storyboards for them. We started with storyboards, since, according to [9], they can show the sequence of steps required to support tasks, allowing to see and understand how our application will flow and react to user’s interaction. We considered that the most important tasks of our solution would be: obtain the values for a given time of the day for the wind and current and change map layers. We considered these because they are the most critical: either they are more complex or more frequently performed by the user.

As a second step in our solution development process we created low-fidelity and non-functional prototypes. Since our main goal is to display meteorological and maritime information both on desktop and mobile devices, we started designing our application view for mobile devices screens. After this, having in account our main tasks defined while designing storyboards, we chose to implement our Wind and Current display functionalities and added the different map layers. At this stage we wanted our application to be available to everyone, independently from where users are, so we decided to design our low-fidelity and non-functional prototypes in English.

After having created and evaluated the low-fidelity nonfunctional prototypes, we started to develop the functional one. Considering that our goal was to create an intuitive, easy to learn and use application, we chose to start implementing the interface functionalities iteratively, and only after that we created a simulation of a route.

As a final step of our development process we evaluated our solution in terms of usability and utility.

EVALUATION

Our solution evaluation consisted of two different kinds of evaluations. One was the evaluation of our interface in terms of usability and utility and the other to test our solution in sailing conditions.

Concerning usability and utility, to obtain early feedback from the users about how to build our application in an intuitive way, easy to use and learn, and reduce the number of modifications in our final application, we carried out three evaluation phases. Two took place during development (evaluation of our low-fidelity non-functional prototypes and formative evaluation of our functional prototypes), and the third one was performed after completing our solution, to evaluate the application sumatively in terms of usability and utility.

During both low-fidelity non-functional prototypes and formative evaluation of our functional prototypes, we asked users to perform some tasks, while thinking aloud, and classify these tasks in terms of ease. Additionally, at the end of the evaluation we asked users general opinions, as well as task classification. We were also able to find out which aspects were more difficult or less intuitive in terms of the users’ perspective. We were also able to identify possible improvements to be introduced to our application.
In our final solution regarding usability and utility we conducted usability tests, and tests to evaluate our application in actual sailing conditions. We choose both because these two tests complement each other, since they allow us to assess both usability and utility. In the final evaluation stage, since we wanted to clearly evaluate our solution efficiency, effectiveness and user satisfaction, we chose to collect data from each test and treat them statistically. We chose to collect time taken to complete each task, number of errors, and quantity of tasks successfully completed, and treat them statistically, since, according to [6], these are the most commonly used. Besides these measurements, to assess mostly efficiency and effectiveness, we also asked users to answer a usability quiz, to evaluate user satisfaction. To make sure our tests were all performed under the same conditions, we defined a test script. From collected data, more precisely number of tasks successfully finished, time spent performing each task, errors made, tasks classifications and users ‘satisfaction, we can conclude that there is room for improvement, since some mistakes were made by users and some tasks were not classified as easy or very easy by all users. However, all tasks were successfully completed by all users, users were able to recover from errors and overall users’ satisfaction was relatively high, at 83.16. So, in our opinion, we were able to create an intuitive, easy to use and learn solution that also allow users to recover from errors. We also conducted another test under sailing conditions. Our goal was to find users’ opinions about our application while interacting with it in open air conditions. We chose users that corresponded to our users target group, interested in sailing, and we conducted intense illumination tests, because usually, when we sail, the light reflection by screens of mobile devices can affect the whole visualization and users may sometimes barely see screen contents. With this test we concluded that in high light conditions, for example at 12:00AM on a sunny day, we confirmed that map providers with lighter colors are most effective at displaying the BayNav’s information visualization.

CONCLUSIONS

Sailing is an art. The development of navigational software is one of those areas that intends to inform / advise a vessel in estimating routes given the meteorological and maritime conditions at the moment or in the near future. Currently the support given to offshore vessels is very reliable. In the case of the navigation of sailing vessels in small estuaries, small bays and lakes, currents, winds and restrictions (channels, rocks, etc.) have a great impact. The reduced support given to such situations demands more accurate forecast data and route planning should focus mainly on wind and current. We began by analyzing the existing technology for the construction of BayNav application, not forgetting that the goal was a solution that would adapt to different device screen sizes and orientations. We created an appealing and coherent design for the entire application, allowing easy and effective access to the information that users are looking for. We followed an iterative and incremental approach, with cycles of design, testing, assessment and redesign, repeating as many times as necessary for the prototype to respond to the specified needs.

BayNav allow us to access from any computer or mobile device, connected to the Internet using only a standard browser without any prior installation, and adapts to any resolution through the responsive mechanisms of a web application [10].

A group of fifteen users tested the BayNav application. The users were presented with twelve tasks to perform using the BayNav application and their performance was evaluated through quantitative measures: time the user takes to perform the task, the number of errors committed and the level of satisfaction (SUS questionnaire) to the perform such tasks. The usability of the system was considered excellent, reaching an overall score of 83.16.

CONTRIBUTIONS

Our main contributions with this work were:

- The creation of an intuitive, easy to learn web application, BayNav, that merges maps, wind, currents and route visualization.
- Wind and current variables are represented simultaneously and individually by BayNav.
- Data processing and transformation for the variables wind and current.
- Basic route representation.
- Web Application for estuaries, lakes or small channels.
- Baynav is available for the majority of mobile devices and also desktop devices.

FUTURE WORK

We identified some improvements that can be done to our work. More specifically, some examples are:
In the general architecture of the application we present a partial solution that starts from the one-day simulation whose data is already properly analyzed after the validation of the different fields by Maretec and meteoTécnico. As future work it would be necessary to create a data processing job, with three subprocesses, i.e., it would be necessary to create a subprocess that daily verifies the availability of data from the two data providers. Other job would validate the fields from the two providers. And one final job would convert the data for the Baynav client application to use.

- Daily update of meteorological and maritime data.
- Definition of an algorithm to plot routes based on winds, currents and bathymetry.
- Definition of a polar diagram of a vessel to draw a route based on that information.
- Definition of a smooth coastline representation
- Improve the extraction and conversion time when preprocessing data from Maretec and meteoTécnico.

REFERENCES


