UCF Senior Design I

Title: Swarm Operations & Autonomous Rescue (SOAR)

Department of Electrical Engineering and Computer Science
University of Central Florida
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Initial Project Document and Group Identification
Divide and Conquer

Group 15

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Chapter 2 - Project Description

2.1 Project Background and Motivation

When disaster strikes, the clock starts ticking. Search and rescue teams face tremendous challenges, including limited resources and hazardous conditions that put responders at risk. Our SOAR project (Swarm Operations & Autonomous Rescue) has the goal to overcome these obstacles, as we are building a coordinated fleet of specialized drones that can work together autonomously to locate people at risk, utilizing multiple sensor technologies to search hazardous areas quickly and effectively.

For our senior design capstone, SOAR represents an essential test of our engineering skills, as it challenges us to integrate knowledge from aerospace, electrical, computer, and mechanical disciplines into a cohesive system. As this experience mirrors real-world engineering challenges, it teaches us how to innovate and problem-solve as a team while developing the AI that enables them to communicate, make decisions, and collaborate as a true swarm.

The prospect of our project can go beyond a concept, where, if successful, this technology could transform the way emergency responses are conducted, dramatically reducing search times and ultimately saving lives. The core swarm intelligence and multi-sensor integration we're developing can also be adapted for other critical necessities, such as environmental monitoring and assessment, as well as security operations, demonstrating the real-world value of autonomous collaborative systems.

2.2 Current Commercial Technologies and Existing Projects

2.2.1 Drone Technologies in Search and Rescue

- Commercial drone platforms such as the DJI Matrice 300 RTK and Parrot Anafi USA have demonstrated the usefulness of UAVs (Unmanned Aerial Vehicles) in emergency responses
- These drones are typically equipped with thermal imaging cameras, LiDAR, and optical sensors to locate individuals in challenging environments (building, forests, disaster zones)
- Effectiveness is limited by reliance on human operators to pilot the drones; primarily designed for single-unit operation

2.2.2 Swarm and Multi-Agent Systems

- Research organizations and defense industries have begun developing drone swarms that demonstrate autonomous coordination such as DARPA's OFFSET program (Offensive Swarm-Enabled Tactics) and the ETH Zurich Flying Machine Arena
- Potential of swarms in terms of scalability, redundancy, and adaptability
- Current systems are either proof-of-concept demonstrations in controlled environments or developed for military applications

2.2.3 Sensor and Communication Technologies

- Thermal imaging allows detection of body heat in low visibility conditions, multispectral and hyperspectral cameras capture data across multiple bands of the electromagnetic

spectrum to provide environmental insights, and LiDAR enables mapping in smoke or debris filled environments
- Many drones depend on direct operator link such as dedicated radio frequency (RF) or Wi-Fi connection between the UAVs and ground controller; limited range
- Emerging solutions include mesh networks and 5G-enabled drones which will enable multiple UAVs to maintain situational awareness and data sharing even when infrastructure is damaged

2.2.4 Limitation of Current Technologies

- Short battery life, often less than 30 minutes, restricts mission duration
- Direct operator link communication face Beyond Visual Line of Sight (BVLOS) restrictions, limiting operational range

2.2.5 AI and Autonomy

- Object detection models are being trained to recognize human figures, vehicles, or signs of movement in aerial imagery
- Simultaneous localization and mapping (SLAM) techniques enable navigation in GPS-denied environments
- Projects like Skydio's AI powered obstacle avoidance and Goggle's Wing drone navigation demonstrate how autonomy can transform UAV operations

2.2.5 Summary

- Existing technologies provide a strong foundation for UAV-based search and rescue
- Commercial drones deliver reliable platforms with advanced sensors, while swarm research proves the potential for multi-agent collaboration
- Sensor and communication systems continue to evolve, offering tools to locate survivors
- Limitations such as short endurance, limited range, and incomplete autonomy still prevent widespread deployment
- Our SOAR project aims to bridge these gaps by integrating multi-sensor payloads, swarm intelligence, and autonomous decision-making into a cohesive system designed for real-world rescue operations

2.3 Goals and Objectives

2.3.1 Goals

Basic goals:

- Develop a functional heterogeneous swarm of four drones capable of basic autonomous flight and inter-drone communication.
- Integrate distinct sensing modalities (e.g., Infrared, Optical Camera) onto individual drones to enable complementary data collection.
- Establish a foundational communication network for sharing basic telemetry and status updates between drones.
- Demonstrate a proof-of-concept search pattern within a defined area.

Advanced goal:

- Implement distributed AI algorithms for dynamic task allocation, allowing drones to autonomously divide and conquer a search area.
- Achieve real-time sensor fusion, combining data from multiple drones to create a unified, confident identification of a target.
- Develop and demonstrate efficient route optimization algorithms that minimize total search time while ensuring complete area coverage.
- Create a robust system that can successfully locate and identify mock targets (e.g., heat signatures, objects) within a strict time limit.

Stretch Goal:

- Enable the swarm to autonomously adapt its search strategy based on real-time findings from a subset of drones.
- Incorporate a ground control station to visualize swarm movement, sensor data, and target identification in real-time.
- Implement machine learning-based target recognition to improve classification accuracy of objects of interest.
- Expand the swarm's operational capabilities to include basic mapping of the search area.

2.3.2 Objectives

Basic Objective:

- Construct and configure four flight-ready drones, each equipped with a Pixhawk (or similar) flight controller for autonomous operation.
- Integrate at least two different sensor types (e.g., IR thermal camera, HD RGB camera) across the swarm, with each sensor functional and streaming data.
- Establish a mesh network using ESP-NOW or Wi-Fi protocols, demonstrating successful transmission of GPS coordinates and status messages between all drones with a latency of <100ms.
- Program a basic pre-defined search flight path (e.g., lawnmower pattern) that all drones can execute simultaneously to cover a 100m x 100m area.

Advanced Objective:

- Develop a distributed algorithm where drones broadcast discovered sub-areas, enabling the swarm to collectively avoid redundant search efforts and achieve >95% area coverage.
- Fuse IR and optical camera feeds to correctly identify and classify a minimum of three distinct target types (e.g., person, vehicle, backpack) with 90% accuracy in a controlled environment.
- Implement a route optimization algorithm that reduces total search time by at least 20% compared to a simple parallel lawnmower pattern.
- The full swarm must successfully locate and identify all mock targets within a 15-minute time constraint in a designated outdoor search area.

Stretch Objective:

- Design a decision-making algorithm where a drone that identifies a potential target can summon the nearest drone with a complementary sensor for verification, without human intervention.

- Develop a ground control software interface using Mission Planner or a custom Python application to display live drone positions, sensor status, and target confirmation alerts.
- Train a convolutional neural network (CNN) model for object detection that can be run on the drones' companion computers, achieving a mean Average Precision (mAP) of >0.85 on test data.
- Generate a basic 2D georeferenced map of the search area, overlaying the locations of identified targets, using data collected from the swarm.

2.3.3 Hardware

2.3.3.1 Drone Platforms & Autonomy – Basic Goals:

The SOAR system's core consists of a minimum of four quadcopter drones, forming a scalable and heterogeneous swarm. Each drone platform must be capable of stable, autonomous flight and serve as a robust base for specialized sensor payloads. The primary autonomy for each unit will be managed by a Pixhawk 4 (or similar) flight controller, running the PX4 open-source autopilot software. This enables pre-programmed mission execution, failsafe behaviors, and low-level flight stability.

The critical hardware differentiator is the assignment of a unique sensing modality to each drone, creating a complementary data-gathering system. The physical integration of these sensors requires careful consideration of weight distribution, power draw, and vibration damping to ensure both flight performance and sensor data integrity. Each drone will be powered by a high-capacity 4S Lithium-Polymer battery to provide sufficient flight time for search missions, with all electronic speed controllers (ESCs), motors, and propellers selected to provide the necessary thrust-to-weight ratio for the added payload.

2.3.3.2 Heterogeneous Sensing Payloads – Basic Goals:

The swarm's effectiveness hinges on its heterogeneous sensing suite, with each drone equipped for a specific detection role: Thermal Imaging Drone: This unit will be equipped with a FLIR Lepton or similar miniature radiometric thermal camera. Its primary function is to detect heat signatures, crucial for locating living persons or recent mechanical activity through visual obstructions like foliage or in low-light/night conditions. The camera will be mounted on a vibration-isolated gimbal for stable imagery and connected to an onboard companion computer (e.g., NVIDIA Jetson Nano) for initial image processing.

Optical Imaging Drone: This drone will carry a high-resolution RGB camera, such as a GoHeroic or similar, capable of streaming live video and capturing still images. Its role is to provide detailed visual confirmation and identification of targets located by other drones, and to gather general situational awareness of the search area. Computer vision algorithms will run on its companion computer to perform real-time object detection.

LIDAR Mapping Drone: This unit will be fitted with a lightweight 2D or 3D LIDAR sensor (e.g., RPLIDAR). Its objective is to generate real-time 2D elevation maps or 3D point clouds of the terrain. This data is critical for identifying potential hazards, understanding the topography for route optimization, and locating objects based on structural shape rather than thermal or color properties.

Communications Relay & Backup: The fourth drone may carry a secondary sensor (e.g., a zoom camera) but will primarily function as a communications relay node. It will be equipped with a longer-range communication module (e.g., LoRa) to help maintain the integrity of the swarm's mesh network over larger distances and challenging terrain, ensuring no drone becomes isolated.

2.3.3.3 Swarm Communication Network – Advanced Goals:

A robust inter-drone communication network is the backbone of swarm coordination. The system will implement a hybrid communication architecture. For high-bandwidth, short-range data transfer (e.g., sharing sensor data, video streams), a Wi-Fi mesh network protocol will be used, allowing any drone to act as a node and relay information. For critical, low-bandwidth command and control messages (e.g., task allocation, status updates, heartbeat signals), a more reliable and longer-range protocol like ESP-NOW or LoRa will be utilized. This ensures that even if the high-bandwidth link is degraded, the swarm can maintain coordination and execute fundamental commands. Each drone will be equipped with multiple transceivers to manage these simultaneous communication channels.

2.3.3.4 Onboard Computation – Advanced Goals:

Each drone's sensing payload will be managed by an onboard companion computer, such as an NVIDIA Jetson Nano or Raspberry Pi 4. These devices are responsible for the initial processing of raw sensor data (e.g., cropping thermal images, running inference on object detection models, parsing LIDAR point clouds) before transmitting relevant findings to the swarm. This edge computing approach minimizes the volume of data that needs to be transmitted wirelessly, reducing latency and bandwidth requirements. The companion computers will also host the distributed AI algorithms that allow for decentralized decision-making, such as negotiating task division based on proximity and sensor capability.

2.3.3.5 Ground Control Station (GCS) – Stretch Goal:

A central Ground Control Station will serve as the human-machine interface for the swarm. The hardware for the GCS will be a ruggedized laptop running mission planning software like QGroundControl or a custom-developed application. This station will be equipped with a long-range radio telemetry link (e.g., 900 MHz) to maintain a constant connection with the swarm, allowing an operator to monitor the overall mission progress, view live sensor feeds from individual drones, update mission parameters on the fly, and receive automated alerts upon target identification. The GCS will also log all telemetry and sensor data for post-mission analysis.

2.3.4 Software

2.3.4.1 Core Swarm Intelligence – Basic Goals:

The software architecture for SOAR is the central nervous system that transforms individual drones into a cohesive, intelligent swarm. The core software goals are divided into four pillars: autonomy, communication, coordination, and perception.

The foundation is Autonomous Flight & Navigation, managed by the PX4 flight stack on each drone's Pixhawk controller. This software handles low-level stabilization, waypoint navigation, and failsafe procedures, providing a stable platform for higher-level algorithms.

The Communication Layer will be implemented using the MAVLink protocol, a lightweight messaging standard for communicating with drones. To create a resilient swarm, a mesh networking protocol will be built on top of MAVLink, allowing any drone to act as a router, relaying commands and data to extend the network's range and prevent single points of failure.

The most critical component is the Swarm Coordination Algorithm. This distributed AI will be hosted on each drone's companion computer and is responsible for decentralized decision-making. Its primary functions include:

Dynamic Task Allocation: Using a market-based or consensus algorithm, drones will autonomously negotiate and assign search sectors based on their proximity, battery life, and sensor capability.

Collaborative Path Planning: Drones will not only plan their own routes but also share their intended paths to optimize overall area coverage and avoid intra-swarm collisions, ensuring the entire search area is scanned efficiently.

Distributed Sensor Fusion: Software modules will be developed to fuse data from different drones. For example, the thermal drone's detection of a heat signature will trigger a request for the optical drone to provide visual confirmation, creating a unified, multi-modal target identification.

Finally, the Perception & Detection software will include machine learning models for real-time analysis. This includes a convolutional neural network (CNN) for the optical drone to identify objects of interest and computer vision algorithms for the thermal drone to isolate human-sized heat signatures from background clutter.

2.3.4.2 Adaptive Machine Learning & Mapping – Stretch Goals:

A key stretch goal is the development of Adaptive Learning Algorithms. This software would allow the swarm to learn from its search patterns and target discoveries in real-time. If a specific area or type of terrain consistently yields false positives, the swarm could collectively adjust its detection parameters or search strategy for subsequent missions, continuously improving its performance without human intervention.

Another advanced objective is the creation of a Real-Time Collaborative Map. Software on the ground control station (GCS) would ingest and synthesize LIDAR data, target coordinates, and geotagged images from all drones to construct a live, shared 2D/3D map of the search area. This map would be broadcast back to the swarm, providing each unit with an updated common operational picture to inform their future navigation and search decisions.

2.3.4.3 Advanced Ground Control Station (GCS) Interface – Stretch Goal:

The stretch goal for human-swarm interaction is a sophisticated GCS Software Suite. This custom application would be built using a framework like NASA's OpenMCT or ROS. Its features would include:

- Live Swarm Visualization: A real-time map display showing the position, status, and live video feed of every drone in the swarm.
- Mission Orchestration: A user-friendly interface for defining search areas, setting priorities, and initiating the mission with a single command, leaving the complex task division to the swarm.
- Target Management Console: An alert system that aggregates and displays all potential targets identified by the swarm, complete with confidence levels and fused sensor data (e.g., a thermal image alongside an optical confirmation shot).
- Data Logging & Post-Mission Analysis: Comprehensive logging of all telemetry, communication messages, and sensor data to enable detailed performance review and algorithm refinement after a mission.

2.4 Required Specifications

Drone Communication Subsystem

Parameter	**Specification**
GPS Update Rate	10-20 Hz
Video Transfer Frequency	5.8 GHz (Analog/Digital)
Communication Range	> 1 km (LoRa / SiK radio)

- Description: Each drone will transmit telemetry and video data using long-range modules (e.g., SiK radios for telemetry and 5.8GHz analog/digital transmitters for video).
- Usage: Enables swarm-to-ground communication and data logging during missions.

Obstacle Detection Subsystem

Parameter	**Specification**
Horizontal FOV	360°
Effective Detection Range	12–25 meters

- Hardware: 1x LIDAR module (Benewake TF-Luna / TFMini-S) for depth sensing and collision avoidance.
- Usage: Allows each drone to detect static and dynamic objects in the environment for safe navigation.

Camera Systems

a) Normal RGB Camera (EO)

Parameter	**Specification**
Resolution	2688×1520
Field of View (FOV)	104° × 57°
Frame Rate	20 FPS
Size	109.9mm × 81mm
Weight	470g

- Usage: Used for daytime search, target detection, and visual navigation.
- Notes: Mounted on Drone A. May stream to ground station or record locally for AI processing.

b) Thermal IR Camera

Parameter	**Specification**
Resolution	32×24
Field of View (FOV)	55° × 35°
Frame Rate	32 FPS
Size	25.7mm × 17.7mm × 16.0mm
Weight	3.5g
Temperature Detection Range	-40°C to 300°C
Accuracy	±2°C
Cost Estimate	$40 < x < $60

- Hardware: FLIR Lepton or similar low-cost thermal core.
- Usage: Mounted on Drone B. Identifies warm targets (e.g., humans) in low visibility or night conditions.

Ultrasonic Sensor System

Parameter	Specification
Detection Range	Up to 7.5 meters (25 ft)
Accuracy	±1 cm
Weight	~4g
Power Consumption	~5V @ 15–20 mA

- Hardware: MaxBotix MB1240 or HC-SR04 (if low-cost option).
- Usage: Used on Drone D for close-range scanning, edge detection, and perimeter confirmation in cluttered zones.

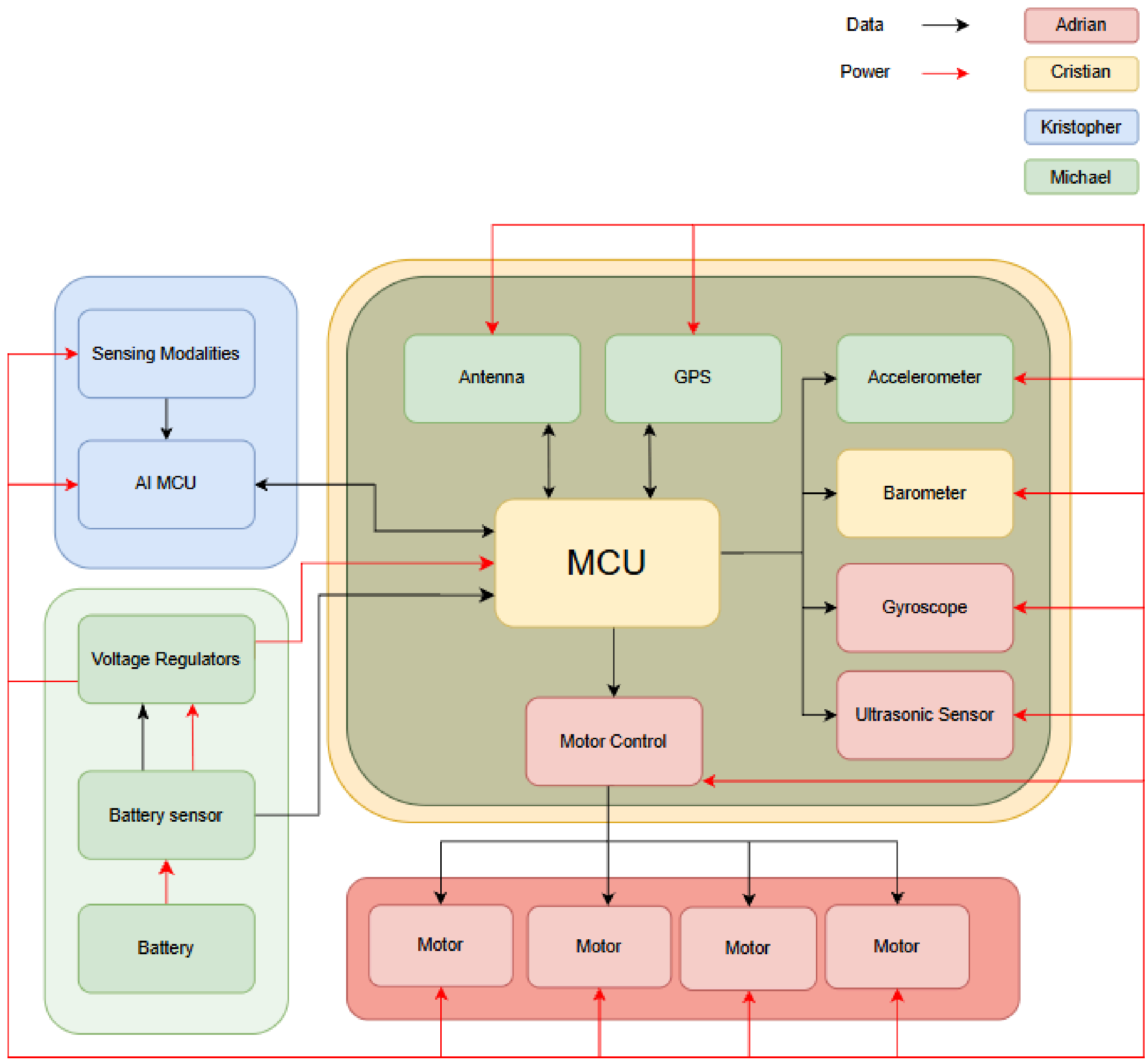
Processing & Control

Component	Specification
Flight Controller	Pixhawk 6C Mini or Holybro variant
Companion Computer	Raspberry Pi 4 / Jetson Nano
Operating System	Ubuntu + ROS 2 / ArduPilot firmware
Communication Protocol	MAVLink / ESP-NOW

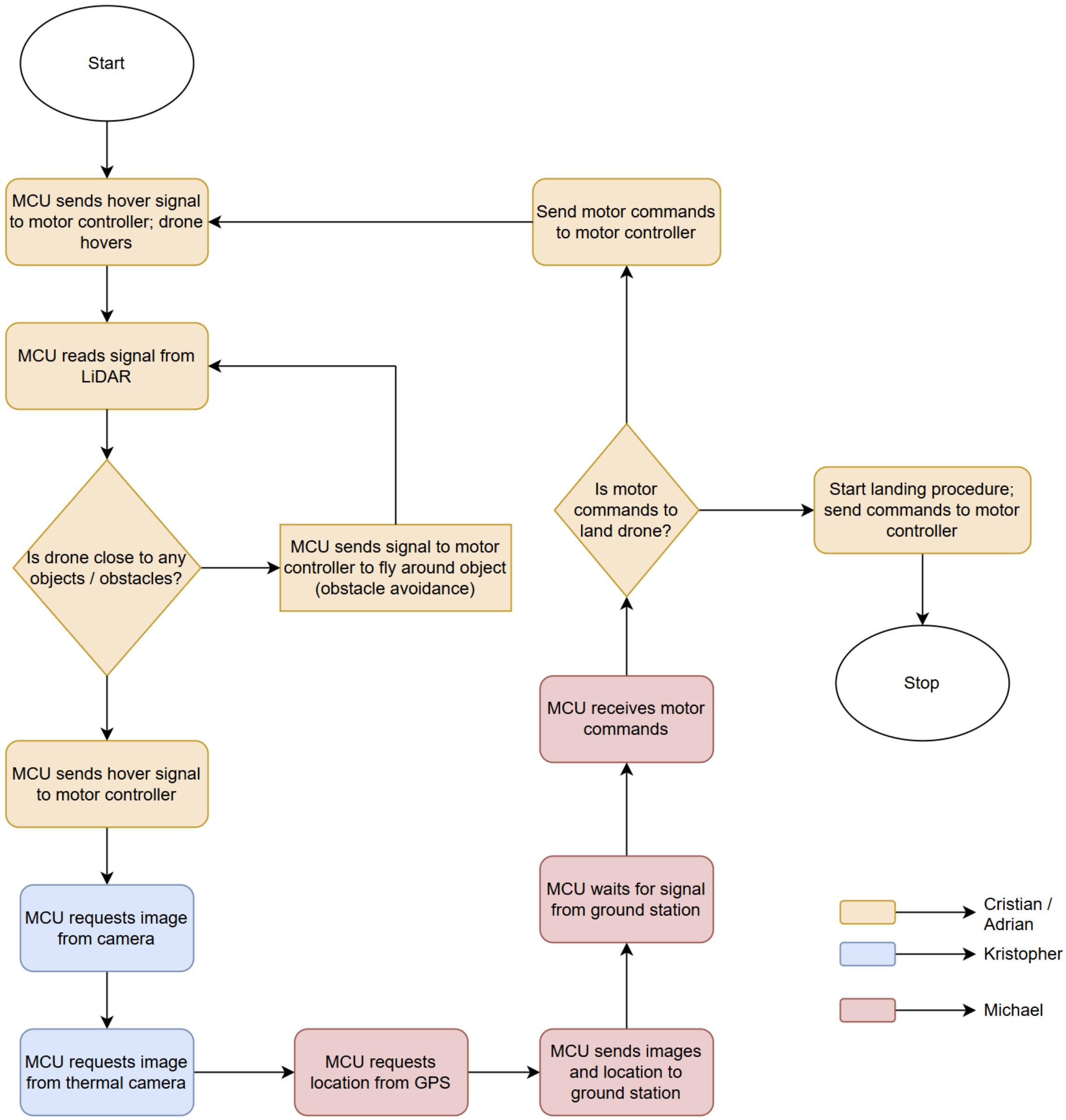
- Description: Companion computers process onboard data, run AI/ML inference, and manage swarm logic. Flight controllers interface with sensors and motors via real-time firmware.

Ground Station

Component	Function
Ground Laptop	Mission control & visualization
Software Tools	QGroundControl, ROS Rviz, Custom GUI
Connectivity	Telemetry radio, Wi-Fi uplink

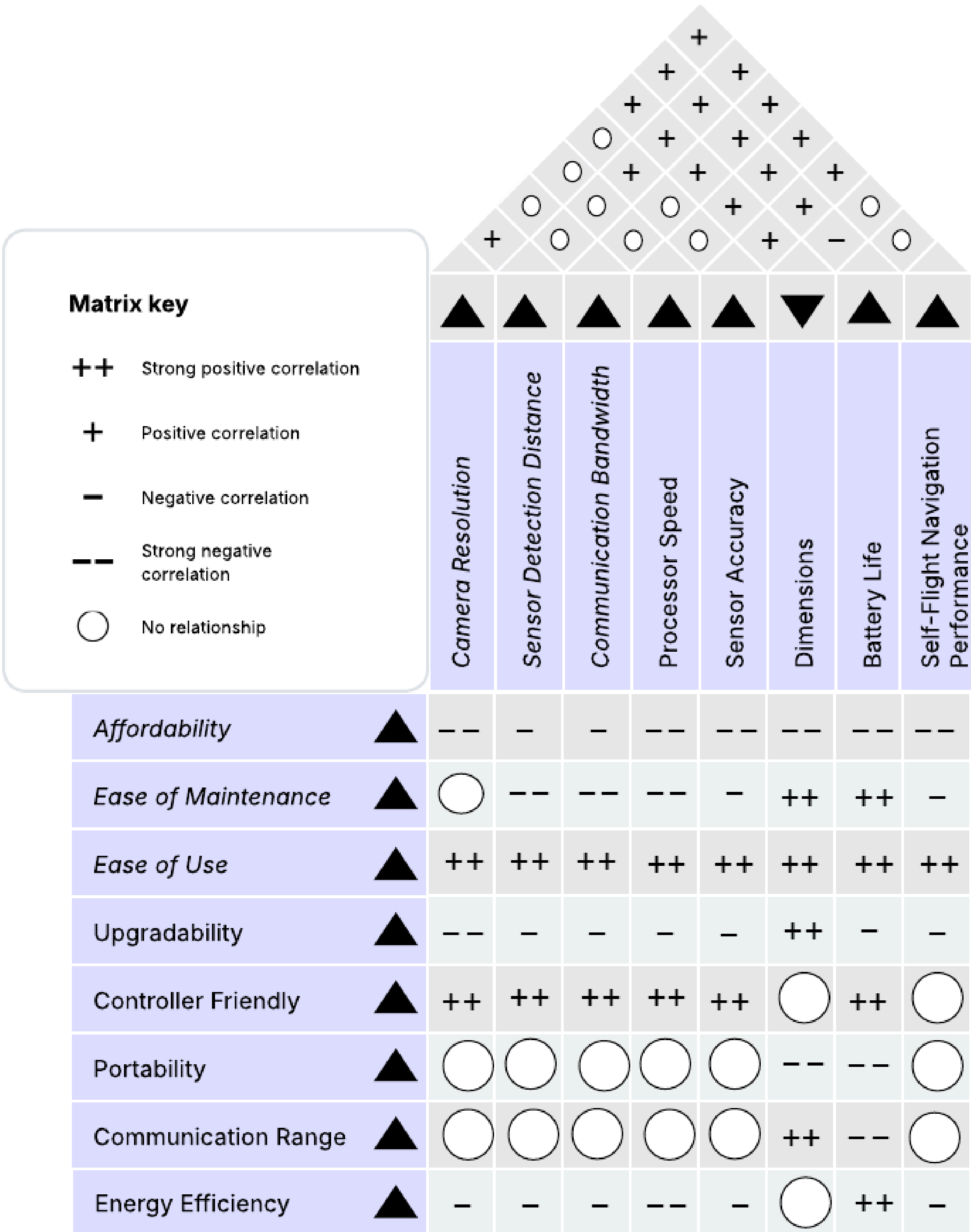


SOAR hardware system diagram is shown above. The diagram demonstrates the core hardware components needed for SOAR to perform flight and detection. Separated by color, are the different part systems.
Figure 2.4.1 System Hardware Diagram by Authors



The Software Flowchart outlines the process of the SOAR following directions and detections.
Figure 2.4.2 Software Flowchart by Authors

2.5 House of quality



The picture above is the house of quality for our SOAR which provides a visual aid of engineering characteristic tradeoffs. The left-handed columns depict features that are deemed important to the end user. The columns located at the top of the table demonstrate the features that could potentially be traded off during engineering parameter considerations.

Figure 2.5 House of Quality by Authors

Chapter 8 - Administrative Content

8.1 Budget

Our project is supported by Lockheed Martin and the University of Central Florida (UCF), with a projected total budget of $5,000. We plan not to use the full funding and hope to use as minimal as spending as possible. This funding will be used strategically to cover both hardware and software resources necessary for the development, testing, and demonstration of the SOAR drone swarm.

The budget will be primarily allocated to the following key components:

- Drone Frames and Flight Controllers: Includes the base hardware for each of the four drones, such as ESCs, motors, propellers, and flight controllers (e.g., Pixhawk or STM32-based).
- Sensor Packages (1 per drone):
  - EO (RGB) Camera: For real-time visual feedback and target recognition.
  - Thermal (IR) Camera: For detecting human heat signatures during SAR.
  - LIDAR Module: For environmental mapping and obstacle detection.
  - Ultrasonic Sensor: For short-range proximity awareness in cluttered environments.
- Microcontrollers and Embedded Systems: Microcontrollers (e.g., STM32, ESP32) will handle sensor interfacing, real-time control, and communication.
- Communication Modules:
  - Wi-Fi mesh transceivers for drone-to-drone and drone-to-ground networking.
  - Optional LoRa or APRS modules for long-range GPS data transmission.
- Power Systems: Batteries, BMS (Battery Management Systems), and charging hardware to support extended operations and safety compliance.
- Development Tools: Software licenses (if needed), soldering kits, cabling, and 3D-printed mounts for hardware integration.
- Spare Components & Contingencies: A reserve of approximately 10–15% of the total budget will be set aside for unexpected hardware replacements or upgrades during development and testing.

We plan to take advantage of Lockheed Martin's sponsorship to source advanced sensors (e.g., thermal and LIDAR) directly through their procurement channels, reducing cost burdens and ensuring the use of industrial-grade components. The budget will be tracked throughout the semester using a shared financial spreadsheet, and any major purchase decisions will be made collectively by the team and approved by the faculty advisor.

Sub-System	**Estimated Budget**
Microcontroller Units (MCUs)	$300

Communication Modules (e.g., Wi-Fi, APRS)	$600
EO (RGB) Cameras	$200
Thermal Cameras (IR)	$200
GPS Modules	$150
Additional Sensors (LIDAR, Ultrasonic)	$600
Motors & ESCs	$600
Power Systems (Batteries, Power Mgmt)	$300
Drone Frames & Assembly	$400
Licensing & Registration	$400
Total	**$3750**

8.2 Milestones

The development of this project relies on regular meetings and events to strengthen teamwork and guide progress toward success. At the start, new members are welcomed into the group, and during the first week of Senior Design I, brainstorming sessions are held to exchange ideas and lay down a clear plan for moving forward.

Project Initialization				
Start Date	Planned End Date	Required End Date	Task	Description
08/18/2025	08/18/2025	08/18/2025	Recruiting	Members Recruited: Adrian Castillo (CpE) Cristian Gomez (CpE) Kristopher Tellez (CpE) Michael Palin (CpE)
08/18/2025	08/24/2025	08/24/2025	Brainstorming	Meeting in person to decide and pick a project idea for the group
08/24/2025	09/04/2025	09/05/2025	Initial Document	First 10 Pages of Divide and Conquer task
08/24/2025	10/30/2025	10/31/2025	60-Page Document	First half of the assignment

08/24/2025	11/24/2025	11/25/2025	Final Document	Final Report for Senior Design I

Table 8.2 Project Initialization Milestones
By Authors

Appendices

• Appendix A – References

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- **Appendix B – copyright permission**

- **Appendix C – etc.**