Design and Experimentation of Complex Dynamical Systems for Intelligent Navigation

Penn Engineering | GRASP Laboratory
General Robotics, Automation, Sensing & Perception Lab

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ScalAR Lab

Introduction

Objective

- Produce and evaluate complex flows, consequentially creating a environment susceptible to machine learning optimization and intelligent pathfinding techniques.

Numerical Integration

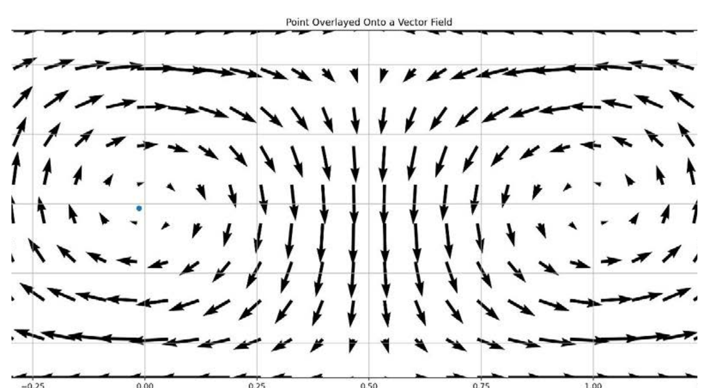
- Current popular method to examining dynamical systems
- Utilized Euler's/Refined Euler's Method

Time Independent Double Gyre

$$\psi(x,y) = \sin(\pi x)\sin(\pi y)$$

$$\dot{x} = -\frac{\partial(\psi}{\partial(y}$$

$$\dot{y} = \frac{\partial(\psi)}{\partial x}$$



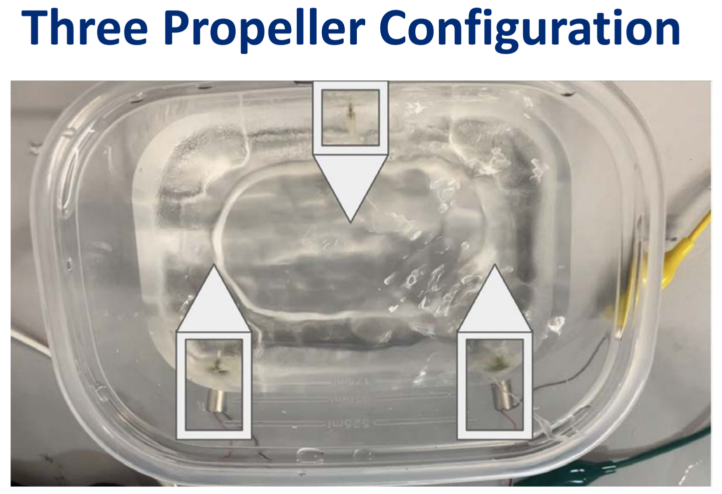
Current Issues with Dynamic System Simulation

- Simulations of dynamical systems can quickly mutate into inaccurate and computationally expensive representations. Popular methods of numerical integration include both the refined and unrefined versions of Euler's Method. Both see non-trivial losses in their accuracy due to compounding minute discrepancies between the calculated and actual values

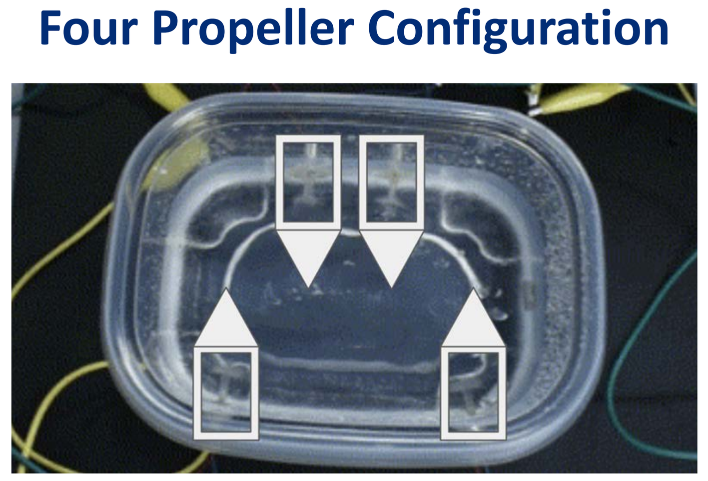
Mini - Tank Experiments

- Utilized containers to develop flow-construction intuition
- Allowed for rapid prototyping and qualitative observations for ideal water to flow speed ratio.
- Compared models such as a three and four propeller configuration double gyre to observe differences flow stability
  - Determined that a four propeller configuration held stronger individual gyres, potentially due to the more defined median line

Three Propeller Configuration



Four Propeller Configuration

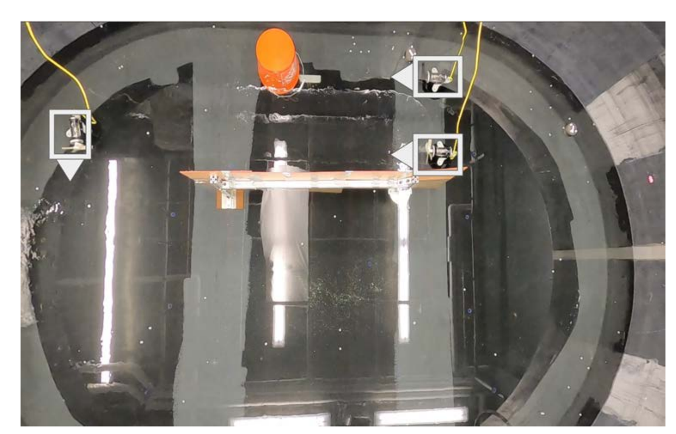


Methodology

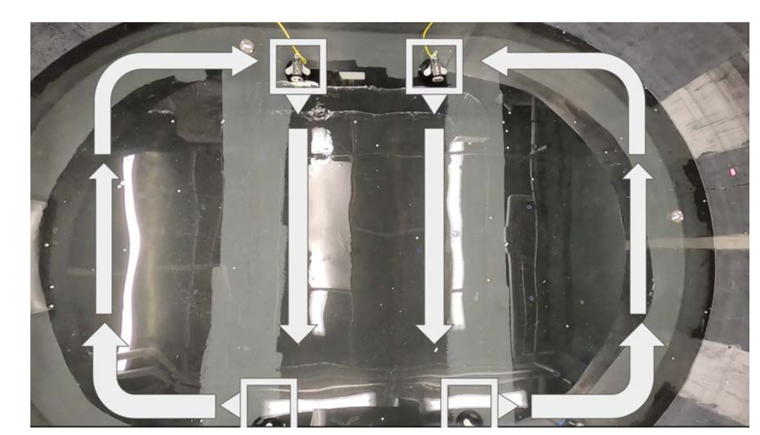
Multi-Robot Tank Experiments

- Mini-Tank renditions of the flows were translated into ScalAR's Multi-Robot tank
- Drifters were placed into the system, collecting data using the lab's Optitrack system
- Utilizing Robotic Operating System (ROS), positions and orientations were tracked, allowing clear imaging of movement throughout the flow

Obstacle Flow

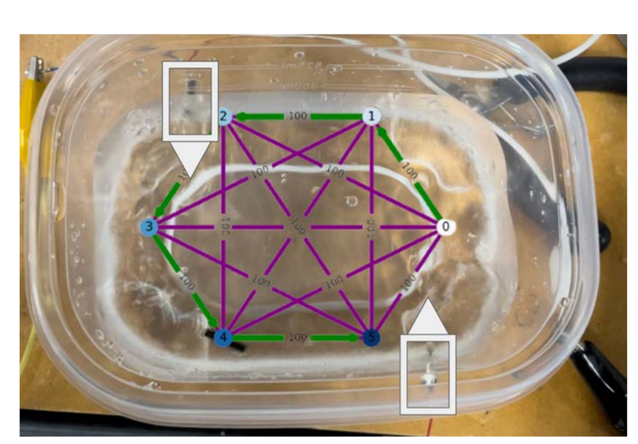


Double Gyre Flow

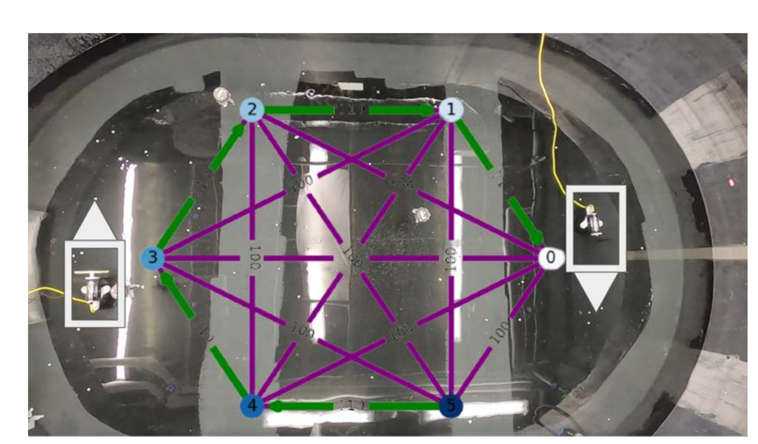


Data Structure and Algorithm Implementation

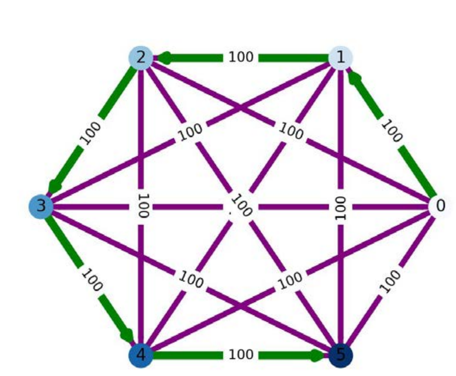
- Developed to assist in future works regarding intelligent pathfinding techniques to maximize locomotive efficiency in complex environments
- Implemented Dijkstra into a dictionary composed complete graph, meant to model a single gyre flow capable of traveling whichever direction best fits the flow

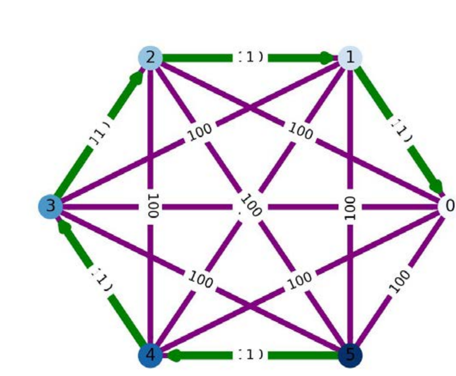


Path in CCW Single Gyre



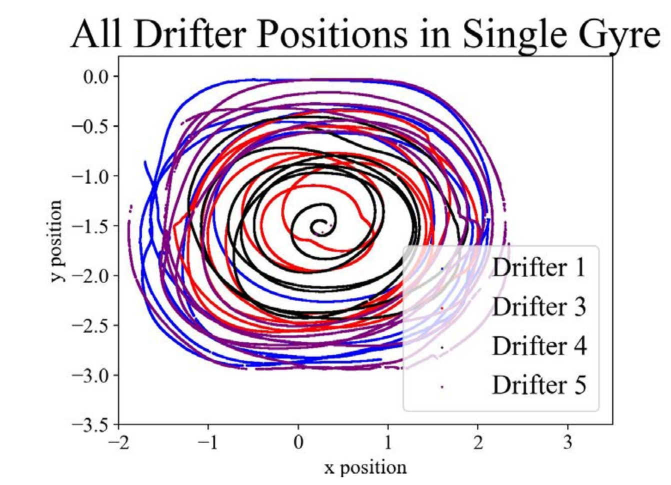
Path in CW Single Gyre



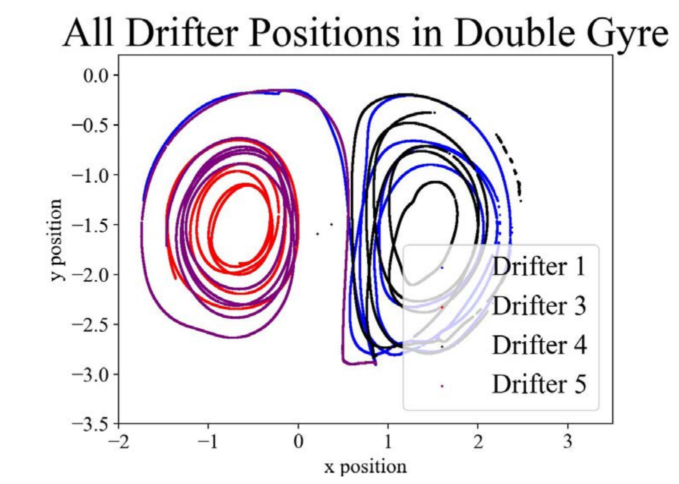


Results and Future Applications

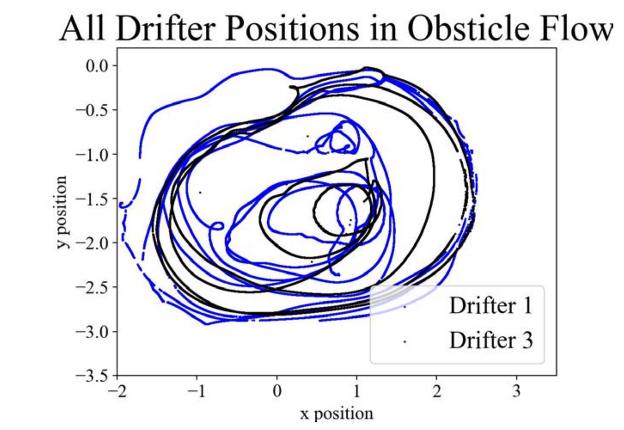
Results



- Strong presence of a single gyre, as well as identification of the tank's blind spot
- drifter velocity greatly decreases as it trends closer to the center



- Median line proves difficult to cross
- Invites further examination into manipulation of that median line



- Drifters maintain path of greatest force
- Through propeller manipulation, obstacles are circumvented in different ways

Future Applications

- Data derived from the drifters have already been used to examine the properties of various positions in the flows. They can also be used to learn the flows using various machine learning methods.
- Armed with novel intuition regarding the fabrication of these complex flows, navigational experimentations can now occur with them, utilizing the developed algorithms such as dijkstra.

Acknowledgements

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