ELECTRICAL & COMPUTER ENGINEERING
SUMMER RESEARCH INTERNSHIP PROGRAM

**FACULTY MENTOR**
Jorge I. Poveda

**PROJECT TITLE**
Experimental Demonstration of Perception-Based Control in the Hybrid Kapitza's Pendulum

**PROJECT DESCRIPTION**
The Hybrid Kapitza's Pendulum (HKP) is a new mechanical system built at UCSD that enables the vertical stabilization of a pendulum using only high-frequency vibrations and from any initial condition (including the downward position ) — a property that cannot be achieved in traditional Kapitza's pendulums. The HKP showcases the power of using control systems that switch between multiple algorithms to achieve a common goal, a feat unattainable with a single algorithm. Such types of switched control systems are becoming ubiquitous across modern engineering applications that involve high-performance specifications in real-time decision-making problems, and they can be systematically and rigorously studied using tools from hybrid dynamical system theory.

The main goal of this experimentally oriented project is to demonstrate these advantages by implementing a *closed-loop* hybrid controller for the HKP system. The controller will use perception-based feedback (i.e., images and videos from cameras) to close the loop and implement the switching algorithms that have already been tested in an open-loop fashion. The use of perception-based control implies that suitable machine learning techniques might be needed to accurately predict/observe the (average) position of the pendulum. In this way, by carrying out the actual implementation of high-performance perception-based feedback control algorithms, the project offers an excellent opportunity for students interested in controls and robotics to advance their skills and knowledge. A video of the HKP system operating in open-loop can be found at: https://www.youtube.com/shorts/Hz87vSf7wRE.

The results of this project are intended to be disseminated through technical reports and publications.

This project will be in person.

**INTERNS NEEDED**
- 1

**PREREQUISITES**
- Basic knowledge of implementing feedback control systems and Arduino programming.
- Basic knowledge of machine learning is a plus.

## FACULTY MENTOR
Jorge I. Poveda

## PROJECT TITLE
Modern Machine Learning for Real-Time Obstacle Avoidance in Vehicle Systems

## PROJECT DESCRIPTION
Obstacle avoidance problems are typical in robotic applications. To robustly avoid an obstacle in real-time, the robot needs to solve a decision-making problem that is usually binary (e.g., turn right or turn left). Such binary decision-making problems lead to discontinuities in planning and navigation algorithms, making them highly susceptible to measurement noise or adversarial jamming signals. The goal of this project is to overcome some of these limitations by synergistically merging tools from machine learning (e.g., LLMs, CNNs, RNNs) and non-smooth feedback control systems. ML tools can be used to accurately predict (albeit with some residual error) the vehicle's position based on images and video. Non-smooth feedback control systems can handle imperfect position measurements and still robustly guide the vehicle toward the desired target while avoiding obstacles. This computationally oriented project will numerically test both techniques (ML and non-smooth control) in a 2-D simulation environment and under a variety of adversarial signals acting on both the ML and the control algorithms.

The student working on the project will learn important skills at the intersection of ML and control systems in a practical application of importance to multiple companies and research laboratories. Earlier, preliminary work in this direction (using CNNs) was presented in the paper: [https://ieeexplore.ieee.org/document/9867532](https://ieeexplore.ieee.org/document/9867532).

The goal of the project is to advance these results by considering more modern ML-based techniques. The results of this project are intended to be disseminated through technical reports and publications.

This project can accommodate both remote and in-person students.

## INTERNS NEEDED
- 1

## PREREQUISITES
- Strong background in math and machine learning for image processing and classification problems.

## FACULTY MENTOR
Jorge I. Poveda

## PROJECT TITLE
Federated-Learning via Dynamical Systems Tools

## PROJECT DESCRIPTION
Federated learning (FL) has emerged as a powerful paradigm for the solution of semi-decentralized learning problems where data privacy is fundamental. Consequently, several companies, such as Google, Amazon, and Meta, are currently interested in developing more efficient and robust algorithms for the solution of FL problems. There is also interest in understanding the fundamentals behind many FL techniques using tools from dynamical systems, an approach that has been successful in the context of optimization algorithms. Since many FL techniques rely on periodic or aperiodic combinations of gradient systems (run in each node) with averaging techniques (run over the network), the area of switching dynamical systems might provide insight into the behavior and design of FL algorithms from a dynamical systems point of view.

The goal of this mathematically-oriented project is to pursue this idea by reviewing the state of the art in FL and reformulating existing algorithms as switching dynamical systems, for which a variety of analytical tools already exist in the control literature. Students working on this project will become experts in modern FL techniques and will also learn useful (and perhaps unusual in the area) tools for the synthesis and analysis of such algorithms. The results of this project are intended to be disseminated through technical reports and publications.

This project can accommodate both remote and in-person students.

## INTERNS NEEDED
- 1

## PREREQUISITES
- Strong mathematical background.
- Prior knowledge of federated learning algorithms is desirable but not required.