Session I Abstracts

Experimental Demonstrations of Robust Safety Critical Control on a Quadrotor
Jana Woo
Mentors: Aaron Ames and Ryan Cosner

Safety in robotics, especially in fields like autonomous vehicles and medical devices, relies on control theory and mathematical concepts of control invariance to ensure system safety by maintaining it within a predefined safe region. However, these theoretical ideas often assume ideal conditions such as perfect sensing, exact dynamics knowledge, infinite resources, and no delays, which are too idealistic for practical scenarios. For the robot to account for these stochastic uncertainties and disturbances, significant theoretical work has gone into developing Control Barrier Functions (CBFs) with probabilistic safety guarantees to create safety-focused controllers capable of handling stochastic uncertainties and disturbances in the real world. To the best of our knowledge, these methods have only ever been demonstrated in simulation. We seek to conduct hardware experiments using a quadrotor to demonstrate the efficacy of these robustified CBF-based methods. Using the laboratory’s motion capture system and other sensing tools, we aim to quantify the effects of disturbances and unmodeled dynamics.

Non-invasive, Computer-based Therapy to Reduce Tremors in Parkinson’s Patients: StableHand2 Prototype
Sanvi Pal
Mentors: Joel Burdick and Drora Samra

Paradoxical Kinesia (PK) is the sudden ability of subjects with Parkinson’s Disease (PD) to show reduced symptoms, such as reduced tremors. While the mechanism of PK is poorly understood, visual stimuli can induce PK. Leveraging these visual stimuli to create non-invasive therapy for PD subjects can significantly impact many lives because current treatment options for PD like Levodopa medication and Deep Brain Stimulators are expensive and inaccessible. This project aims to create an interface for PD subjects that displays various visual stimuli like moving chevron, sinusoidal, and checkerboard patterns while having the subject type displayed words. The keystroke timings and error rate is then analyzed and interpreted to gauge if the visual stimulus induced an improvement in typing significantly enough that it can be classified as PK.

Enhancing Parkinson’s Disease Therapy With StableHand 2: A Web-Based Visual Stimulus Platform
Sneh Patel
Mentor: Joel Burdick

Parkinson’s disease (PD) is a debilitating neurological disorder affecting millions in the United States, imposing a significant healthcare burden. PD results from dopamine production reduction in the basal ganglia, leading to symptoms like tremors, stiffness, and impaired coordination. Current treatments, such as levodopa and deep brain stimulation, offer limited long-term relief. Dr. Drora Shevy’s research explores the potential of Visible Moving Patterns (VMPs) to reduce dyskinesia in PD patients. Building upon this promising foundation, Caltech undergrad Sneh Patel, along with his partner Sanvi Pal, has developed StableHand 2, a user-friendly website which offers customizable visual patterns, including chevrons, squares, and sinusoids, underneath a typing display. Keystrokes, timestamps, and errors are logged; secondary data derived from these will evaluate the patient’s dyskinesia severity. Monitoring the progress of the severity, and hopefully inducing a decrease, the parameters responsible for customization of the patterns will be fine-tuned to each patient, strengthening the VMP therapy’s effectiveness. This research represents an innovative approach to improve the lives of PD patients by leveraging visual stimulus therapy through StableHand 2. The development of a user-friendly platform holds promise for advancing PD symptom management and therapy effectiveness.

Simultaneous Velocity and Temperature Measurements Applied to Combustion Processes
Kyle Lethander
Mentors: Joseph Shepherd and Charline Fouchier

Understanding thermal ignition is critical for safety and performance in aviation and process industries. However, the standard method of autoignition testing (ASTM E-659) is limited to visual observation and pointwise temperature measurements. Recent work has demonstrated the promise of thermographic particle image velocimetry (TPIV) for obtaining full-field velocity and temperature measurements in high-temperature flows. This technique is applied to study thermal ignition by seeding a test volume with BAM:Eu²⁺ phosphor particles, illuminating the flow with a combined 532/266 nm pulsed light sheet, imaging the scattered light for PIV analysis, and detecting the luminescence intensity of two emission bands for temperature measurements. The spectral response to temperature was investigated for particles on a heated surface, and a temperature calibration using two-color thermography achieved better than 20 °C accuracy for surface temperature measurements over 20 °C – 550°C. A luminescence imaging system was designed to capture 2D intensity fields of two emission bands, and a similar calibration was performed on BAM:Eu²⁺ particles suspended in a gas flow. Finally, the temperature calibration was applied in conjunction with a previously developed PIV system to provide full velocity and temperature fields inside a combustible mixture preceding thermal ignition.
Lab-Scale Demonstration of a Reflector Assembled in Space
Diego Attra
Mentors: Sergio Pellegrino and Jongeun Suh

Due to the demands of future space missions, building large-scale structures on the order of hundreds of meters in space has become of interest. Current deployable design approaches are limited by the stowed size of these designs. A new design approach of an in-space assembled reflector has been studied and is being developed as an alternative to deployable designs. The multifaceted nature of this concept has required different modules to be developed simultaneously. The “Truss Builder” is one of the modules, and it is responsible for the storage of structural components as well as the autonomous fabrication of the structure itself. This work details the development and initial testing of a lab-scale demonstration of the “Truss Builder” system.

Modeling Viscous Compressible Flow for the Diffuse Boundary Simulation of AP/HTPB Burn
Juan Luchsinger
Mentors: Brandon Runnels and Melany Hunt

The deflagration of solid composite propellants, particularly ammonium perchlorate embedded in a hydroxyl-terminated polybutadiene binder (AP/HTPB), can be complex to simulate. This project aims to develop a computational model that simulates and couples the solid and gas phases of AP/HTPB burn, with a focus on the simulation of the gaseous phase and the role viscosity plays in this process. The model utilizes the self-similar diffuse boundary approach and couples it with adaptive mesh refinement to improve upon traditional methods for simulating complex multiphase flows. This combination allows for the precise modeling of the complex geometries and topological changes while minimizing computational costs. By simplifying the flux boundary conditions of source terms such as Couette flow, we can apply these examples to the model to verify its accuracy.

Design, Modeling, and Manufacturing of a Flexible Flying Vehicle
Keyu Wan
Mentors: Morteza Gharib and Ioannis Mandralis

Unmanned Aerial Vehicles (UAVs) have revolutionized numerous industries with their remarkable versatility and autonomy. The integration of deformable wing structures presents a transformative approach, enabling UAV wings to dynamically morph and adapt in real-time. This innovation takes inspiration from bird wings, and a novel bio-inspired flying carpet prototype has been meticulously designed and manufactured. The flying carpet’s flexible movements, facilitated by multiple tiny motors, Electronic Stability Controls (ESCs), and Inertial Measurement Units (IMUs) integrated with a flexible thin sheet, allow for rotation and shape formation akin to natural avian flight. To optimize the flying carpet’s performance, simulations and analysis have been conducted to identify optimal shape trajectories and potential nonlinear relationships between various deformation angles and air thrust. Testing demonstrates its ability to achieve preliminary flight capabilities by hovering and suspending itself in mid-air from a tabletop. Ongoing research aims to enhance the carpet’s efficiency by incorporating advanced controls, such as neural networks. The integration of deformable wing technology and the bio-inspired flying carpet prototype holds promise for advancing UAV capabilities, ushering in more adaptive, efficient, and maneuverable aerial platforms.

Flexible Flying Surfaces for Dynamic Multi-Modal Flight
Steven Lei
Mentors: Morteza Gharib and Ioannis Mandralis

Unmanned Aerial Vehicles (UAVs) are quickly gaining in popularity in a range of fields such as search and rescue, exploration, as well as package delivery. However, the rigid design of these systems limits the possible flight modes that can be explored. By loosening these restrictions, we can hope to design flying vehicles that can achieve more agile and energy efficient flight. In this work, we utilize a set of embedded brushless motors, inertial measurement units, and thin mylar sheeting to produce a flexible flying surface that flies in both a folded and unfolded configuration. This mechanism allows the ability to achieve multi-modal flight (flapping and hovering) while also allowing freedom for shape manipulation. We investigate the controls necessary for this mechanism, with current results showing that a modified proportional-integral-derivative (PID) controller can achieve basic flight. More experimentation will be conducted to produce stable flight with smooth shape control.

Development of a Propulsive Vertical Landing Vehicle
Enzo Celis
Mentors: Morteza Gharib and Jack Caldwell

In recent years, private space launch vehicle companies have developed propulsive vertical landing technology, allowing rockets to return in more reusable conditions, leading to reduced costs and increased launch frequency. However, there is much to explore regarding the control schemes behind vertical landers and their limitations in adverse wind conditions. For the Graduate Aerospace Laboratories (GALCIT) to conduct experimental research on
these topics, this project is dedicated to developing a proof-of-concept cold gas vertical landing vehicle, implementing its preliminary control scheme, and verifying its functionality. Our work has shown that cold gas, despite its low specific impulse, produces sufficient thrust for powering a descent-controlling main nozzle and attitude-controlling RCS nozzles. Our pneumatic circuitry design also circumvents flow limitations imposed by commercial off-the-shelf components and delivers throttling capability to our main nozzle to more closely replicate true vertical landing vehicles. Future work includes implementation of a PID loop that controls RCS actuation and benchtop testing to verify its functionality. Final demonstrations in an aerodrome will provide full-system reliability confidence and testing against a wind maker that emulates shear wind patterns at flight-realistic Reynolds numbers will provide insight on the limitations of these systems.