– COS 426: Computer Graphics Spring 2022 –

Intercollegiate Sailing Racing Simulator

Final Project Report

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Abstract

Our project simulates the effects of different forces affecting the 420 class racing dinghy in a real racing environment. The project contains an implementation of a graphical user interface depicting a Z420 boat with various forces acting on it. The user is able to control the wind speed and direction in order to manipulate the speed and direction of the boat, which in turn is then dependent on the various other forces acting on it, including wind pressure, buoyancy, and water pressure on the centerboard. The user is also able to control the position of the mainsail with respect to the hull in order to further manipulate the effects of the forces on the boat.

Introduction

Goal

As members of the Princeton Sailing Team, we were interested in building a highly realistic sailing simulator which would accurately simulate the dynamics and physics involved in the process of racing a real double-handed dinghy. For building out our MVP, we focused on basic maneuvers of the mainsail (i.e trimming and luffing), and how these maneuvers would affect the speed and direction of the dinghy in atmospheric conditions such as current, wind pressure, and weight distribution on the boat. By moving the sails against these forces we can affect how fast the boat moves, as well as its heel and direction relative to the wind. Our original plan for our stretch goal was to put this boat simulator into the graphical context of a simulated college race course, by implementing a number of racing features, including more advanced user interaction and gamification such as rudder controls, as well as more realistic wind noise which mimics the oscillations and pressure you would get from a real race, and current/tidal shifts. The purpose of building this is that we thought it would be a fantastic learning tool for college sailors to simulate learning to control a dinghy in realistic racing conditions. At the most primitive iteration of the simulator, the user would see the results of their actions displayed in the form of the speed and direction which is output in a graphical display, and be able to make adjustments accordingly.

Previous Work

We are fortunate to cite two existing works which have involved some aspect of sailing simulation, either by manipulating external conditions and displaying the results graphically, or in the context of also teaching real college racing by providing a race course experience in the form of a gamified virtual simulator. The former is in reference to the Sailing Simulator built by COS 426 grad-turned-TA Caio Costa in Spring 2021. Costa's sailing simulator contains realistic rendering of the environment such as waves, sky, and nearby land masses, in addition to a rendering of a small sailboat. The GUI contains many different external factors that can be controlled by the user, such as the wave height, wind speed, and drag, and changing these factors in turn changes how the boat travels along the water and the dynamics of the sail. The latter is a successful native app which easily falls into the realm of eSports, and has been hugely successful in recent years in teaching young and amateur sailors how to race dinghies effectively. By focusing more on directing the boat up and down a number of different race courses, implementing real racing maneuvers such as tacks, jibes, and spins, real racing conditions are simulated combined with oscillating winds and variable current. Our aim was to implement a basic gamification which toys the line between the two aforementioned implementations: for our MVP we would focus more on implementing and teaching sail control and its effects, before going on to thinking about broader race course strategies such as those implemented by Virtual Regatta Inshore. Therefore, our app would be able to fill in the niche demand of teaching more focused sail handling, but still in the context of a real racing environment.

Approach

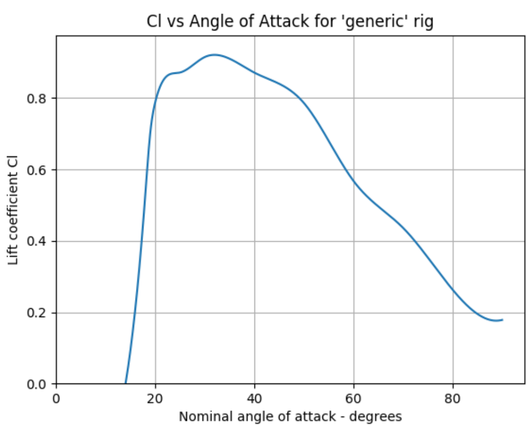
Our approach was to use Assignment 5 as the base for the cloth in our project. We thought this would be a good idea because this assignment implements a cloth and directs variable forces on it in order to induce natural movement of some kind. Since the main sail is also a cloth impacted by various forces working in tandem in realistic conditions, we took inspiration from the setup of Assignment 5 in order to build up our simulator. We extended the assignment in our implementation of the rest of the boat. In order to simulate the forces to produce realistic results we consulted with papers demonstrating phenomena such as the flow of wind over the sail, and also took into account other forces acting on the boat, such as the drag through the water and the water pressure on the centerboard, and the buoyancy on the hull. We also calculated the torque which would be applied to the hull as a result of the forces acting on it. The depiction of the boat is based on a real Z420 dinghy, and we decided to build this to scale with a 1:1 ratio between Three.js units and meters. We chose to do this in order to make the boat look and feel proportionate when moving and reacting to the forces applied on it.

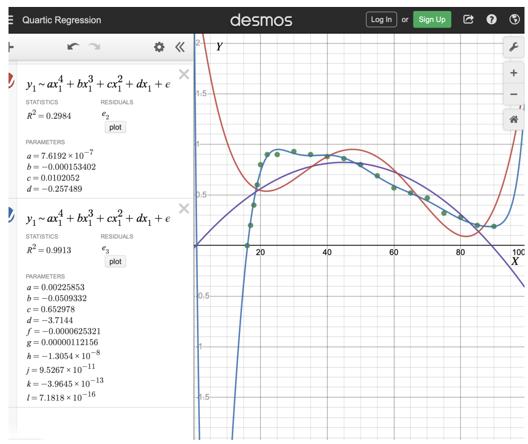
Methodology

The main components that we had to implement were the forces acting on the boat, and then the resultant reaction of the boat to these forces in the form of changing position and appearance.

Forces

In order to implement the wind pressure as it acts on the sail, we consulted with sources detailing the flow of the wind over the sail and the lift coefficient for the sail depending on the angle of attack. We recreated the graphs detailing this phenomena, shown in the figures below, and interpolated the equation which we would use to calculate the resultant force perpendicular to the surface of the sail. This resultant force we calculated for each ‘particle’ on the surface of the sail (the particles we implemented as done for the cloth in Assignment 5), and then used Verlet Integration to get the net force that this would produce at the luff and the clew of the mainsail (where the sail attaches to the boom and the mast, transferring the wind pressure force to the boat to make it move).





Besides the wind pressure, we also calculated the water pressure on the centerboard of the boat. In order to make the boat move forwards, the forward force responsible is a vector sum of the wind pressure force and the resistance force of water on the centerboard which is perpendicular to the body of the boat. Additional forces which we implemented were the force of gravity and the force of buoyancy (calculated by assuming the weight of the boat along with the density and volume of displaced water), as well as the drag produced by the boat moving through the water. Our implementation of the forces is heavily inspired, yet again, by Assignment 5, and how it uses Verlet Integration and summation over all of the forces in order to produce one resultant force which makes the boat move in a certain direction. In addition to force we also calculated the torque applied to the boat by utilizing the lever of each force along with its magnitude. This would prove to be important in visualizing the effect of the forces on the body of the boat, as explained in the next section.

Boat Reaction

We used the geometry and mesh classes of the Three.js library to build out the structure and components of the dinghy. As mentioned before, our dinghy and its components are true to scale, as we constructed them as separate geometries and components. Each component has the same rotation and translation applied to it as a result of the forces, and therefore all the components ‘move together’. As with the poles and the cloth corners in Assignment 5, the sail is tethered by a position locking function to the end of the boom by its clew, and to the length of the mast by its luff. The torque creates a rotation effect and the resultant force creates a translation effect which is applied to each component of the boat in order to simulate movement which can be seen in on the display.

Feedback on Speed and Direction

As mentioned previously, the user can interact with the GUI to manipulate the wind pressure and the positioning of the sail. The result of these efforts is given in the form of another graphical interface displaying the speed the boat is traveling at, and the direction relative to the wind. There is also a marker depicting where the wind direction is at any given point.

Results

We measured success as seeing the boat move in the correct direction with the correct speed given certain forces acting on it, and the trim of the mainsail. Initially, to see the cloth moving correctly as a response to the wind pressure was also a point of success as we continued to iterate and expand on the features of the project. We tested different wind pressures, and also different mainsail trims, in order to see if the results for speed and boat movement direction were variable in the correct way.

Discussion

We think the approach we took is promising. We were able to model several different complex physical phenomena to actually see our boat react and move in our simulated environment as a real boat does, by only adding natural forces to it. It was also responsive to our controls in the same way that the boats we actually sail in are. One design choice we made was to lock the perspective of the camera and let the boat move freely in our environment, whereas an alternative which might work better for gamification would be to fix the camera perspective relative to the boat. However, we liked our approach, because we could see the real speed and direction of our boat very easily. In terms of follow-up work, we could make our controls more analogous to sailing a real boat by creating a GUI to turn a tiller, or drag a rope inwards to control the angle of the boat and sail. We could also implement buoys at fixed positions for the user to sail the boat around. During this project, we learned a lot about how complex the physics are for phenomena such as lift and fluid flow. Originally we planned to integrate the effects of moving air and water particles on each point on the sail and boat, but we had to abstract these using empirical data we found because we learned that it is incredibly computationally complex and difficult to model fluid flow, and we realized it would be beyond the scope of our project.

Conclusion

Overall we are pleased that we implemented the MVP with the desired results. We managed to create an interactive simulator which is based on the real-life mechanics of controlling a racing dinghy in race conditions, by implementing the forces and resultant boat movements, as originally planned. In future renditions of this project, it would be ideal to ‘beautify’ the interface, introduce more forces and ways to interact with them (for example variable weight in the boat, and dynamic center of mass), and introduce more complexity into the boat handling (i.e introduce the jib or headsail and the relevant forces on it). With respect to boat handling, it would also be ideal to create a rudder and to take into effect the consequences of mechanically maneuvering the boat using it. We think that we did a good job, overall, covering all of the most essential forces which drive the boat in realistic conditions, and introducing further complexities would make the experience even more useful and realistic. Of course, it would also be great to implement the stretch goals introduced earlier. These include more the implementation of a race course, and more challenging (but realistic) racing conditions such as oscillating winds, puffs, and lulls. These could be introduced by way of noise algorithms, and implementing them would further aid the learning process. A currently implemented feature that would be improved upon is by making more precise the calculations stemming from the wind pressure interacting with points on the mainsail. We could delve deeper into the physics behind the lift force here, and slightly adjust the shape of the main sail (and also head sail) to better replicate the shape of the sails on the 420 class dinghies (which are not perfect triangles!) in order to make this even more accurate.

Contributions

Aliya: Construction of boat geometry and meshes in Scene.js, implementation of some global parameters, and implementation of forces and their impact for the centerboard (keel). Implementation of certain sail behaviors like locking. Graphical display for speed and direction. Sections of the write up.

Anna: Construction of cloth sail object and forces on the sail, deriving lift equations and modeling lift and wind. Boat class file — implementing torque and force handling, implementing buoyancy force, gravity force, forces exerted by sail on the boat, as well as translation and rotation on the objects that make up the boat. Implemented water surface.

Works Cited

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