REU SITE: APPLIED COMPUTING RESEARCH IN UNMANNED AERIAL SYSTEMS

I. Summer 2018: Project Summaries

1. Vision Based Coastline Detection Using Autonomous Unmanned Aerial Systems

REU Participants: Wei Chen and Simon Merheb
Mentor: Dr. Dulal Kar
Graduate Assistant: Samuel Allred

The acquisition of high-quality videos and pictures of coastlines is of interest to many scientific and engineering fields. For example, coastal data can be used to estimate land resources and provide the basis for urban planning, conservation, and environmental protection. Accordingly, autonomous tracking of the coastline using an Unmanned Aerial Vehicle (UAV) can provide valuable data for various research endeavors. However, the dynamic nature of the coastline present numerous problems for such tasks. Guided by Dr. Dulal Kar and assisted by Samuel Allred, the REU participants Wei Chen and Simon Merheb worked on a real-time coastline detection algorithm. For testing the algorithm, data was collected using a commercial quadcopter and processed after flight (Fig. 1. Results showed that the algorithm was able to identify the coastline through minor calibrations to the algorithmic parameters using images of the coastal region. Based on the work, a paper has been submitted in an international conference for publication.

Fig. 1. DJI Phantom 4 Pro.

Fig. 2. Shoreline boundary.

Our ultimate goal is to develop an autonomous system for monitoring coastal regions using UAVs. An autonomous system for monitoring the coastal regions using an UAV has many applications. The coastline detection algorithm that is fast enough for an UAV to execute in real-time. Given a coastal region, the algorithm can identify the coastline by highlighting the threshold between land and water. The coordinates of these pixels can be applied to flight control purposes. However, the algorithm does not perform well in conditions with excessive wave interferences. Areas of future work include improving the technique used in this algorithm to tackle the conditions of high wave movements. In more challenging conditions, machine learning approach will be more effective. In our future work, we plan to develop the flight control algorithm that can utilize the results of the coastline detection algorithm to guide an UAV.

2. Particle Image Velocimetry to Determine Wave Properties Using Unmanned Aerial Systems
REU Participants: Hailey Chapman and Henry O'Connor
Mentor: Dr. Michael Starek
Graduate Assistants: Samuel Allred, Jake Berryhill, and Kevin Wilson

Accurate mapping of currents in the surf zone has value across multiple domains, including public safety, logistics, and environmental science. One of the applications of this technology is in detecting and predicting the locations of rip currents. There is a need for a robust beach hazard detection system which could warn swimmers about the locations of rip currents. Another application is bathymetric mapping. Given a sufficiently large set of velocity vector maps of a coastal area, it is possible to get good estimates of properties such as wave celerity and phase. Accurate bathymetric data is extremely important for transportation and logistics. Ships use bathymetric maps to chart safe courses in and out of port, and due to the dynamic nature of the seafloor, it is important to be able to take quick and accurate measurements as needed. The low cost and flexibility of the UAV, compared to traditional pole- or building-mounted cameras, make it an ideal choice for the image-gathering component of such systems.

Particle image velocimetry (PIV) is a method for determining the velocity of particles in sequential images. PIV has been used to determine current properties in rivers and lakes, but there is a lack of this type of research in surfzone environments. Because the surfzone is so dynamic, understanding the wave properties in that area is a matter of great importance. Guided by Dr. Michael Starek, the REU participants Hailey Chapman and Henry O'Connor developed an effective technique to apply PIV to aerial footage of the surf zone acquired from a UAS. This project utilized unmanned aerial systems (UAS) to gather high-quality video footage of surfzone waves. The footage was then run through an algorithmic code that processed the individual frames in the video to yield an accurate velocity vector field over the entirety of each image. Ground truth data was used to calibrate and verify the resulting vector field.

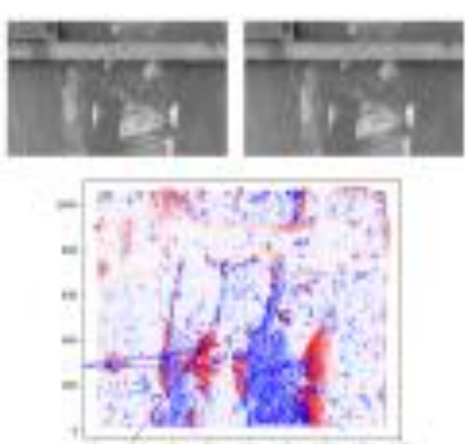

Fig. 3. Python PIV sequential image pair and velocity vector field output.

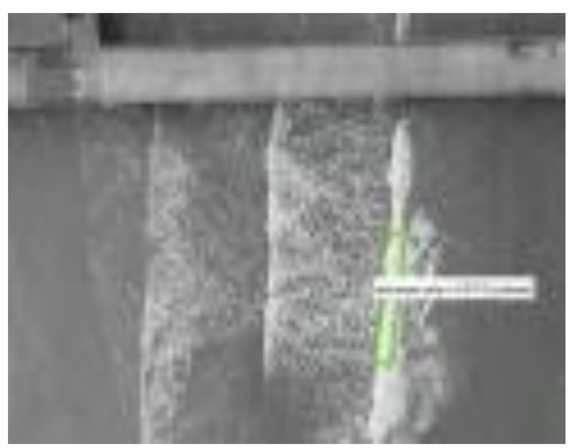

Fig. 4. Local velocity estimation with PIVLab.

For one instance, the result of the ground truth experiment on the velocity of a wave was found to be 2.60 meters per second. From PIV analysis, the average wave velocity was calculated to be 2.40 meters per second. There was some error on the order of 0.10 meters per second due to camera movement. This estimate was based on average velocity measurements taken of known static areas. Similarly, the result on the depth of water was estimated to be 0.59 meters deep, which was within the acceptable range of -0.84 to 1.21 meters. In future, the accuracy of the results could be improved by a more accurate field experiment, camera calibration to account for radial distortion, and finding the threshold value for determining invalid vector results.

3. Protecting the Unmanned Aerial Vehicle from Cyberattacks
REU Participants: Jesus Nunez and Vincent Tran
Mentor: Dr. Ajay Katangur
Graduate Assistant: Samuel Allred

UAV technology is rapidly growing in popularity. Primarily used by the defense department, UAVs are now utilized for non-military tasks putting them at high demand by both average consumers or hobbyist, and commercial businesses like Google and Amazon. Companies are already utilizing drones for specific tasks such as delivery services, agriculture, infrastructure development, aerial surveying, and tasks that might be dangerous for a human to perform. As a result, UAV traffic is going to increase in the coming decade, and with it the possibilities of cyberattacks will rise. UAVs can be hijacked, their paths can be changed, and they can be made to collide with other UAVs or objects. Furthermore, if they are equipped weapons system, they can be maliciously utilized to fire in non-hostile situations. Commercial aircraft, although not a UAV, is still an aerial vehicle and it currently does not have a solid defense against a cyberattacks.


Fig. 5. AR Parrot 2.0 Drone


Fig. 6. 3DR Solo Drone


Fig. 7. DJI Phantom 4 Pro

The REU participants Vincent Tran and Jesus Nunez, guided by Dr. Ajay Katangur, performed vulnerability analysis on three different types of drones. Simulated attacks were carried out and observations were made for security vulnerabilities in the AR parrot 2.0, 3DR Solo, and the DJI Phantom 4 Pro drones. The current auto-pilot systems and security protocols were also examined for vulnerabilities and cyberattacks that are common in network systems. Currently the AR parrot 2.0 drone communicates through an open Wi-Fi connection making it vulnerable to multiple forms of attacks. The 3DR Solo works through a password protected Wi-Fi signal, however, it was possible to obtain such password with the use of specific tools available publicly. This poses a potential threat to the system leaving it open to intrusion. Although the DJI has improved security compared to previous models, GPS spoofing still remains a viable form of attack making it a possible vulnerability in the system. Other forms of attacks were also explored beyond tampering with the network communications of the drones that might pose a threat to the system.

4. Navigating UAV Optimal Path Using Genetic Algorithms
REU Participants: Jonie Moya and Tyler Rook
Mentor: Dr. Alaa Sheta
Graduate Assistant: Samuel Allred

The interest in using Unmanned Aerial Vehicle (UAV) is growing at both in the military and civilian application level. One of the main challenges in the design of a UAV mission is to select an optimal path planning method for hazardous environments. A UAV's mission is to follow a safe path and arrive at a given target while minimizing the traveling distance and maximizing the safety of the flying zones. Another challenge is that the UAV must maintain a constant velocity with no sharp turns to reduce the controller complexity.

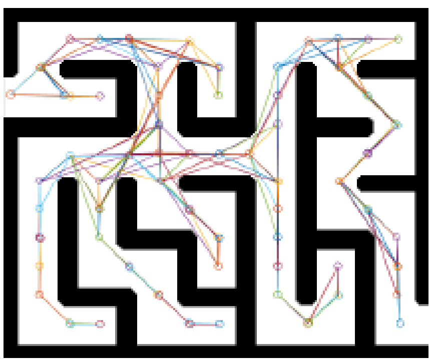
Fig. 8. Connection road map.

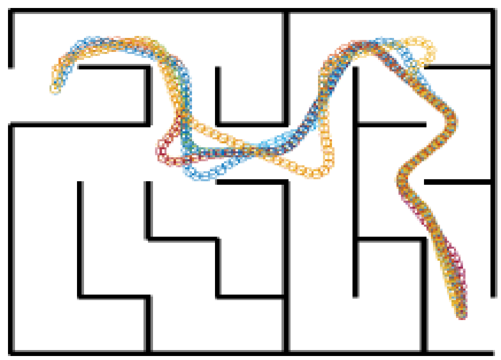
Fig. 9. Pure pursuit path.

In the work, the REU participants Jonie Moya and Tyler Rook developed a path-planning algorithm based on waypoints computed using Genetic Algorithms (GAs). The GAs were used to explore various waypoints from the start point to the target goal. The proposed fitness function can find these points on predefined possible points in the domain of search. The GA produces points of the shortest distance between the start point and the end point by following the pure pursuit algorithm. The results showed the powerful ability of the GA in finding the optimal path. To have successful optimal path finding in complex environments with the use of waypoints brings the future of completely autonomous aerial vehicles closer to reality.

5. Counting Fruits Using Classification with Convolutional Neural Networks
REU Participants: Andrew Garcia and Abrahan Ramirez
Mentor: Dr. Maryam Rahnemoonfar
Graduate Assistant: Samuel Allred and Hamid Kamangir

Farmers need to know how much their crops will yield. They tend to do this manually, going out to the agricultural field and counting their crops in order to estimate a yield. The process is not only time-consuming but also expensive. In the work, the REU participants Andrew Garcia and Abrahan Ramirez worked on developing and testing a software tool that can count fruits through classification implemented in a convolutional neural network. When a farmer needs to know the estimated yield, an individual using the tool would be able to go out, fly a UAV, take images of the crops, run it through the tool, and produce an estimate of the yield for the harvesting season.

Specifically, our proposed tool makes use of deep learning techniques. Deep learning has been a popular method in recent years to classify images for making predictions on images it has never seen before. This research presents a novel approach for classification by integrating counting into classification. This is done by adding classes to the neural network to identify the fruits as well as the number of fruits in the image. The tool developed in this research is a 2D convolutional neural network modeled using TensorFlow. The corresponding network was trained on synthetic image data and then tested on synthetic and real images. In order to test the network, three fruits were chosen: oranges, bananas, and apples, as our main datasets. Images were collected and created to produce a vast amount of training and test data. Experimental results showed, with training the model off a large dataset of synthetic data, provides 96% accuracy for classifying numbers of fruit in an image. When tested with synthetic data, accuracy was found to be between 80% and 100% for counting fruits. However, the accuracy was found to be not good with real images and hence, more research is needed with extensive data set to train the model with real images.

II. Summer 2019: Project Summaries

1. Autonomous Searching and Tracking of Shoreline Using Unmanned Aerial Systems

REU Participants: Adnan Yunus and Garrett Shake
Mentor: Dr. Dulal Kar
Graduate Assistant: Jimmy Dani

With coastal erosion and landscape monitoring becoming more important, scientists and engineers have focused on deriving ways to develop a robust model for shoreline detection. Existing ground surveying techniques for shoreline detection are time-consuming and hazardous due to certain obstacles that are unavoidable and unsafe. Also, techniques based on satellite imagery can miss many important details. As a result, often the measurements obtained from ground surveying and satellite imagery techniques are unreliable or inaccurate. In this work, a new computation model is proposed that involves the photography of shorelines obtained by UAVs (unmanned aerial vehicles) due to their affordability, ability to fly remotely, navigate precisely, and detect vast details. The augmented method reduces the inaccuracies caused by the factors mentioned above. Using computer vision and image processing algorithms, the methodology can detect shorelines by analyzing the characteristics of each of the video frames. Specifically, the image filtering techniques are used to preprocess the data in video frames to extract distinctive features that are used again for SVMs (support vector machines) to detect a shoreline. The results corroborate that the proposed method provides more accurate results for shoreline detection compared to the traditional human based surveying approaches.

Fig. 10. Original image.

Fig. 11. Image with extracted shoreline.

2. Surfzone Bathymetry Estimation using Wave Characteristics Observed by Unmanned Aerial Systems
REU Participants: Hailey Chapman and Henry O'Connor
Mentor: Dr. Michael Starek
Graduate Assistant: Jimmy Danni

Bathymetry, or the measurement of depth in oceans, lakes, and seas has been an area of research since man began to venture out on the open waters. Historically, researching the nearshore surfzone has been a time consuming and expensive process. The tools and methods used to gather data points in the surfzone are either time-inefficient, expensive or both. This is an issue considering how dynamic the surfzone environment can be. It is possible that by the time the surfzone bathymetry measurements have been completed, they are already out of date. This project utilizes unmanned aerial systems (UAS) to gather high-quality video of the nearshore surfzone waves' crest. This footage is processed using scripts that utilize particle image velocimetry (PIV), a method for determining the velocity of particles in sequential images, and then processed further using a well-known relation for calculating wave celerity from bathymetry, in reverse, to obtain the bathymetry itself. Ground-truth data is used to verify the resulting velocity
vectors and depth.

The velocities were manually analyzed and compared to the PIV data. For 50 meters the PIV data was within 4% of our hand timed velocities. And for 75 meters, the PIV data was within 10% of our hand timed velocities. The PIV data was then used to manually calculate bathymetry using velocities found on wave edges. For 50 meters, the results were within our 10 cm margin of error for our ground truth data and were within 10% of error. For 75 meters, the depth data was within 30% of error, and hence, was no longer within our margin of error. Image stabilization and lens correction were not used due to technical issues during processing.

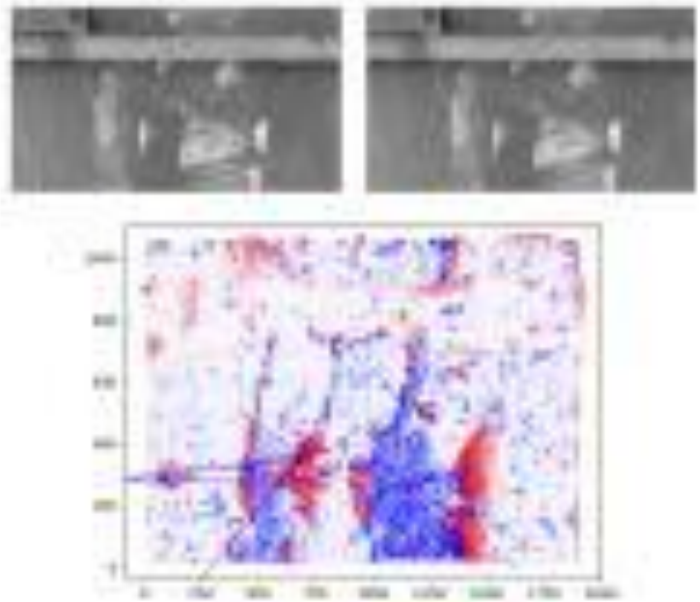

Fig. 12. Python PIV sequential image pair and velocity vector field output.

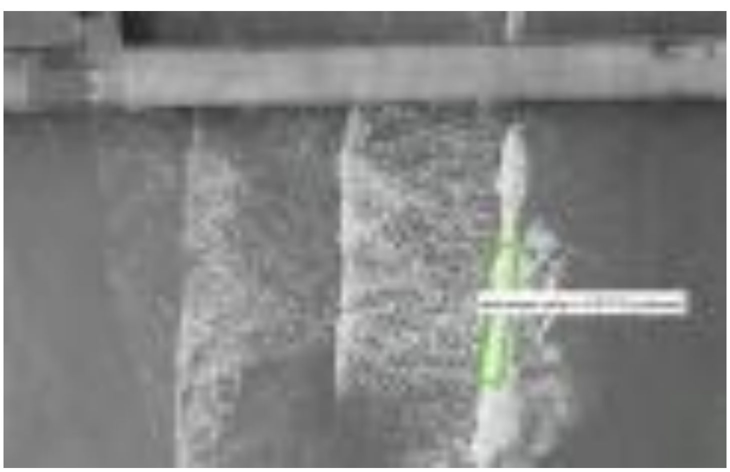

Fig. 13. Local velocity estimation with PIVLab.

3. Drone Collective App: A Multi-UAV Communication System
REU Participants: Matthew Hancock and Angelica Everett
Mentor: Dr. Mamta Yadav
Graduate Assistant: Jimmy Dani

Traditional search and rescue operations include the use of boats and helicopters, which can be both time-time and expensive; therefore, unmanned aerial vehicles (UAVs) are becoming the aircraft of choice with regards to search and rescue operations for natural disasters. For such operations one UAV is not adequate enough to monitor large, affected areas, so a swarm of UAVs is needed to monitor such areas as fast as possible. To complete the missions faultlessly, the swarm UAVs must be able to communicate efficiently with each other and navigate properly. In this work, a mobile application is developed that has the potential to handle communication among multiple UAVs. The design process includes three main parts: preparing the source code and graphical user interface (GUI) design, preparing the cloud database for storing UAV information necessary for flight operations, and designing a simulation to test the efficiency of the mobile application and cloud database. We use Android Studio and Java to design the mobile application's GUI and access the cloud database, Firebase Realtime Database to create the real-time database, and MORSE simulator to design and develop the simulation for testing purposes.

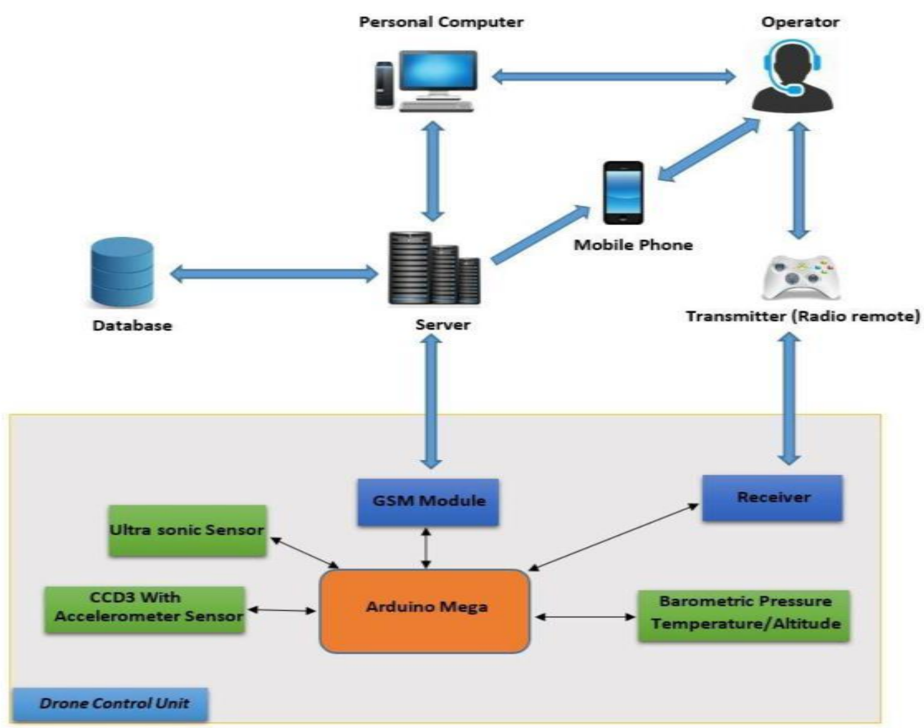

Fig. 14. System Design.

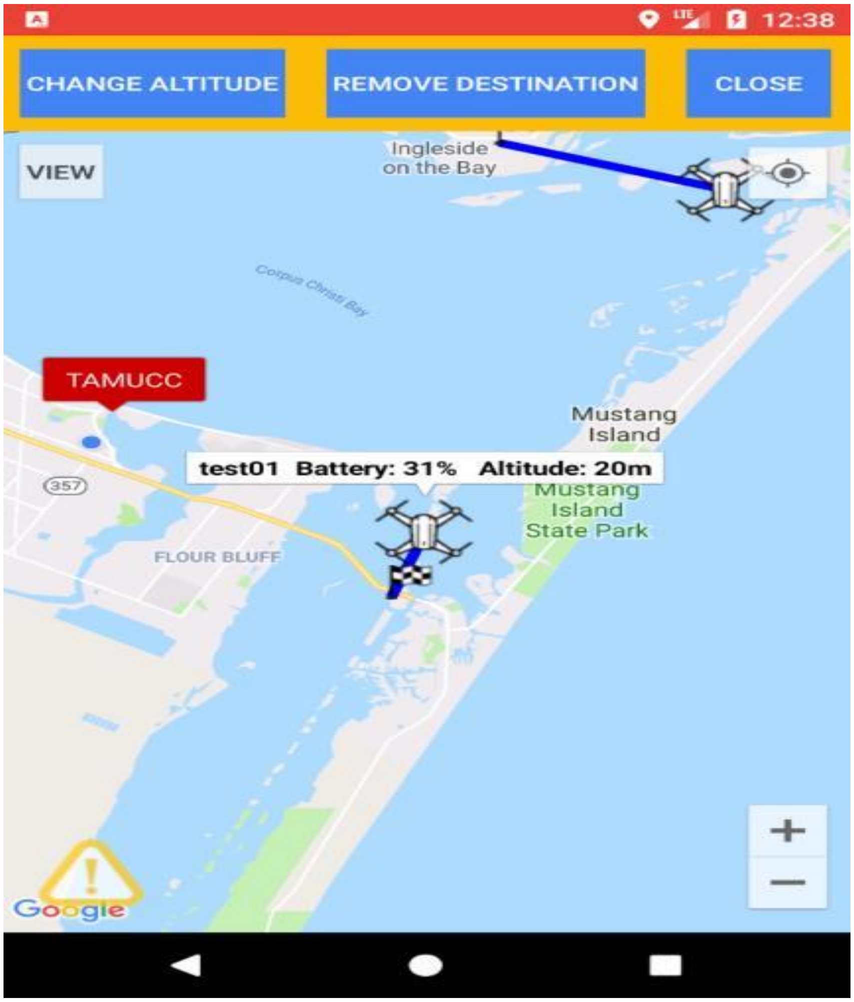

Fig. 15. Map for Drone Collective App.

The app Drone Collective allows us to use real-time data to control and communicate with multiple UAVs during flight operation. Compared to several similar applications that have attempted to create this kind of versatility, our Drone Collective is very extensible and can be applied to many of these organizations' pursuits in the autonomous flight and operation of UAVs.

4. Path Planning of Unmanned Aerial Vehicles Using Metaheuristics
REU Participants: Jacob Hopkins and Forrest Joy
Mentors: Dr. Alaa Sheta and Dr. Hamza Turabieh
Graduate Assistant: Jimmy Dani

Unmanned Aerial Vehicles (UAV) have been a growing part of aviation for quite some time now and have proved to be useful across many civilian and military applications. UAVs are often low resource machines, meaning they often are too small to contain the same amount of resources as other flight capable machines, like airplanes. Thus, careful planning of the missions is required to efficiently use these limited resources and accomplish the mission task. A major aspect of these mission planning is path planning. Path Planning is widely recognized as being one of the most difficult problems within the field of Robotics. The purpose of path planning is to find a path between a starting point to a goal point in an environment while optimizing the use of various resources and avoiding obstacles. The difficulty of path planning comes from exponential increase of complexity as the dimensions of the problem space increases. Thus, a search algorithm is necessary to explore the environment for a possible path and critical to determining the optimal path. For a search algorithm to be suitable for path planning, it must be able to find the global optimal path that is feasible from a M x N environment within an acceptable time and avoid premature convergence. This work proposes the use of a penalty based constrained Genetic Algorithm (GA) paired with Gazebo simulator to simulate the execution of the path produced.

The proposed GA was compared to a more classical method, A* algorithm. In the comparison test, the proposed GA was able to find a solution in a significantly faster time and with much less computational complexity than A*. To simulate the generated solutions of GA, a pure pursuit controller was created that could interface with a Gazebo simulated environment. The GA path planning system and pure pursuit controller were combined into one system. A proof-of-concept test was done with the system, a blank Gazebo environment, and the Hector model quadrotor. The test showed that the path planning and controller system could operate the simulated quadrotor.

5. Classification of Seagrass using Machine Learning Models
REU Participants: John Penaranda and Shawn Smith
Mentor: Dr. Scott King
Graduate Assistant: Evan Krell and Jimmy Dani

Coastal seabeds are often inhabited with an abundant amount of aquatic species which include turtles, fish, shrimp, and crabs. In order for these creatures to thrive there needs to be a presence of seagrass meadows. These meadows provide food, shelter, and a place for aquatic animals to lay their eggs. Unfortunately, seagrass meadows have been compromised due to human activity. The presence of seagrass in underwater habitats has severely declined along the US coastline; reductions of over 70% has occurred along coastlines and continue to decline. Surveying these areas of interest as well as determining their conditions will help determine the effects of altering these ecosystems. This can help scientists and marine biologist to get a better understanding of this evolving ecosystem.

The test system used to collect raw data is shown in Fig. 16. The vehicle was built using common tools and a DIY drone kit whose main unit is a Pixhawk running a customized firmware for operation. In this work, we investigate the applicability and viability of using an RGB camera for data collection of near-shore areas using an ASV (autonomous surface vehicle) to determine the presence of plant life using computer vision for pre-processing and feature extraction, as well as machine learning algorithms for classification. For image enhancement, defogging, normalizing, and color balancing filters were applied prior to implementing a machine learning algorithm in order to determine their effectiveness.

Our research utilized various machine learning models that were available in a machine learning toolkit Orange which includes Neural Networks (NN), Support Vector Machine (SVM), Random Forrest, Naive Bayes and K-Nearest Neighbor (KNN). Our research found that NN and SVM were the two algorithms that yielded the best results for the data that was extracted from the images. The overall classification accuracy (CA) for the NN was 84%. This value was compared to the other CA results generated by the other models that were used. The model that produced the next best result was the SVM which had a CA of 71%.

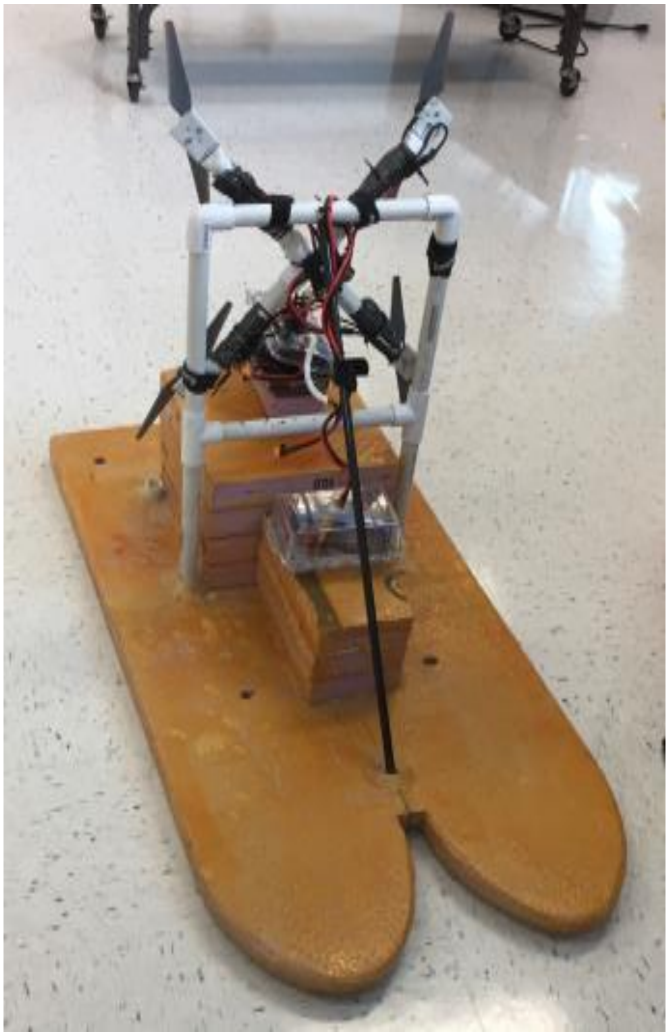

Fig. 16. Surface Vehicle


Fig. 17. Original Image

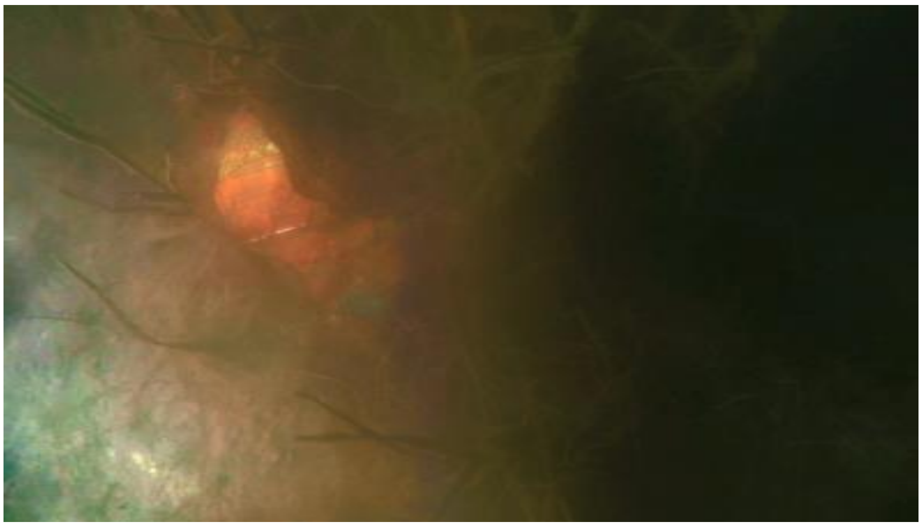

Fig. 18. Enhanced Image.

III. Summer 2021: Project Abstracts

1. Coastline Detection through Image Segmentation Using UNet

REU Participants: Kristine Veneles and Donovan Dahlin
Mentor: Dr. Dulal Kar
Graduate Assistant: Jacob Hopkins

Abstract—Coastlines are an important yet volatile part of the environment and frequently change over time. Studying changes in coastlines can give important insights about the environment, so using efficient means to observe them is important. UAVs are cheap, fast and effective tools in gathering information, and segmentation can be used to detect and record the coastline. This paper proposes the use of CNN models to assist UAVs in detecting coastlines. Specifically, our research focuses on the combination of a neural network model, such as UNet, with transfer learning using a pre-trained model. The resulting model achieves semantic segmentation of coastlines to distinguish water and land. This allows UAVs to better recognize coastlines and reinforce their role in remote sensing image processing.

2. Detection of GPS Spoofing in UAVs Using Deep Learning and Machine Learning

REU Participants: Jaron Burns and Dimitris Amiridis
Mentor: Dr. Longzhuang Li
Graduate Assistant: Rohith Mandala

Abstract—Multiple approaches to detect drone GPS spoofed signals using machine learning and deep learning algorithms were investigated. Methods such as PCA, autoencoders, and LSTM-based autoencoders were implemented to reduce the dataset dimensions. Detection was achieved using machine learning algorithms such as SVM and logistic regression. Ultimately, it was the machine learning SVM based approached that yielded the highest detection rates at over 99.8% in terms of accuracy, precision, F1 score, and recall, regardless of whether it was handling a clean dataset, an imbalanced one, or one with Gaussian noise.

3. Surfzone Bathymetry from UAS Footage Using Water-Masking Stabilization and Deep Learning PIV Techniques

REU Participants: Emily Maxey and Lorryn Berry
Mentor: Dr. Michael J. Starek
Graduate Assistant: Bradley Koskowich

Abstract—The surfzone bathymetry project was started in summer 2019 as an REU Site project. The goal of this research was to improve upon the previous methods that were used by the earlier REU participants, as well as to apply a deep learning technique to the particle image velocimetry aspect of the project. There were many new techniques added that the prior REU had not implemented. First and foremost, stabilization was added to provide more accurate results. Under the stabilization technique that was implemented, the water within the frames was masked out so that it would not provide false keypoints. Using parallelism, the computation time for the previous code was significantly decreased from multiple days to right around 6 hours, for the same data set. While this was a great contribution, the goal of creating more accurate results was

only partially met. There was an error of just about six percent when running every tenth frame in the Deep-PIV method, as opposed to fourteen percent running the entire dataset with the traditional OpenPIV library.

4. Channel-wise PartitionShap and Multispectral XAI Techniques
REU Participants: Joshua Friesen and Julianna Judge
Mentors: Dr. Scott King and Mr. Evan Krell

Abstract—Advances in explainable artificial intelligence (XAI), a subfield of computer science dedicated to AI with the ability to explain its reasoning for the solutions it produces, has given way to numerous approaches and techniques and further advances to them. To that are featured predominately in this research are the use of 3D XAI techniques, and those that can produce channel-wise explanations, allowing for the analysis of more complex models with localized explanations. These techniques are employed in two satellite image classifying models, one with RGB bands and the other with RGB and near-infrared (NIR). They were found to meet the expectation that the 4-band model would learn to rely on its fourth band, NIR, and outperform its 3-band counterpart. A new XAI technique, channel-wise PartitionSHAP, is then demonstrated with its ability to give channel-wise explanations.

5. Exploring Feature Correlation in Complex Models with High Dimensional Data Through Clustering and XAI
REU Participants: Aaron Moreno and Ramon Villalobos
Mentors: Dr. Scott King and Evan Krell

Abstract—The increasing complexity of today's AI applications has turned more and more models into black boxes. The use of explainable AI (XAI) aims to offer a solution to this problem by providing a summary of the features the model determines important for making a prediction. However, this is not a perfect an all-encompassing solution. All current XAI methods struggle greatly with high dimensionality models and models with correlated features. In this work, we aim to create a way to visually compare different XAI techniques and to use clustering on correlated features to provide a more significant explanation of feature importance to the user. In order to accomplish this goal, we have worked on a fog prediction model that uses over a thousand highly correlated features. This technology would help greatly in clearing black box AI models and offer researchers a new tool to improve and debug their work.