Autonomous Marine Vessel

A project journey

THRACE MARINE
WHERE GREEN MEETS BLUE

motus
DESIGN GROUP

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Thrace Marine's Hydrogen Future

Thrace Marine is a start-up company developing a hydrogen-electric recreational vessel, 8 metres in length. Early in the design process, Thrace Marine identified that fully electric marine vehicles have opportunities for features that would be difficult or impossible to implement in a typical gasoline powered boat. The motor response time and control accuracy of a fully electric drive system opened the possibility of an autonomous drive system, similar to Tesla's AutoPark System.

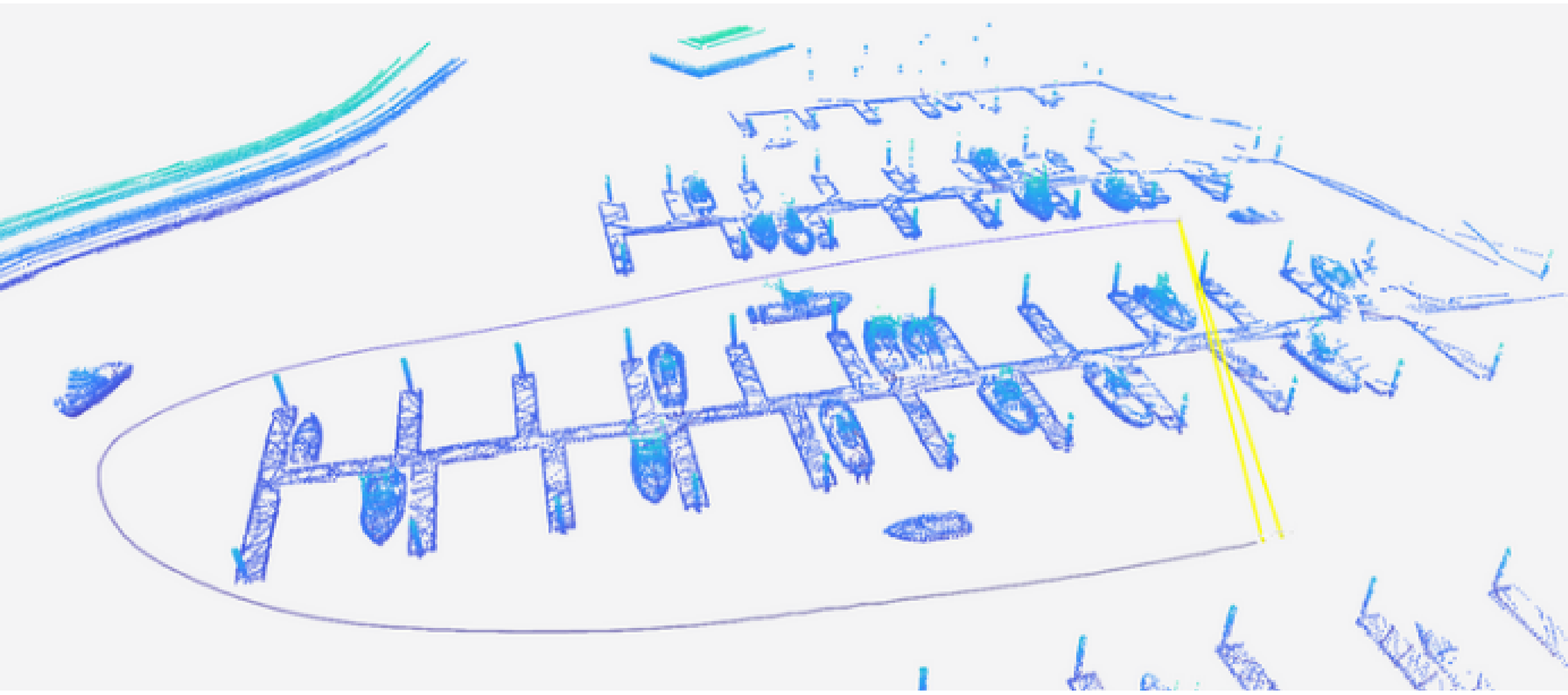
Navigating a boat can be unintuitive and challenging; boats have a tendency to drift on top of moving water, power delivery from the stern is prone to oversteer, and the lack of a rudder reduces control. In inclement weather, the system becomes even more difficult to control as wind, current, and waves all affect how the boat handles. An autonomous navigation solution has the ability to incorporate measurements of all environmental conditions and plan a path that can be predictive, rather than reactive.

The Need

The majority of marine accidents happen in marinas, with inexperienced owners at the helm of large boats that are difficult to manoeuvre. The majority of accidental damage in marinas is caused by these inexperienced owners hitting the wharf or other vessels in the marina. The autonomous drive system in Thrace Marine's hydrogen electric vessel focuses on preventing these accidents and saving money by fully automating the parking process.

There are currently no autonomous drive solutions for boats. In order to determine the feasibility and expected performance of an autonomous system, Motus Design needed to simulate the performance of an autonomous vessel with current sensor technology. Simulation environments can reliably predict performance of a physical prototype for a fraction of the time and cost.

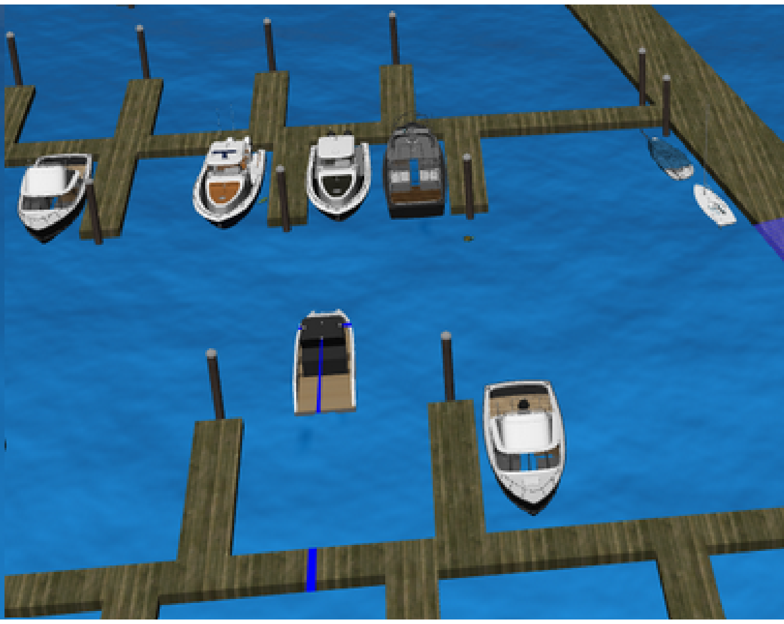
The goal of the first project phase was to simulate and test a full autonomous vessel system. The project would vet performance in order of highest risk to the feasibility of the full system. Controls are most critical to autonomous systems, followed by path planning, and then perception. Once all the subsystems were vetted and tested, the integrated system would be created and evaluated for key performance metrics.



Initial Analysis

Initial work focused on vetting available robotics technology and establishing which toolchains, models, and software infrastructure could be used for Thrace Marine's application. In robotics, there is a challenge separating hobbyist tools and materials, from legitimate industry-level products. Many tools are created as open source, however, once they begin to show real promise of cutting edge progress, they are often taken private. Motus selected ROS (Robot Operating System) as our middleware due to its open source code, longevity in the robotics community, professional standards, and compatibility with many other tools

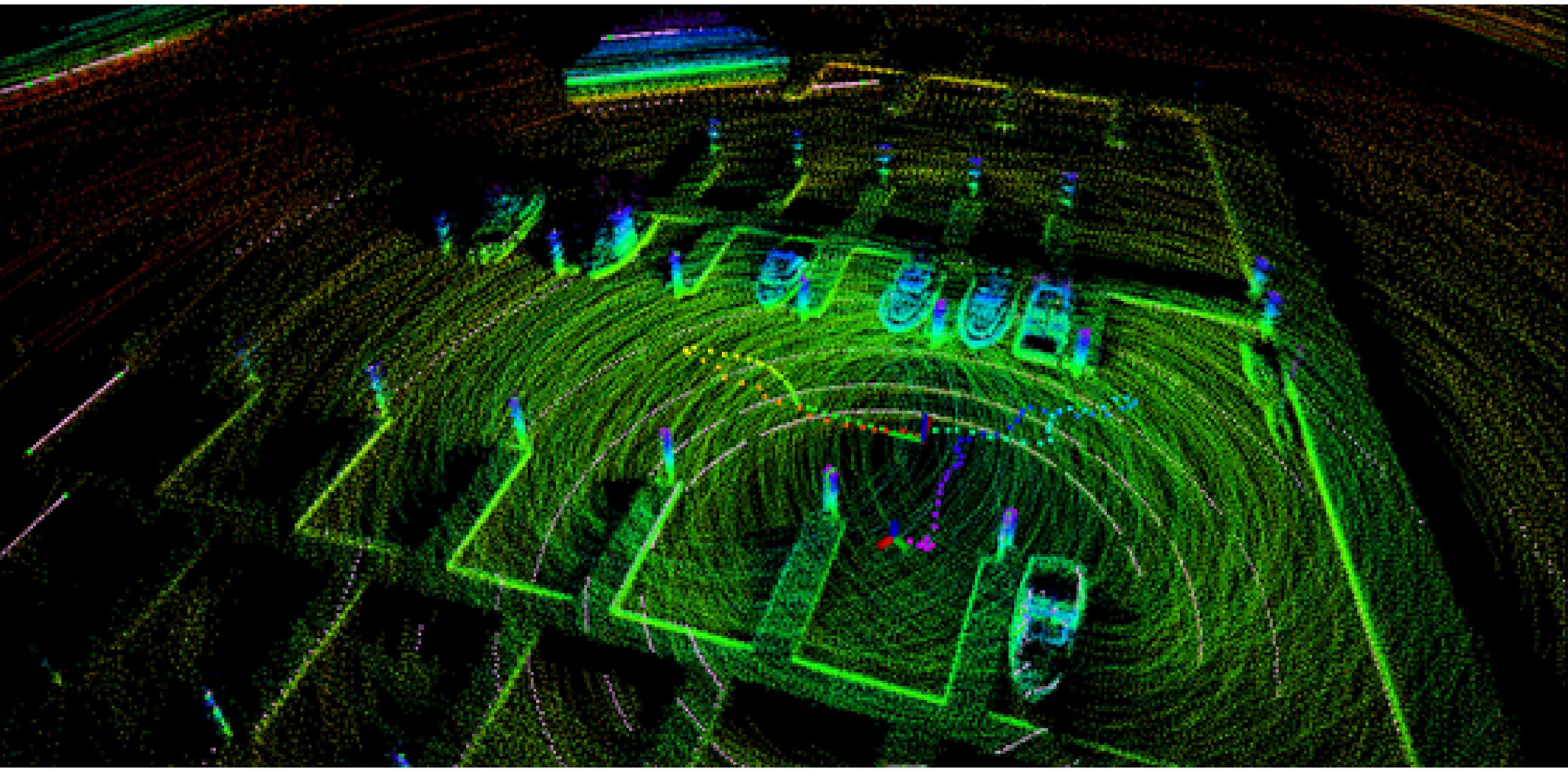
Mapping packages were particularly challenging to validate and select. Most mapping packages require a stable base, higher fixed reference content, and clear conditions. Mapping algorithms are typically designed for autonomous vehicles or robots that are operating on firm ground with a relatively static environment. After several iterations, we found success with LIO SAM, an open source mapping software that worked with minimal environment features.



Proof of Concept

In robotics, simulations can be used to determine how a system will react to a variety of environments and conditions. Simulated models allow multiple parameters to be rapidly tested in order to inform design decisions. Adjustments can be made to individual sensor configurations, environmental conditions, and control systems. These iterative changes provide an effective method for verifying a system's functionality, and detecting where and when a sensor has failed. Another benefit to simulations is that they can be recorded and saved for post-test analysis. The key to obtaining relevant information from simulated results is to accurately model the environment that the physical model will be operating within.

For the Thrace autonomous vessel, Motus used the Virtual RobotX (VRX) marine simulation environment. VRX is built on top of Gazebo Ignition, and is designed to test Autonomous Surface Vehicles (ASV's). A custom VRX environment was built using various vessel sizes, wharf configurations, and wave profiles. Our marine environment had three main configurations: low boat traffic, med boat traffic, and high boat traffic.

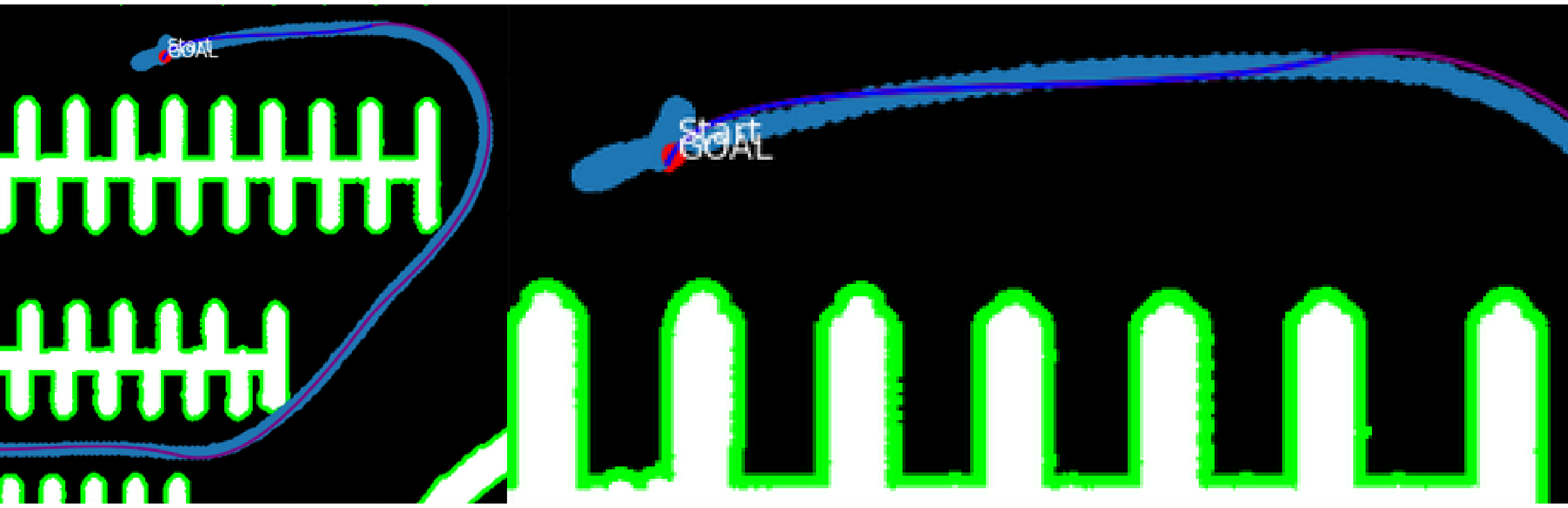


Focus Areas

Adapting off the shelf, open source solutions allowed us to save time on the proof of concept system and focus on systems that we needed to design. Our requirements allowed us to use pre-built sensor models, communications protocols, and post processing software. This allowed us to focus our time on the systems that needed to be fully custom, such as the path planning, object recognition, and control logic.

A key system that allowed for the integration of off the shelf solutions was Robot Operating System (ROS). Robot Operating System (ROS) is the de-facto standard for robotics middleware. Middleware handles the low level communications, logic, and data recording for the system. While custom solutions are frequently used in production robotics, ROS makes it quick and easy to get the full system up and running.

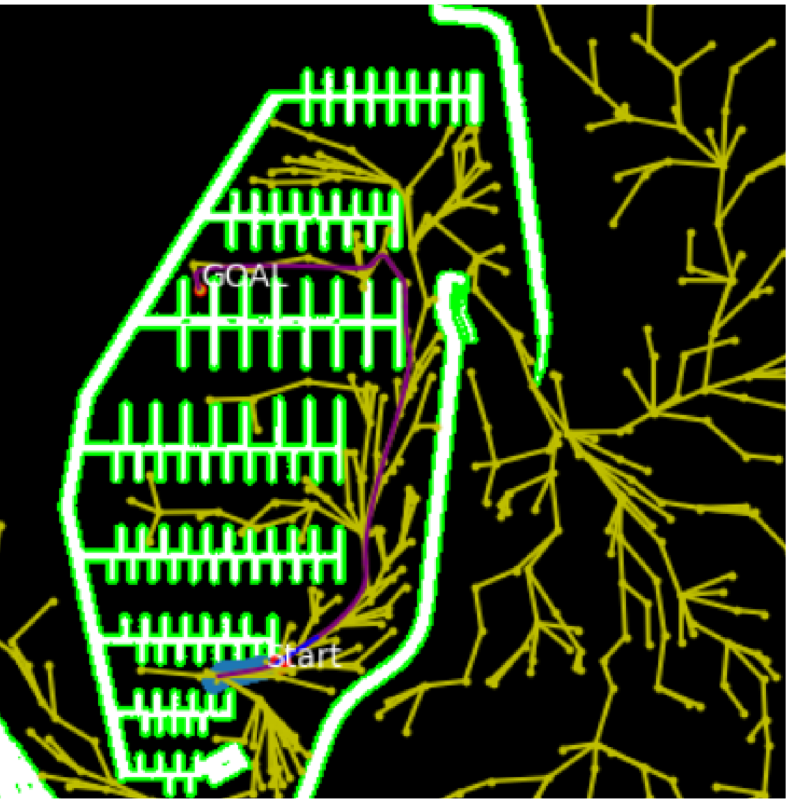
Using ROS, we are able to record sensor data and control signals that occur during the simulation. This level of access to data allowed for faster testing and debug loops, informed troubleshooting, and better incident recreation. Recorded simulation data can be played back with a number of open source tools. We decided to use Foxglove Studio, which enables in depth data review as well as visually appealing simulation recreations.

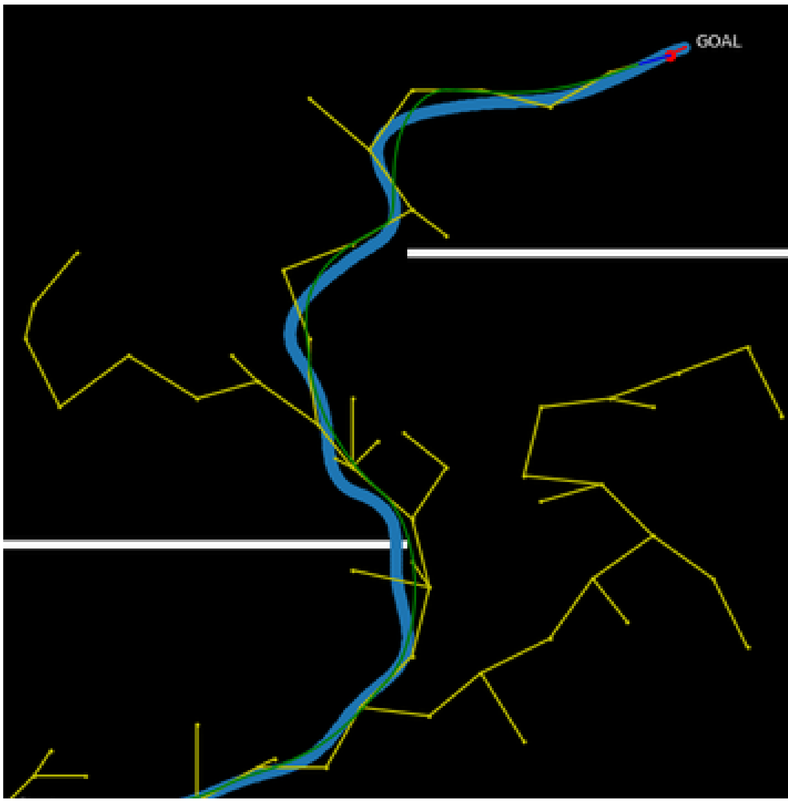


Path Planning

An optimised model of Rapidly-Exploring Random Trees (RRT*) was selected as the best path planning approach to use. RRT* is statistically guaranteed to find a path and continually improves the path between system operations. This is possible due to the system's ability to cycle freely between each time step. A custom RRT* implementation was chosen because its underlying principles are not overly complex and the module could interface with our existing systems which had specific data format requirements. The custom implementation also gave us much greater flexibility around how the algorithm explored the map and optimised its search for the goal.

The path was smoothed using a 5-point Bézier curve. This provided a continuous path that allowed the vessel to move efficiently and smoothly. The path was created using a costmap of the environment, provided through our mapping package. The costmap ensures that the path does not interfere with any impassable objects or terrain.

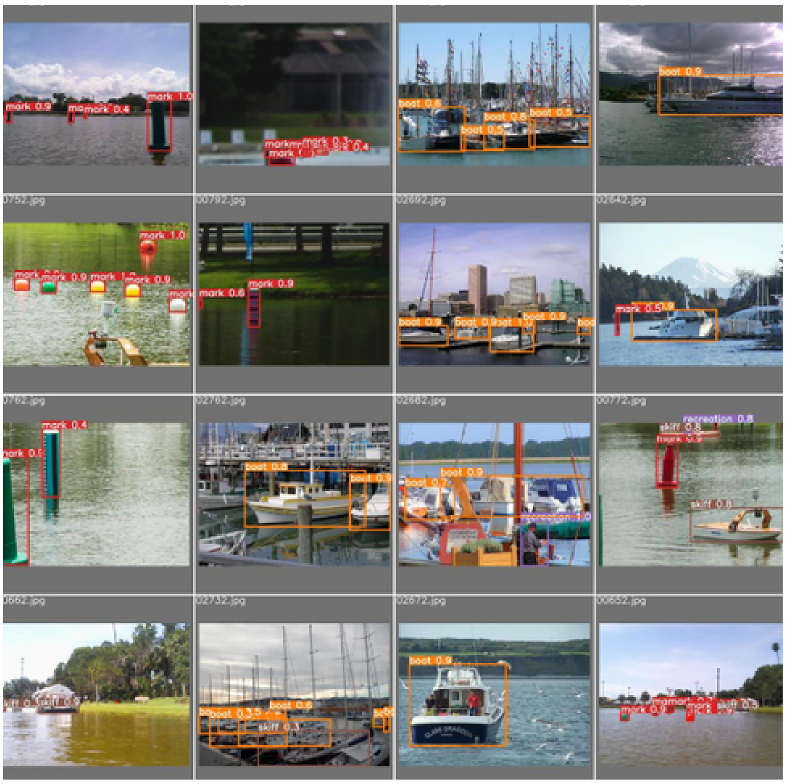


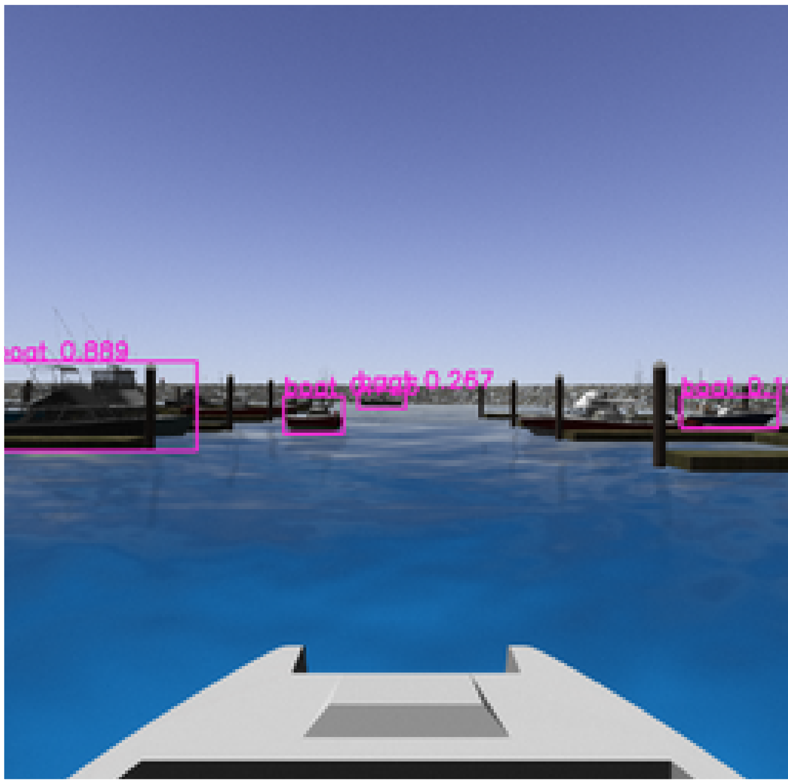


Real-Time Object Detection

Recent advancements using convolutional neural networks (CNN) for object detection allow for smarter decision making and mapping in autonomous vehicles. There was no existing model that could recognize and track the range of objects Thrace would encounter in a marina setting - we needed to build and test our own.

We built a custom CNN marine object detection model using YOLO v7, a high performance real time object detection and tracking algorithm that can run on edge devices. We chose YOLO v7 due to its high performance, ease of use, ability for customization, and reliability when running edge devices. Images were sourced from Roboflow and labelled by our team using CVAT.



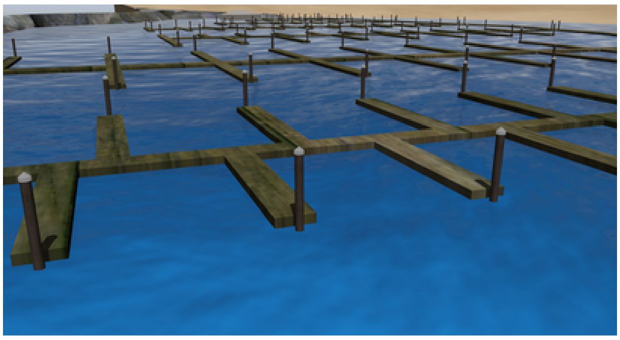


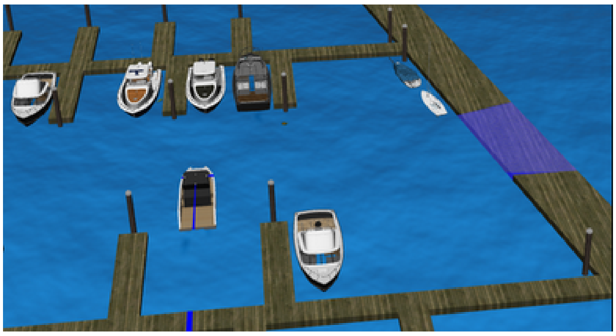
Simulation Environment

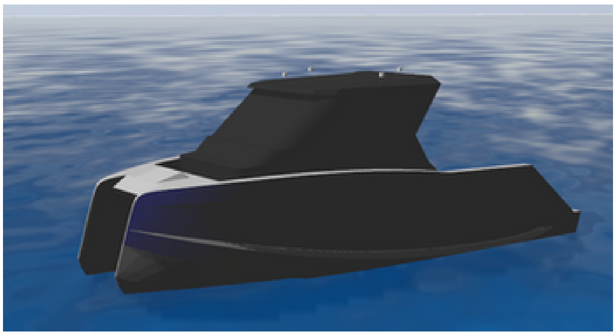
The simulated environment was a difficult design problem. There are limited buoyancy and hydrodynamic focused simulation environments, and none that come with assets that could be used for realistic autonomous navigation simulations. We utilised the VRX plug-in for gazebo ignition to create the base framework for the marine environment. The dock, boats, and surrounding landscape had to be modelled by Motus.

Simulation environments need to walk a fine line between having enough detail for the mapping and object detection packages to function, but not so much detail that the simulation becomes too slow. We focused the detail around objects that would need to be detected by the cameras, and left features such as the dock and breakwater with lower resolution textures.

The resulting environment was a balanced representation of how the vessel would experience a real marine environment, while maintaining the real time execution of the simulation. Moving to a full feature rich, real world environment, will likely result in better mapping and localization, but raise difficulty for object recognition and path planning.







Completion

The complete Thrace Autonomous Navigation Proof of Concept solution is an effective harbour navigation system that has the capability to reduce low speed accidents in marinas. It can map the local environment, navigate to a goal, identify objects in the environment, make decisions based on the objects, and avoid collisions. The dual electric stern drive powertrain allows for high manoeuvrability. The electric control system and drivetrain enables fast response times that would not be possible in a typical internal combustion drivetrain.

The full autonomous system was tested over a range of marina traffic densities and wave/wind conditions. In each scenario, the vessel was able to map the environment and navigate to the destination without colliding into any objects or features.

Thrace Marine can successfully navigate through a marine environment, avoiding obstacles and adapting its path based on real-time information. The next step is to create a proof of concept demonstration vessel. This could take the form of a scale vessel that can be used to validate the sensors, data processing, and control systems. With the core navigation system functional, we will also spend time refining some of the more critical precision system functions, such as station keeping and docking.

Edge cases will be introduced, tested, and solved in future development cycles. Having control protocols and systems in place for events like obscured cameras, 3rd party fault collisions, and extreme weather are essential for moving from a proof of concept to commercial product.

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