Session H Abstracts

Numerically Consistent Data-Driven Subgrid-Scale Model for Large-Eddy Simulation
Michael Lawrence Garcia
Mentor: H. Jane Bae

In this work, we train a data-driven subgrid-scale (SGS) model for large-eddy simulation (LES) which incorporates numerical error arising from the LES equations. LES solves the low-pass filtered Navier-Stokes equations while using a model for unclosed SGS terms. The typical approach for generating data-driven closure models in LES computes required SGS terms using a filtering operator on direct numerical simulation (DNS) data. Recent research highlights that the numerical error between the derivative and filter operators is comparable to the modeling error of traditional SGS models. We develop an artificial neural network (ANN) trained on both filtered DNS data and computed commutation error to act as a numerically consistent closure model in LES. We develop an artificial neural network (ANN) trained on both filtered DNS data and computed commutation error to act as a numerically consistent closure model in LES for forced isotropic turbulence. Our goal is to create a high fidelity SGS model for LES which can adapt to different numerical methods in computational fluid dynamics solvers. We discuss the details of the LES model and the training process.

Advancing Autonomous Underwater Vehicles Through the Innovation of a Robotic Fish Fin Propulsor
Hambik Margoosian
Mentors: Morteza Gharib and Meredith Hooper

Autonomous Underwater Vehicles (AUVs) have the potential to revolutionize exploration methods by offering convenience and cost-effectiveness. However, conventional AUVs utilizing screw propellers for propulsion face limitations such as inefficient power consumption, reduced maneuverability, and a large acoustic footprint, impacting their practicality in certain applications. In contrast, bio-inspired AUV designs, mimicking fish locomotion, have the potential to improve power efficiency, maneuverability, and operate quietly. The power efficiency optimization of AUVs is of high priority to maximize its potential use in longer missions. This project focuses on developing a mechanism that utilizes a fish-like caudal fin capable of three-axis rotation controlled by a fin trajectory optimization algorithm which aims to achieve efficient propulsion.

Exploring a Range of Sound Frequencies to Create Mucus Flow in the Eustachian Tube
Juhi Dalal
Mentors: Mory Gharib and Alexandros Rosakis

Eustachian tube dysfunction arises from persistent obstruction within the tube due to the accumulation of fluid, mucus, and inflammation, leading to chronic discomfort. This study aims to investigate the potential for dislodging mucus from the eustachian tube by subjecting it to various frequencies of sound. To replicate the eustachian tube conditions, an air chamber-based model was devised to simulate pressure gradient, accompanied by a tube emulating the tube's inherent characteristics. Mucus was introduced into this model and subjected to a diverse spectrum of sound frequencies to observe its responses. The findings from this endeavor will yield insights into the simulation of eustachian tube dysfunction and how different sound frequencies impact mucus behavior within the tube. Moving forward, the project's progression should encompass a continued exploration of diverse sound frequencies to discern alterations in mucus flow dynamics within the eustachian tube.

Bio-inspired Underwater Propulsion: Advancements in Fin Mechanisms
Jacob Schuster
Mentors: Morteza Gharib and Meredith Hooper

Modern marine thrusters have revolutionized underwater propulsion, reaching impressive levels of efficiency and power. Yet, some aquatic animals are able to propel themselves at much higher energy efficiencies than even the best human-made propulsion systems. Taking inspiration from the propulsion of aquatic creatures, The Gharib Research Group aims to create a bio-inspired alternative to traditional marine thrusters by mimicking the movements of fish fins. To achieve this, we are developing a fish robot that can achieve collinear flow, while executing trajectories determined by a machine learning algorithm. The robot uses a central motor and a swash plate mechanism connected by a universal joint to complete these trajectories. In the future, we hope to optimize the design of the fish robot and fin trajectories in order to improve underwater propulsion methods around the world, making them both more efficient and eco-friendly.
Characterizing a Thruster Array Water Tunnel
Shana Hartwick
Mentors: Morteza Gharib and Sean Devey

Traditional water tunnels used for fluid dynamics experiments push fluid through a large circuit, which include complicated features like turning vanes, diffusers, pumps, and more. Most of the body of a traditional water tunnel consists of these flow conditioning and straightening features; the test section is only a small percentage in comparison. An alternative water tunnel design and its characterization will be presented that takes up less space and resources than large circuit water tunnels but still has a comparable test section size. The design’s flow velocity range and spatial and temporal characteristics were determined using particle image velocimetry (PIV). This facility will support a variety of research experiments, from fundamental fluid mechanics to the hydrodynamics of boxfish.

Bayesian Active Sensing and Planning Applied to Attitude Dynamics and Spacecraft Control
Arnauld Martinez
Mentors: Soon-Jo Chung and Jimmy Ragan

Modern spacecraft must be equipped with a high degree of fault tolerance to ensure safe and successful system operation during critical moments in the spacecraft’s mission. To combat total system failure, engineers implement redundancy to allow multiple failures to occur without compromising vehicle performance or objectives. However, if a redundant system fails, the source of the failure reduces to a family of potential problems that requires significant time to analyze and repair. To combat this, the ARCL lab developed FEAST (Fault Estimation via Active Sensing Tree Search), a novel algorithm that identifies failing sensors and actuators in a redundant system. The accuracy of FEAST has been verified on planar spacecraft models. In this paper, we extend FEAST to consider the attitude/orientation of the spacecraft about its center of mass. We model the spacecraft using quaternions and vary its orientation using reaction wheels. Additionally, we build a more realistic sensing model to simulate known failure modes in monocular cameras. By designing a procedure to identify faulty sensors and actuators, we aim to increase spacecraft reliability and crew safety.

Monte Carlo Tree Search on a Graphics Processing Unit in the Context of Online Robotic Decision Making
Felix Steinberger Eriksson
Mentors: Soon-Jo Chung and Benjamin Rivière

Effectively leveraging parallel computation on graphics processing units (GPUs) is a promising direction for speeding up online robotic decision making and planning algorithms. Monte Carlo Tree Search (MCTS) is an established method with well-known empirical results. Since it was first described, MCTS has been adapted to areas beyond turn-based games with full observability, expanding its domain of applicability to areas like control and robotics. There are also recent theoretical results on the non-asymptotic convergence properties of MCTS. Although there exist parallel implementations of MCTS, parallel MCTS implementation is underexplored in the context of robotics. Furthermore, several recent methods for online robotic decision making make use of MCTS as a subroutine to obtain solutions to decision problems, or generalize it to explore the sample complexity of Markov Decision Processes (MDPs). We provide parallel implementations of some variants of MCTS and related newly proposed tree search algorithms. These parallel implementations are used in empirical analysis of a newly proposed anytime tree search-based planning algorithm that provides insight into new sample complexity measures for finite deterministic tabular MDPs.

Terrain Aware Adaptive Control
Emilia Sjögren
Mentors: Soon-Jo Chung and Sorina Lupu

Developing robust algorithms for robots is essential to ensure reliable and efficient motion capabilities. We are exploring how we can integrate information about the terrain into control algorithms in order to take the environment into account. By extracting images in real time that the robot is taking, we are utilizing machine learning models, specifically a vision transformer called DinoV2 from Meta AI. By analyzing the feature vectors and performing dimensionality reduction using principal component analysis, the most important properties can be extracted. The ground properties together with depth images can be visualized as point clouds and elevation maps. These representations can then be used as inputs into adaptive control algorithms running on the robot.