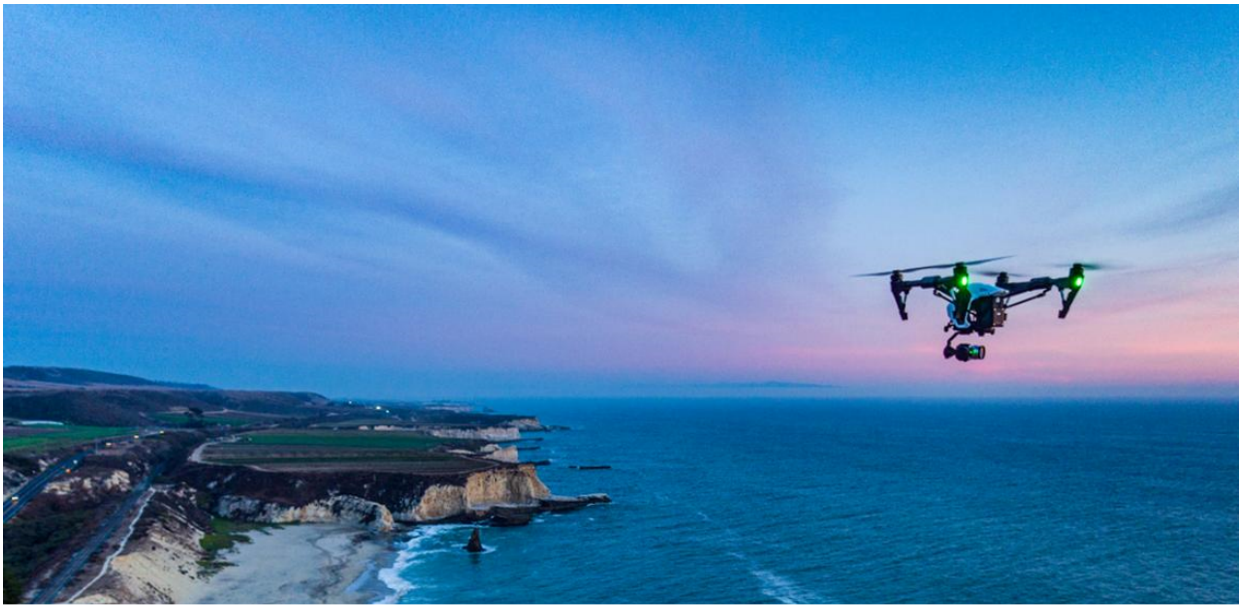

Autonomous Aerial Assistance for Search and Rescue

CONCEPTUAL DESIGN REVIEW

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1. Project description

1.1 Motivations

A typical search and rescue mission has very stringent requirements on time and the operating environment. This makes direct human involvement in the operation difficult and expensive, and has led to the use of automated vehicles to conduct the first wave of search. In such hazardous operations, where little information is available about the environment, aerial vehicles have a unique advantage of being able to quickly cover ground and gain an overview of the situation.

However, most of the existing approaches to SAR(Search and Rescue) using aerial vehicles currently rely heavily on teleoperated drones with minimal autonomy, which increases the risk for the rescue team and the cost of SAR operations. Apart from the huge cost, current approaches also impose strict piloting requirements on the operator, which limits the pervasiveness with which such technologies can be deployed. In addition, the capabilities of a teleoperated mission is extremely limited to certain categories of local terrain that always allow a link between the vehicle and the operator. All these issues in addition to the fact that there are roughly 11.2 SAR incidents each day at an average cost of $895 per operation[1], stress the need for building systems that are as autonomous as possible.

1.2 Objectives

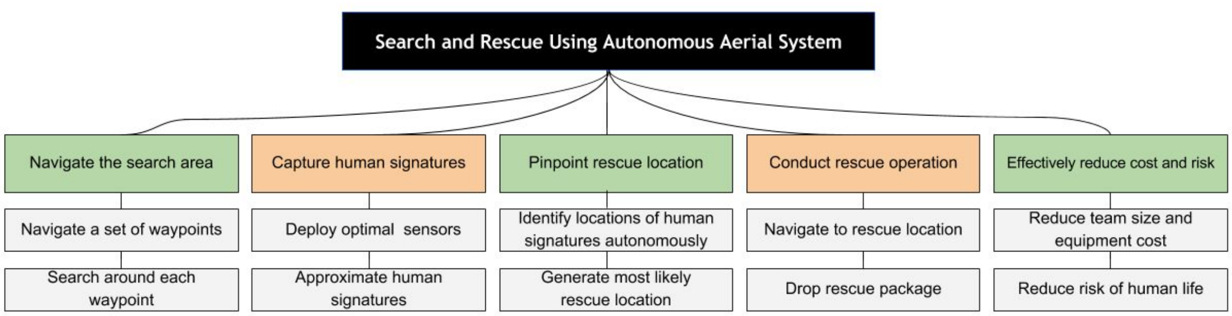

Fig 1.1 Objective Tree

As part of our quest towards solve this challenging problem, we propose an autonomous aerial system for search and rescue, in order to effectively reduce rescue team size, equipment cost, as well as risk to human life. A programmable hexrotor will be used to autonomously navigate the search area and collect data through sensors. A system will be built which can then analyze the data to detect human signatures, and pinpoint the most beneficial location to conduct a rescue operation efficiently and reliably.

Due to the time constraint and limited team size, a readily available drone with inbuilt maneuvering capabilities will be provided by our sponsor, Near Earth Autonomy. Due to this, most of the efforts will be focused on planning strategies for generating and searching around waypoints, as well as using machine learning and vision algorithms for capturing human signatures and pinpointing rescue locations. Also, a mechanical actuator system will be designed to hold and drop a rescue packet when conducting rescue operations.

2. Use case

Jamie is the Team coordinator at the Yosemite Search and Rescue (YOSAR)[6] team. His team is mainly responsible for conducting SAR activities in the Touloumne Meadows region. He is proud that his team is one of the most well-oiled SAR machines in the world. But that comes at a cost. His team employs only well trained individuals with strong alpine skills and also makes use of helicopters to search in large areas.

YOSAR team conducts rescue operations on a "pay by mission" basis and the rescue operations involve thorough searches in the meadows, forests and mountains. The operations are expensive and each rescuer in the team has to be paid $ 23-34 per hour. Given the large area to traverse, most operations require at-least a couple of helicopters, if not more. Moreover, finding good rescuers is a challenge in itself due to the stringent requirements posed by the task. Browsing over the internet, he stumbles on a video showcasing the "Rescue Rangers" drone with the ability to search for human beings in relatively un-occluded environments. He immediately sees the value in using it for his missions as a cheaper option with much faster response and decides to own it.

When the package arrives, he is excited to open it and finds the set up pretty simple – assembling the parts of the drone – not any more difficult than assembling a furniture these days. He installs a mandatory software on his laptop to help give the drone inputs and goes through a few tutorials provided to help operate the system. It takes him less than a couple hours to set everything up. Happy with his new gizmo, he wraps up the day unaware of the situation that awaits him the next day.

At 6 in the morning, while nicely tucked in his bed, he receives an emergency SAR SOS from the Yosemite Emergency Communications Center. Two hikers had wandered off the trail and had gone missing for the past two hours. The agency managed to get their approximate location two hours ago and there was also a mention of one of them being severely bruised as well. Jamie immediately sends an alarm to gather the team and prepare for rescue. While preparing for his mission, he glances at the drone he had set up the previous night and wonders if this is the right opportunity to put the drone to test , since he also recollects that the area around the location provided is not covered with trees. "Half an hour for assembling the team should be enough to test the drone", he thinks to himself.

He fires up his laptop and switches the drone's power ON in the lawn outside. On the software suite, he is able to see Google maps of the nearby area with GPS coordinates. He selects the option "Search and map" and feeds in the three GPS coordinates (Waypoints W1, W2 and W3 in Figure 2.1) around the provided location where he reckons the hikers might be. The drone takes off (from location S in the Figure 2.1) and he resumes his preparation for the operation. 20 minutes later, his team is assembled with all the equipment and he briefs them on the mission and they are all set to leave. Just as they can start, the drone comes back to the base. Jamie connects the drone to the laptop with a USB cable and data is transferred by the software in 5 minutes. In another 3 minutes,

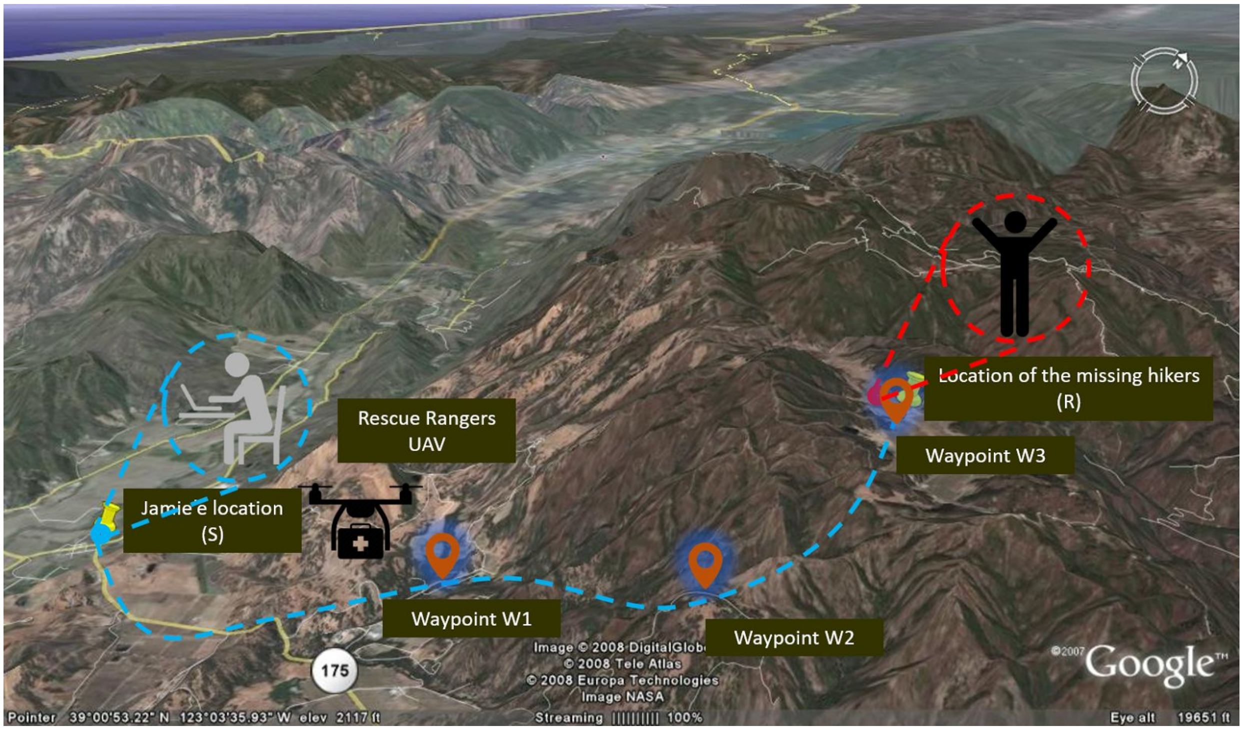

Figure 2.1 Illustration of how Rescue Rangers aerial system works (waypoints, terrain and visible distances only for illustrative purpose only) ***[Background image sourced from:[7]]***

the software pops up with some relevant pictures found and their locations on the map. Jamie is awestruck with the capability. He could easily see the two hikers in one of the pictures. He immediately communicates the location to his team. Figuring that the team still might take some time to reach the location, he attaches a first aid package to the drone and switches ON its power. He selects the option “Drop package” on the software and specifies the chosen location. The drone takes off and comes back in 10 minutes. After another 30 minutes, the team brings the two hikers via a helicopter to the base to treat and tells Jamie that the victim had already got first aid before the team could find them. ! MISSION ACCOMPLISHED !

3. System-level requirements

3.1. Mandatory requirements:

Mandatory requirements were arrived at after exhaustive research on the needs of search and rescue missions, numerous discussions with the sponsors and carefully considering what is achievable in the given timeframe.

Table 3.1 Mandatory Functional and Performance Requirements

Functional Requirements The system shall:	**Performance Requirements** The system will:
M.F.1. Autonomously navigate through a set of provided waypoints	**M.P.1.** Accurately reach the waypoints provided with a tolerance of +-5m
M.F.2. Complete the search within limited time	**M.P.2.** Complete one iteration of search in an un-occluded operating area of 200m x 200m in less than 25 minutes
M.F.3. Explore the surroundings around each waypoint	**M.P.3.** Cover areas around the waypoints with 20% tolerance
M.F.4. Collect perceptual data while navigating	**M.P.4.** Collect perceptual data limited to 3 types
M.F.5. Process the data to identify human signatures	**M.P.5.** Identify 3 human signatures
M.F.6. Analyze the identified signatures to accurately estimate human location	**M.P.6.** Estimate human location with 80% confidence and +-10m tolerance
M.F.7. Navigate to the rescue location carrying the rescue package	**M.P.7.** Carry a rescue package weighing 100g.
M.F.8. Drop the rescue package	**M.P.8.** Drop the package at the rescue location with a tolerance of +-5m

Table 3.2 Mandatory Non Functional Requirements

Mandatory Non-Functional Requirements The system will:
M.N.1. Reduce the rescue team size required to <=2
M.N.2. Reduce risk to human lives
M.N.3. Reduce equipment cost required

3.2. Desired requirements:

Table 3.3 Desired Functional and Performance Requirements

Functional Requirements The system shall:	**Performance Requirements** The system will:
D.F.1. Optimize initial path planning based on geography/terrain of the given search area	**D.P.1.** reduce the initial navigation plan duration by at most 20%
D.F.2. Adaptively generate navigational waypoints during the flight based on the sensor data	**D.P.2.** reduce the overall search and rescue duration by at most 20% in cases where the actual human location is far away from the initial waypoints provided

Table 3.3 Desired Non Functional Requirements

Non-Functional Requirements The system shall:
D.N.1. have an interactive GUI to make it operable by an untrained human being ● Receive inputs from the user on a map ● Show live navigation on a map.

4. Functional architecture

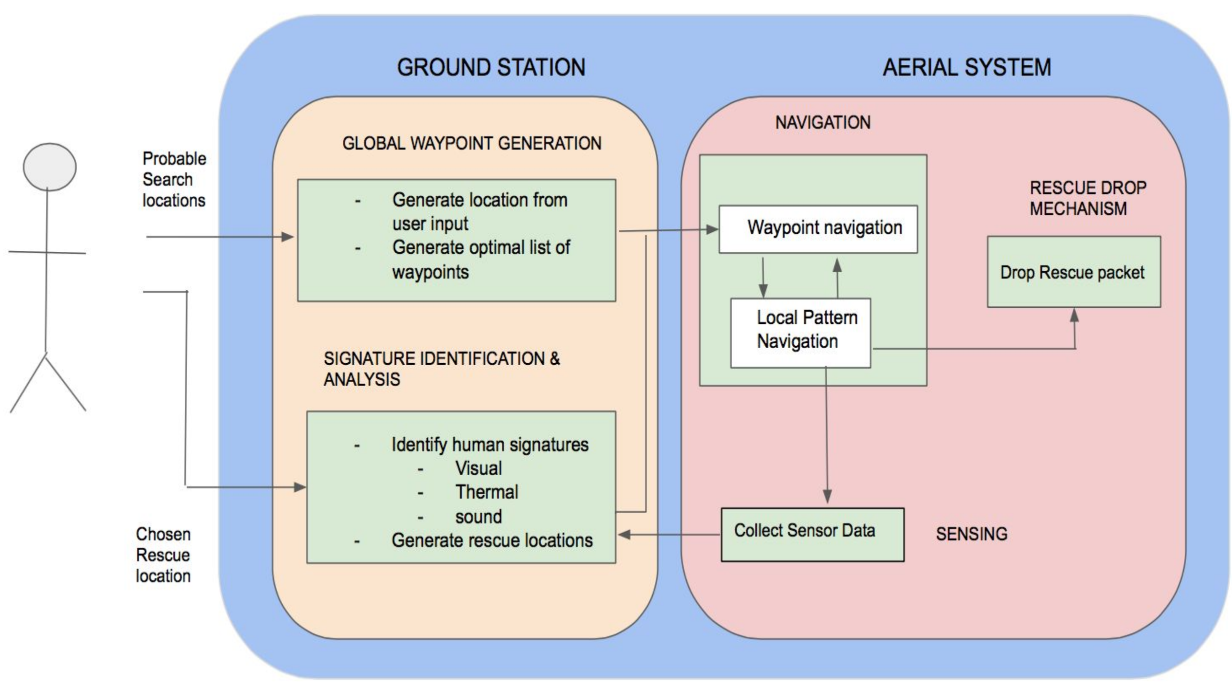

Figure 4.1 Functional Architecture

The architecture is described below as a sequence of functions:

1. A mission begins with a rescue agent providing a list of geographic zones where the system should focus the search on. This information is then translated to GPS coordinates by the system and an optimal navigation path is generated as a list of ordered waypoints.
2. The aerial system navigates the list of waypoints and initiates a localized navigation pattern at each of the waypoints. The localized pattern is specifically designed to enable capturing reliable sensor data at each waypoint.
3. Once the waypoints are navigated and sensor data is collected, the drone returns to the ground station and initiates a data transfer.
4. Once the data is available, the ground station runs sophisticated algorithms to identify human signatures from the data and their precise locations.
5. The aerial system then navigates to the rescue location and drops a rescue packet as accurately as possible.

5. System-level trade studies

5.1 UAV Platform

Table 5.1 Trade study on UAV platform

	Weight(%)	DJI Matrice 100	DJI Matrice 600	3DR Solo
Cost	10	4.0	2.0	8.0
Flight Time	15	9.0	10.0	6.0
Flight Controller Capability	25	9.0	10.0	8.0
Payload Carrying Capacity	15	8.0	10.0	6.0
SDK Provided	20	10.0	9.0	7.0
Flight Simulator	15	7.0	7.0	8.0
Total	100	8.25	8.55	7.2

A proper UAV platform should not only provide stable flight performance, but also is supposed to be easily programmable using provided APIs. Because of that, the two most important factors in choosing UAV platform for search and rescue operations are filght controller capability and SDK provided. In addition, the system is required to employ multiple sensors for extracting sufficient human signatures, which makes payload carrying capacity also a crucial part.

In order to have a structured search, the UAV will need to be able to run on battery for an extended period of time while it completes the task. This will require a drone that has enough basic flight time. Also, since we need to test the planning algorithm before the real outdoor experiments to reduce the risk of damaging the drone, a suitable fight simulator is required and is able to save us a lot of time and money. Finally, cost is a factor in choosing the proper UAV platform, but not a relatively important one, because, many types of drones could be provided by the sponsor. Considering all these factors, although DJI Matrice 600 is quite expensive, it is superior to other platforms in terms of its stable flight performance, extended flight time, strong payload carrying capacity, as well as its various available APIs provided by DJI SDK.

5.2 Sensors

Sensing is an important part in autonomous aerial assistance for search and rescue. Since we want the system to detect and identify locations of human beings, the system needs to extract potential human signatures without human intervention, based on multiple sensor data. In regard with selection of sensors, our system shall have image cameras for human detection, a depth sensor for capturing precise position of human, and a sound sensor for human voice detection.

5.2.1 Image Camera

Table 5.2 Trade study on Image Camera

	Weight(%)	RGB+Thermal camera	RGB Camera alone	Thermal camera alone
Cost	10	3.0	5.0	6.0
Easy to Mount	10	6.0	9.0	8.0
Detection Accuracy	25	9.0	7.0	6.0
Information	20	10.0	8.0	9.0
Robustness to Environment	20	9.0	6.0	9.0
Availability from Sponsor	15	10.0	10.0	10.0
Total	100	8.45	7.45	8.0

To decide the best combination of image cameras, the main criteria is that whether the camera system can capture human signatures accurately. Except for that, the information detected in an image is also very important, because the more information we get through cameras, the more likely system is capable to extract useful human signatures.

Another factor which should not be neglected is that image quality may sometimes be influenced due to illumination or insufficient daylight. This makes the robustness to environment necessary to be considered. Other considerations include the cost of cameras, whether the camera is easy to mount, and availability from sponsor. Finally, the result turns out that the combination of rgb camera and thermal camera can provide high detection accuracy with great robustness to environment for our system.

Trade study comparing RGB cameras and thermal cameras are as below:

RGB Camera:

Table 5.3 Trade study on RGB Camera[2]

	Weight(%)	GOPRO HERO4 SILVER	XIAOMI YI	SONY 4K FDR-X1000V
Cost	15	7	10	6
Photo Quality	25	8	10	7
Feature Supported	15	9	7	10
Battery	20	7	10	8
Memory	25	10	10	10
Total	100	8.3	9.55	8.25

Infrared Camera:

Infrared thermal camera could be classified into five types based on its wavelength, including near-infrared, short-wavelength infrared, medium-wavelength infrared,long-wavelength infrared and far-infrared. Since our system focuses on detecting human, whose average wavelength is about 12 um, we plan to use long-wavelength infrared camera(LWIR camera), which can detect wavelength from 8 ~15um[3].

Furthermore, LWIR camera has two types according to whether the detector is cooled or not. LWIR camera with cooled detector is better in terms of spatial resolution, sensitivity, and spectral filtering, but its cost is generally higher than the one with uncooled detector by a factor of five[4]. Specifically for our project, we plan to use the uncooled one. Our concern is that it can provide sufficient performance to detect human signatures combined with the RGB camera, and it costs much less.

5.2.2 Lidar

Table 5.4 Trade study on Lidar

	Weight(%)	Scanse Sweep	Hokuyo URG-04LX	Velodyne VLP-16
Cost	10	10.0	6.0	2.0
Outdoor Range	30	6.0	2.0	10.0.
Resolution	20	7.0	10.0	5.0
Field of View	25	10.0	7.0	10.0
Availability from Sponsor	15	6.0	6.0	10.0
Total	100	7.2	5.85	8.2

In order to identify the location of human more precisely, we choose lidar over ultrasonic sensor for our system. In terms of specific lidar type, the main criteria should be its outdoor working range and field of view, since more space needs to be inspected. In addition, the resolution of lidar is also important for obtaining accurate position. Cost and availability from sponsor should also be considered.

5.2.3 Sound Sensor

The sound sensor in our aerial system aims to detect human voice by analyzing the decibel and frequency of the external sound. Based on our requirement, It should have the following functions:

- Detectable sound pressure level larger than: 60dB~90dB
- Detectable sound frequency range larger than: 100Hz~2000Hz
- Output measured sound pressure with the error less than 5dB
- Output analog waveform of the sound after filtering the noise
- Ports available for data acquisition

Considering all these requirements, there are actually limited choices which satisfy all of them. Our current decision is to use the Phidgets Sound Sensor, which measures sound with a frequency range of 100Hz to 8kHz and pressure level from 50dB to 100dB. For the frequency of the sound, we plan to add a micro-controller and write software to calculate the sound frequency given the analog waveform of the sound, or design a hardware circuit to attain the sound frequency.

6. Cyber-physical architecture

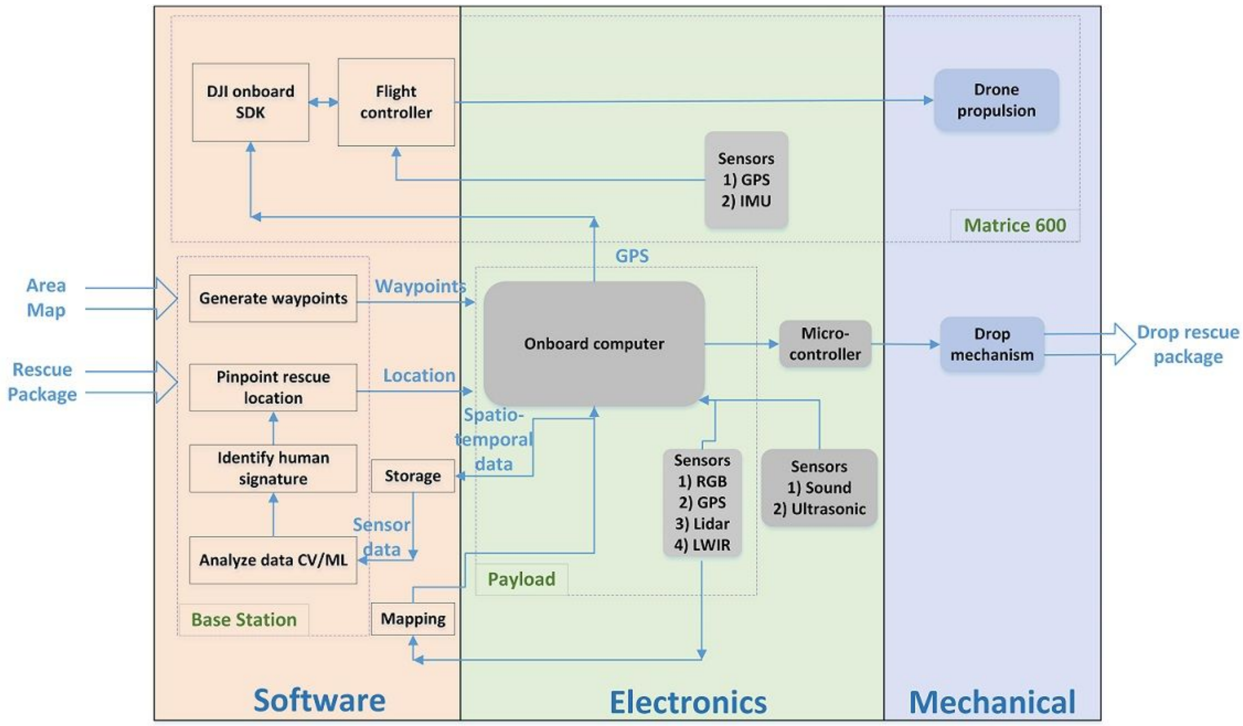

Figure 6.1 Cyber-physical Architecture

6.1 Mechanical System

The mechanical system consists of the following components:

- Drone Propulsion System (in built Matrice 600),
- Rescue packet drop mechanism to be custom designed and fabricated for the drone,
- Payload mounts to add additional sensors to the drone.

6.2 Electronics System

Our electronic system comprises of sensors, an onboard computer and a microcontroller. There are three sets of sensors in this system, one set is contained in the payload provided by Near Earth Autonomy, the other set is part of the DJI Matrice 600.

6.2.1 Matrice 600

The GPS and IMU sensor embedded in Matrice 600 will primarily be used for navigation. The sensor data will be sent to both the flight controller and the onboard computer so that they can analyze and control the real-time flight of the drone.

6.2.2 Payload components

Onboard computer: The onboard computer collects waypoints information from base station and transfer it to our flight controller in order to conduct the first-round navigation. While navigating around certain waypoints, the onboard computer will collect and merge data that sensors on the payload send during the searching process.

Sensors: The sensors on the payload consist of RGB camera, GPS, Lidar, sound and thermal sensor. The rationale behind using multiple types of sensors is so that the system can recognize different human signatures, and thus increase the possibility of finding humans. The Lidar will predominantly be used for precise altitude information while doing a rescue.

6.2.3 Drop components

Microcontroller: The lower microcontroller will receive the command sent by the onboard computer and give the drop mechanism the instruction to drop packages.

Additional Sensors: The system will also have an additional sound sensor for detecting human sound which will be quantified by a certain magnitude and frequency.

6.3 Software System

There are three key software components that power major aspects of the system. The Global Waypoint Generation component accepts fuzzy region information from a Local terrain expert and converts it into waypoints represented as GPS coordinates. It also generates an optimal ordering of the waypoints for the aerial system to navigate.

The Local Pattern Navigation system generates a localized pattern at each global waypoint so that the drone can maneuver in a way that enables the system to collect quality sensor data with both resolution as well as coverage. Finally, the Signature Identification and Analysis system resides in the ground station and is responsible for analyzing all the sensor data and detecting human signatures.

Once the signatures are available, the software will generate a ranked list of candidates which will be presented to the operator to pick the best candidate. Once the candidate is available, the payload map can be used to lookup the coordinates of the location which will then be used by the drone for the rescue mission.

7. Subsystems

The system can be broadly classified into two larger subsystems namely: Ground Station and the Aerial subsystem. Each of these subsystems are further categorized into smaller subsystems based on the functionality they provide.

7.1 Aerial Subsystem

7.1.1 Autonomous Flight System

Two of the key requirements for SAR (Search and Rescue) missions are:

- To be able to carry out precise waypoint navigation in a large, partially unknown environment, within strict time constraints.
- To be able to mount a variety of powerful sensors to detect and capture possible human signatures that could be used to pinpoint the exact location for a rescue operation.

The DJI Matrice 600 hexcopter shown below in Figure 7.1 demonstrates capabilities that satisfy the above constraints and presents a very strong case for use in Aerial Search and Rescue Applications.

Figure 7.1. DJI Matrice 600 with an RGB camera [5]

7.1.2 Localized Pattern Navigation

Given that the input to the system is a set of locations provided by a local terrain expert, the waypoints generated by the system will be in the vicinity of the provided location and cannot be used as a precise location for sensor data capture. To be able to capture sensor data with sufficient coverage and high resolution, the system needs to establish a systematic search pattern around the global waypoint. The Localized Pattern Navigation Subsystem implements the above functionality and will be triggered once a particular global waypoint is reached. It will then generate a new set of waypoints that will guide the hexcopter through a local pattern of expanding concentric circles to maximize sensor coverage and resolution. This pattern is illustrated in Figure 7.2.

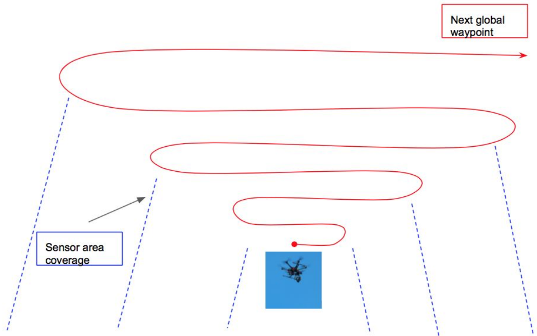

Figure 7.2. Localized navigation pattern for maximizing resolution and coverage

7.1.3 Sensing

There will be two sets of sensors in the system. One of them will be part of the DJI drone and will be used for State Estimation and Waypoint Navigation by the drone. This set will comprise of an IMU for tracking acceleration and orientation, and a GPS system to determine global coordinates.

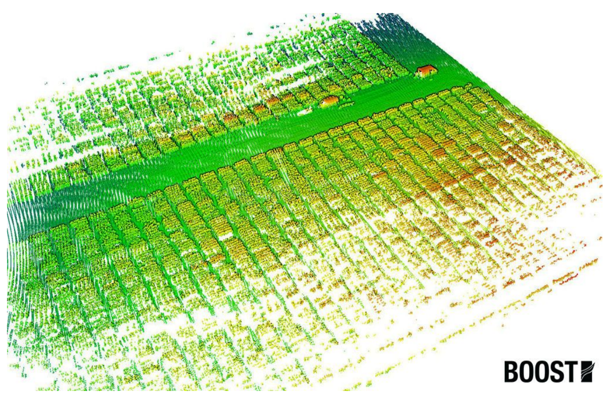

Figure 7.3. Sample Point cloud from the NEA payload [5]

The second sensor package will be built by Near Earth Autonomy based on our recommendations. This package will predominantly be used for building a spatio-temporal map of the points of interest based on fusion of data from multiple sensors like GPS, Lidar, RGB and Thermal imaging cameras. The RGB and Thermal imaging sensors are essential in capturing human signatures and are key to the detection system. The GPS will be used to generate a precise spatio-temporal overlay for the sensor data as shown in Figure 7.3. This is required for being able to pinpoint the rescue location with high accuracy. The Lidar sensor is used as a means to gauge the terrain underneath the drone so that an optimal altitude can be chosen for local flight pattern as well as the rescue operation altitude. In general, this data could be obtained using an Ultrasonic sensor which is generally cheaper but the Lidar was chosen due to its higher precision. Additional sensors like microphones will also be used for more precise signature detection and for breaking ties when there are multiple candidate rescue locations.

7.1.4 Rescue Package Drop Assembly

The rescue phase of the SAR mission involves navigating to the chosen rescue location and implementing a rescue mission. For the current project, the rescue mission entails dropping a rescue packet similar to a first aid kit as close to the rescue location as possible.

7.2 Ground Station Subsystem

7.2.1 Global Waypoint Generation

The inputs that are provided to the system are in the form of localized regions in a map. These regions need to be converted into a precise set of coordinates and also based on a number of other factors like relative locations, distances, priorities and available time, the system shall generate an optimal path that goes through all the waypoints. This is the path that the Aerial subsystem will navigate.

7.2.2 Signature Detection and Analysis

The ability to detect human signatures accurately is one of the key pieces of a Search and Rescue mission. Apart from impacting design choices in other subsystems like sensors etc, the kind of signatures that are used for human detection, directly impacts the mission complexity that the system can undertake. Some of the key signatures the system will rely on are listed below:

- RGB Imagery: RGB imagery will be used to identify specific patterns of colors associated with human presence. For example a bright colored tent in the background of a green foliage or brown terrain can be used as a strong indication of human presence in the region.
- Thermal imagery: Due to the fact that all bodies in nature exhibit unique thermal signatures in various situations, using thermal imagery to detect presence of humans or presence of objects associated with humans (a hot abandoned vehicle for example or hot wood used for fire) can yield very precise results.
- Sound: Sound is yet another useful signature that could be associated with humans in a very distinct way. Similar to thermal fingerprint, there is a very precise sound frequency range that humans produce. This, coupled with other intuitions (associating increased amplitude with a cry for help for example) can potentially be a powerful tool in guiding a search. The one problem with using sound is to be able to filter out the surrounding noise and extract high quality data which needs to be addressed.

The system shall process the sensor data to generate a sanitized version of it. The sanitized data shall then be discretized into a set of candidates keyed by their spatial and temporal coordinates. The system will then employ advanced machine learning algorithms to classify the candidates based on the presence of signatures and generate a filtered list that is ranked by a score indicating the probability of the candidate being a rescue location. The top element in the ranked list shall be deemed as the likely rescue location to send the drone.

8. Project management

8.1 High Level Task Breakdown

This section lays out the high level tasks categorized by their type. Some of the tasks are additionally scoped by the Fall and Spring Validation requirements (abbreviated as FVR and SVR).

8.1.1 Project Planning, Continuity and Delivery tasks

- Initial Planning
  - Define scope of the project and the requirements.
  - Conduct trade studies for parts and approaches.
  - Finalize functional, performance and cyber-physical requirements.
- Project Continuity
  - Develop and maintain project website.
  - Design Fall and Spring demo.
  - Procure parts.
  - Fall demo preparation.
  - Field Tests.
  - Spring demo preparation.
- Project Delivery
  - Deliver Conceptual Design Review.
  - Deliver Preliminary Design Review.
  - Deliver Critical Design Review.
  - Fall Demo.
  - Spring Demo.

8.1.2 Subsystem Tasks

- Autonomous Flight System
  - Ramp-up on Hexcopter operability.
  - Demonstrate waypoint navigation in a controlled environment (as per FVR).
  - Demonstrate waypoint navigation in a larger environment (as per SVR).
- Sensing
  - Finalize type and model of sensors to be used by conducting trade studies.
  - Test/Validate sensors independently to ensure they meet performance requirements.
  - Software to extract and process data for 1 sensor and associate coarse location and time information with the data.
  - Build payload with all sensors.
  - Test/Validate system to generate highly accurate sensor data keyed by spatio-temporal information.
  - Software to extract and process payload data.

- Localized Pattern Navigation
    - Design strategy for localized navigation pattern.
    - Software for planning localized navigation pattern with acceptable sensor coverage (as per FVR).
    - Software for planning localized navigation pattern with high quality sensor coverage (as per SVR).
    - Software for planning localized navigation pattern for rescue operation to drop packet accurately (as per SVR).
- Rescue assembly system
    - Evaluate and finalize the design and actuators for rescue assembly mechanism.
    - Fabrication of mechanical structure and test functionality independently.
- Global waypoint generation
    - Software to generate optimal navigation path based on simplified coordinate input in a constrained environment (as per FVR).
    - Software to translate region information from a Global Map to specific GPS coordinates for a large environment (as per SVR).
- Signature detection and analysis
    - Finalize set of signatures to be used for detection.
    - Collect data and evaluate techniques for signature detection.
    - Build a rudimentary signature detection module (as per FVR).
    - Software for integration of the module with data obtained from payload sensors.
    - Collect large amount of data to train more accurate models.
    - Build advanced signature detection module (as per SVR)
    - Performance optimizations/scaling to operate within acceptable time (as per SVR).
- Integration Tasks
    - Design and fabricate mountings for sensors (if required).
    - Test flight with preliminary sensors.
    - Implement data collection pipeline to transfer data from aerial subsystem to base station.
    - Test end to end system for <u>search only operation</u> (as per FVR).
    - Payload sensor integration and calibration during flight.
    - Interface sensor payload with onboard processor.
    - Integrate rescue drop assembly with Hexcopter and onboard processor.
    - Test end to end system for <u>search and rescue operation</u> (as per SVR).

8.2 Schedule and Milestones

8.2.1 Fall 2016

Table 8.1. Task Schedule for Fall 2016

Milestone Date	Task List
09/30/2016 **Conceptual Design Review**	● Initial Planning ○ Define scope of the project and the requirements. ○ Conduct trade studies for parts and approaches. ○ Finalize functional, performance and cyber-physical requirements. ● Project Continuity ○ Develop and maintain project website. ○ Design Fall and Spring demo ● Project Delivery ○ Deliver Conceptual Design Review
10/20/2016 **Progress Review 1**	● Project Continuity ○ Procure parts ● Autonomous Flight System ○ Ramp-up on Hexcopter operability ● Sensing ○ Finalize type and model of sensors to be used by conducting trade studies. ○ Test/Validate sensors independently to ensure they meet specifications.
10/27/2015 **Progress Review 2**	● Autonomous Flight System ○ Demonstrate waypoint navigation in a controlled environment (as per FVR) ○ Test against accuracy performance measures (as per FVR). ● Localized Pattern Navigation ○ Design strategy for localized navigation pattern. ○ Software for planning localized navigation pattern with acceptable sensor coverage (as per FVR). ● Integration Tasks ○ Design and fabricate mountings for sensors (if required). ○ Test flight with preliminary sensors.
11/01/2015 **Preliminary Design Review**	● Project Delivery ○ Deliver Preliminary Design Review
11/10/2015 **Progress Review 3**	● Sensing ○ Software to extract and process data for 1 sensor and associate coarse location and time information with the data. ● Rescue assembly system ○ Evaluate and finalize the design and actuators for rescue assembly mechanism.

	○ Fabrication of mechanical structure and test the function independently.
11/22/2015 **Progress Review 4**	● Project Continuity ○ Fall demo preparation ● Integration Tasks ○ Implement data collection pipeline to transfer data from aerial subsystem to base station. ○ Test end to end system for search only operation (as per FVR).
12/01/2015 **Progress Review 5**	● Project Delivery ○ Fall Demo
12/12/2015 **Critical Design Review**	● Project Delivery ○ Deliver Critical Design Review

8.2.2 Spring 2017

Table 8.2. Task Schedule for Spring 2017

Milestone Date	Task List
02/15/2017	● Sensing ○ Build payload with sensors ○ Test/Validate system to generate highly accurate sensor data keyed by spatio-temporal information. ○ Software to extract and process payload data. ● Rescue assembly system ○ Fabrication of mechanical structure and test functionality independently.
03/01/2017	● Aerial Flight System ○ Demonstrate flight through a predefined set of waypoints in a larger environment (as per SVR). ● Signature detection and analysis ○ Software for integration of the module with data obtained from payload sensors. ○ Collect large amount of data to train more accurate models. ○ Build advanced signature detection module (as per SVR). ● Integration Tasks ○ Payload sensor integration and calibration during Hexcopter. ○ Interface sensor payload with onboard processor.
03/15/2017	● Localized Pattern Navigation ○ Software for planning localized navigation pattern with high quality sensor coverage (as per SVR). ○ Software for planning localized navigation pattern for rescue operation to drop packet accurately (as per SVR).

	• Integration Tasks ○ Integrate rescue drop assembly with Hexcopter and onboard processor
04/01/2017	• Global waypoint generation ○ Software to translate region information from a Global Map to specific GPS coordinates for a large environment (as per SVR).

04/15/2017	• Signature detection and analysis
	  ○ Performance optimizations/scaling to operate within acceptable time (as per SVR).
	• Integration Tasks
	  ○ Test end to end system for search and rescue operation (as per SVR).

05/01/2017	• Project Continuity
	  ○ Field Tests
	  ○ Spring demo preparation

05/15/2017	• Project Delivery ○ Spring Demo

8.3 System validation experiments

8.3.1. Fall Validation Experiment (FVE):

Test A: UAV waypoint navigation test

Objective:
To validate the autonomous flight control and waypoint navigation capability of the UAV

Test conditions:

Location	Open 50m x 50m area with GPS access and normal wind conditions
Equipment needed	UAV, Laptop, Nets for safety

Test Sequence:

Step	Description	Performance Measures
A.1.	Place UAV on the ground. Feed GPS locations as waypoints	
A.2.	UAV takes off and goes to the first GPS location and hovers there for 20 seconds	- Smoothness of takeoff - Accuracy in reaching desired height (+-1m tolerance)

A.3.	UAV navigates from one waypoint to another	- Accuracy in reaching the waypoints (+-5m tolerance)
A.4.	UAV returns to the starting location	- Accuracy in reaching the starting location (+-5m tolerance)

System requirements validated:
M.P.1. Accurately reach the waypoints provided with a tolerance of +-5m

Test B: Human detection algorithm test

Objective:
To validate the capability of the algorithm to detect human signatures in RGB images

Test conditions:

Location	Lab
Equipment needed	Software implementing the algorithm, images with relevant human signatures

Test Sequence:

Step	Description	Performance Measures
B.1.	Run the algorithm on the set of images	Ability to detect the image which has a human

System requirements validated:
One part of “M.P.5 Identify 3 human signatures”. The system shall identify human being in RGB images.

Test C: Package dropping mechanism test

Objective:
To validate the working of the mechanism to be used for dropping the rescue package

Test conditions:

Location	Lab
Equipment needed	Prototype for the dropping mechanism

Test Sequence:

Step	Description	Performance Measures
C.1.	Place a 100g, 10cmx10cm package inside/below the mechanism	- Ease of placing the package to be grabbed
C.2.	Actuate the mechanism to secure the package	- Grabbing time - Safety of the package while grabbing
C.3.	Subject the mechanism to accelerations in x, y and z directions manually	- Grasp strength: the mechanism should not lose grip of the package under realistic accelerations
C.4.	Actuate the mechanism to release the package	- Release time - Safety of the package during release

System requirements validated:

- **M.P.7.** Carry a care package weighing 100g
- **M.P.8. (partly)** Drop the package at the rescue location with a tolerance of +-5m

8.3.2. Spring Validation Experiment (SVE):

Test D: UAV waypoint navigation test

Objective:
To validate the system's ability to autonomously search for a human in a search and rescue scenario and also dispatch a rescue package

Test conditions:

Location	Open 200m x 200m area with GPS access and normal wind.
Equipment needed	UAV; Laptop; Rescue package; Mannequin: filled with hot water, wearing red shirt and with a speaker

Test Sequence:

Step	Description	Performance Measures
D.1.	Place UAV on the ground. Feed GPS locations as waypoints	
D.2.	UAV takes off and reaches the desired altitude for navigation	- Smoothness of takeoff - Accuracy in reaching desired height - (+-1m tolerance)
D.3.	UAV Reaches the first waypoint and performs localized search	- Accuracy in reaching the waypoint (+-5m tolerance)

D.4.	UAV Flies from one waypoint to another performing localized search	- Accuracy in reaching the waypoint (+-5m tolerance) - coverage as a percentage of planned search area
D.5.	UAV flies back and lands near the starting point after covering all the waypoints	- Accuracy in reaching the waypoints (+-5m tolerance)
D.6.	Transfer data from the UAV to base station	- Ability to collect the three types of perceptual data with spatial-temporal information
D.7.	Process the data to identify any human signatures (mannequin in our case)	- Ability to identify the mannequin
D.8.	Based on the identified human signatures, select the best location for rescue	- Accuracy of the human location conveyed (is it close to the mannequin?)
D.9.	UAV flies to the selected rescue location	- Accuracy in reaching the rescue location (+-5m tolerance)
D.10.	UAV performs localized search to get as close as possible to the human	- Ability to reach the desired altitude and close to the human (mannequin in our case)
D.11.	UAV releases the rescue package	- Ability to release the package
D.12.	UAV flies back to the base station	- Accuracy in reaching the starting location (+-5m tolerance)

System requirements validated:

- All mandatory performance and non-functional requirements

8.4 Team member responsibilities

Table 8.3 Technical role of each team member

Technical Role	Primary	Secondary
Path planning/Localized Navigation	Sumit	Xiaoyang
Flight control	Xiaoyang	Karthik
Electrical design/Sensors	Xiaoyang	Henry
Mapping	Sumit	Xiaoyang
Signature Identification	Karthik	Sumit
Prediction	Karthik	Henry
Drop mechanism	Henry	Sumit
Communication	Henry	Karthik

Table 8.4.Administrative role of each team member

Administrative Role	Primary	Secondary
Budget and Purchase	Karthik	Xiaoyang
Website	Henry	Sumit
Deadline Scheduling	Xiaoyang	Henry
Presentation & Document Review	Sumit	Karthik

8.5 Parts list and budget

Table 8.5 Part list 1(Sponsored by Near Earth Autonomy-Parts still need to be finalized)

Description	Manufac turer	Model/Part Number	Unit	Weight (g)	Unit Cost	Total Cost
LWIR	FLIR		1			
RGB Camera	XIAOMI	YI	1	520	$81.6	$81.6
Lidar	Velodyne	VLP-16	1	590	$7,999	$7,999
GPS			1			
Flying platform	DJI	Matrice 600	1	9,600	$4,599	$4,599

Table 8.6 Part list 2 (Not sponsored by Near Earth Autonomy)

Description	Manufact urer	Model/Part Number	Unit	Weight (g)	Unit Cost	Total Cost
Extra batteries	DJI	TB48S	2	680	$199	$398
Sound Sensors	Phidgets	1133	1	150	$35	$35

8.6 Risk management

The risk analysis for the project is listed as a table below, including the following categories:

- Description: Brief description of the risk
- Likelihood of Occurrence: Possibility of risk, expressed by 3, 2, 1(3 is very likely,1 is not likely)
- Level of Impact: High, Medium or Low
- Area of Impact: Time, Cost, Reliability
- Handling Strategies: How the risk will be resolved

Table 8.7 Risk Analysis

	Description	Likelihood of Occurrence	Level of Impact	Area of Impact	Handling Strategies
1	False positives while capture potential human signatures during rescue operation	2	Medium	Reliability	Deploy multiple sensors to increase detection accuracy .Navigate the drone closer to the ground during searching.
2	UAV Platform is not available in time	1	Medium	Time	Meet sponsor regularly, Set deadline for platforms to arrive
3	Difficult to schedule outdoor flying tests with the sponsor	2	Medium	Time, Reliability	Track requirements for testing. Schedule outdoor flying tests in advance with the sponsor.
4	Drone or payloads are damaged during experiments	1	High	Time, Cost	Use simulator to test algorithm before real experiments. Select UAV platform with stable performance.
5	Breakage of other mechanica or electrical components	2	Low	Cost	Implement safe features on the flight control. Purchase multiples of components.
6	Unexpected delay due to integration of sub-systems	3	Low	Time, Reliability	Leave additional time in the schedule for resolving integration issue.
7	Fail to accomplish all mandatory requirements within 9 months	1	High	Time, Reliability	Reprioritize all mandatory requirements . Work on project based on scheduled timeline.

9. References

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