Autonomous Aerial Assistance for Search and Rescue

Team F

Critical Design Review

December 13, 2016

Team Rescue Rangers

Juncheng Zhang
Karthik Ramachandran
Sumit Saxena
Xiaoyang Liu

Sponsor:

Near Earth Autonomy

© philip lima

Project Description

Motivation

Existing SAR Approaches:

- Require Skilled personnel and Helicopters
  - Expensive
  - Risk of human lives
- Teleoperated drones with minimal autonomy

http://www.carson.org/government/

Objective

Develop an autonomous aerial system to make Search and Rescue operations:

- Speedier
- Cheaper
- More reliable

http://store.dji.com/product/

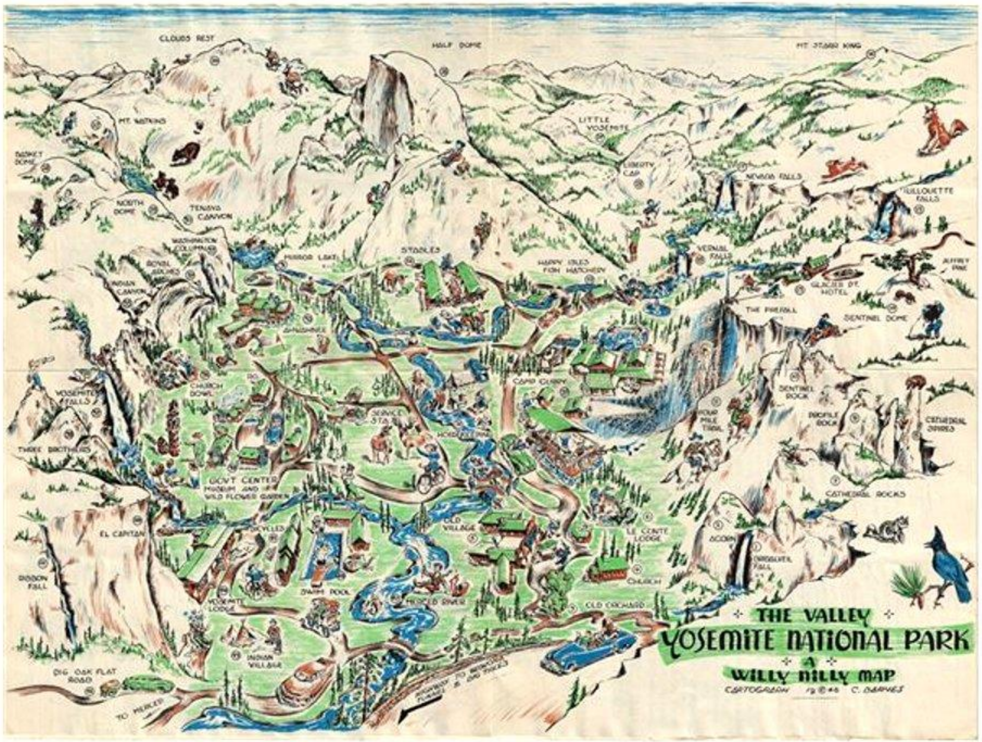
Use Case (Context)

Yosemite National Park (2012)

- Land Mass: 748,036 acres
- Designated Wilderness: 94.45%
- 53,679 overnight hikers
- 800 miles of trail
- 216 Search and Rescue operations

Yosemite Search and Rescue (YOSAR) team

- Well-equipped: 90% of big-wall rescues (~24) require a helicopter
- Rescuers: solid alpine skills required
  - Salary $ 23-34 per hour



http://www.yosemite.ca.us/library/maps/yosemite_valley_map_1946_barnes.jpg

Use Case

Jamie is the Team Coordinator at YOSAR

Use Case

... buys RescueRangers drone

Use Case

1. Aha! Easier than assembling furniture these days
2. Assembles the hardware in 3 hours
3. Installs the mandatory software suite on his laptop in half an hour
4. Goes through the basic tutorials in 2 hours

All done!

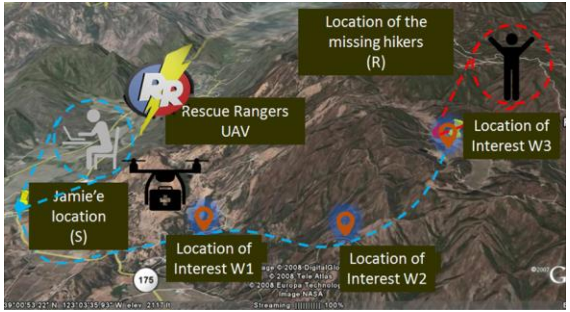
http://store.dji.com/product/

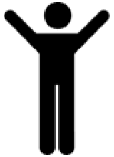
Use Case

5. Emergency SAR SOS at 6 in the morning: 2 hikers missing
6. Sends out alarm to assemble the team
7. Half an hour enough to test the drone?
8. Fires up his laptop
9. Switches the drone on
10. Selects “Search and Map” on the software
11. Inputs the likely locations to search

Use Case

12. Drone takes off, he resumes his preparation
13. 20 minutes later, when the team is almost prepared, the drone comes back
14. Connects the drone to the laptop with a USB cable: data transfer in 5 minutes.
15. In another 3 minutes,the software pops up with some relevant pictures found and their locations on the map. He immediately communicates the location to his team.
16. He attaches a first aid package to the drone and switches ON its power.
17. He selects the option “Drop package” on the software and specifies the chosen location





Humans identified at LOI W3

Use Case

18. The drone takes off and comes back in 10 minutes
19. After another 30 minutes, the team brings the two hikers via a helicopter to the base

! MISSION ACCOMPLISHED !

Functional Requirements

The system shall

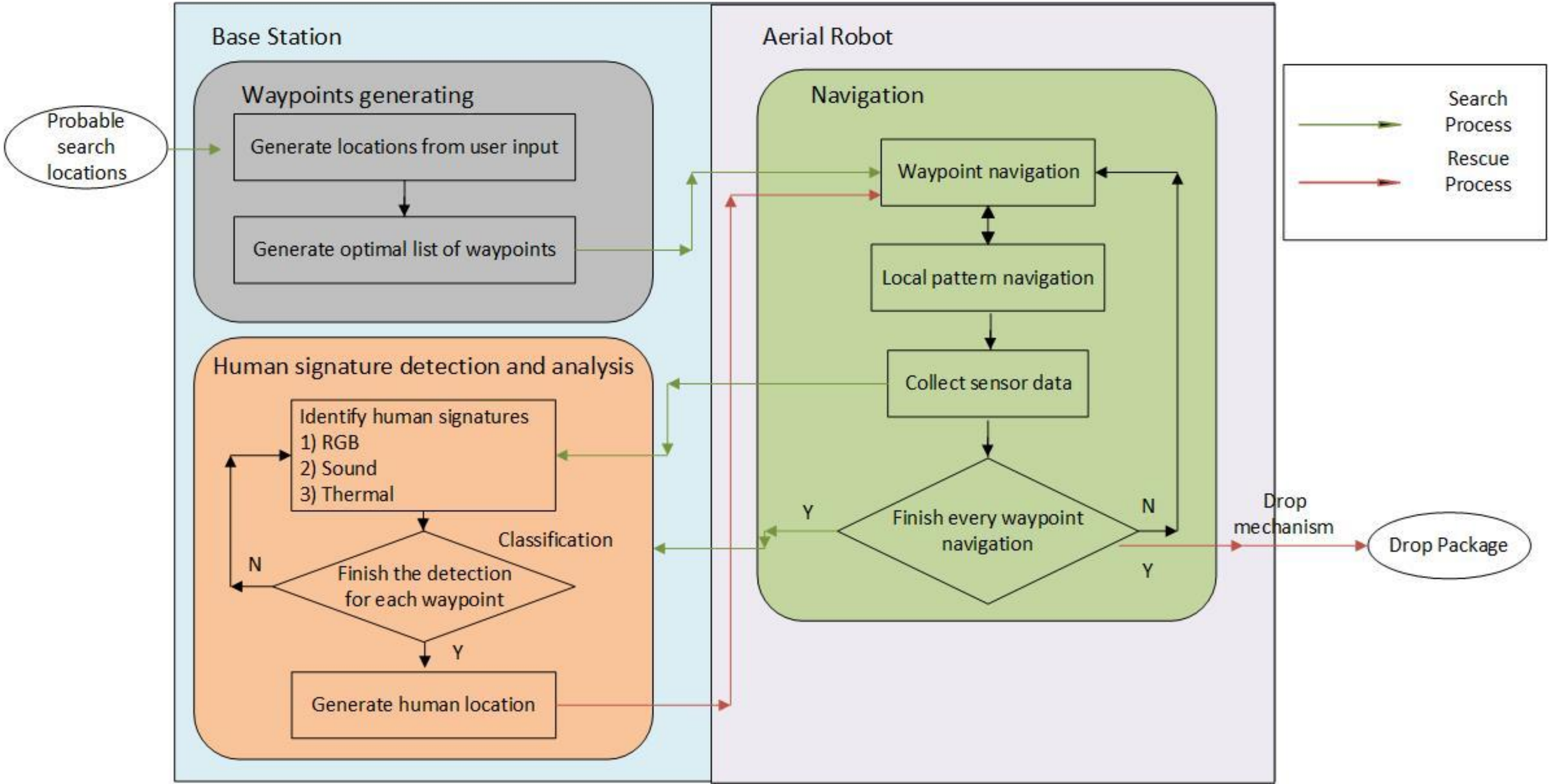
1. Autonomously navigate through a set of provided locations of interest
2. Explore the surroundings around each location of interest
3. Collect perceptual data while navigating
4. Process the data to identify human signatures
5. Analyze the identified signatures to estimate human location
6. Navigate to the rescue location carrying the rescue package
7. Drop the rescue package
8. Complete the search within limited time

Performance Requirements

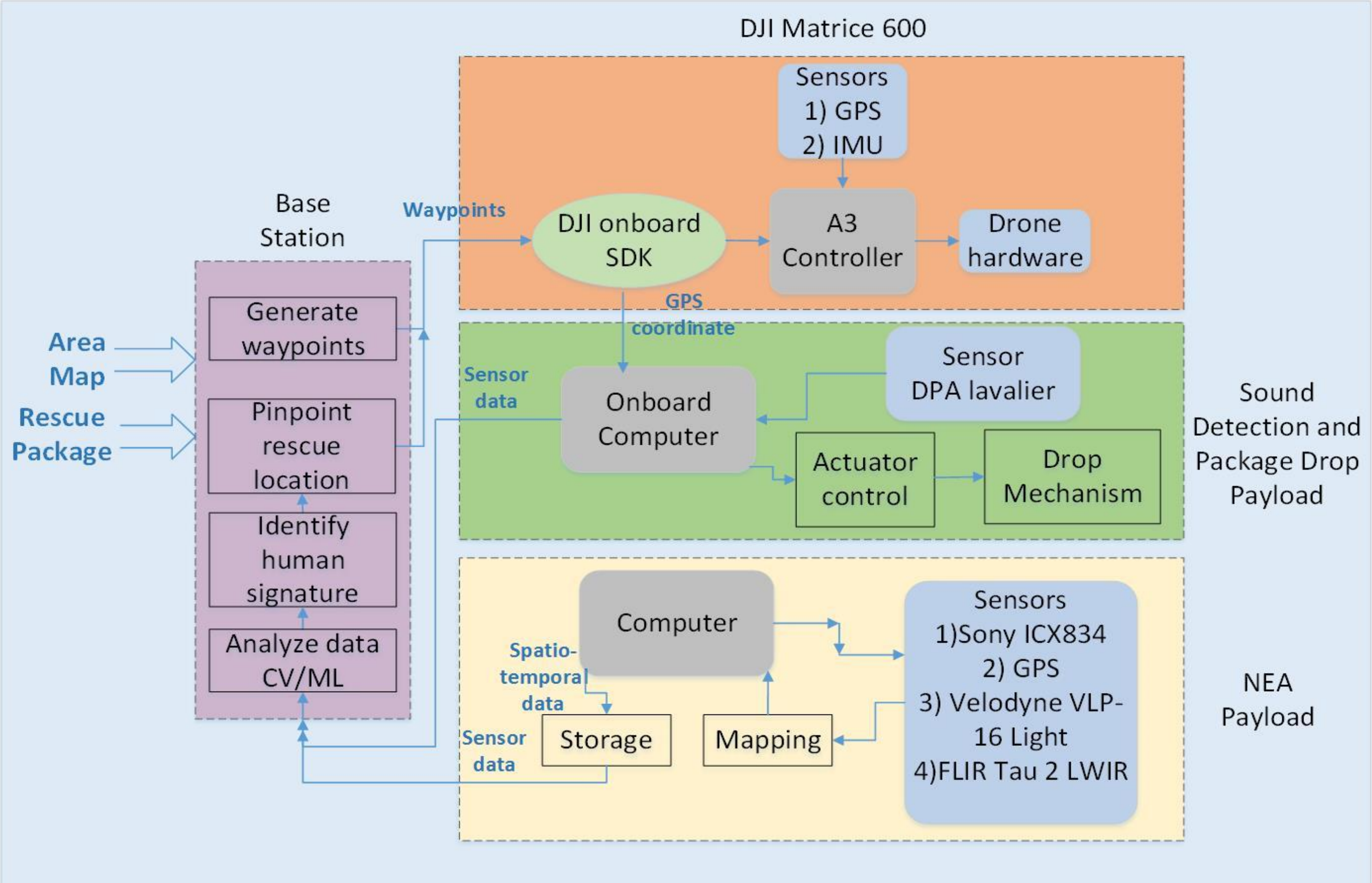
The system will

1. Accurately reach the locations of interest with a tolerance of **+-5m**
2. Attain up to **80%** coverage of the desired local search areas around each location of interest
3. Collect perceptual data limited to **3 types** - IR radiation, visual imagery, and sound
4. Identify at least **67%** of the locations with human signatures
5. Estimate potential human signature location with **+-5m** tolerance
6. Carry a rescue package weighing **100g**
7. Drop the package at the rescue location with a tolerance of **+-5m**
8. Complete one iteration of search in an un-occluded operating area of **200m x 200m** in **<25** minutes

Functional Architecture



Cyberphysical Architecture



Current System Status

Targeted System Requirements

1. ***Autonomously navigate through a set of provided locations of interest***
2. Explore the surroundings around each location of interest
3. Collect perceptual data while navigating
4. ***Process the data to identify human signatures***
5. Analyze the identified signatures to estimate human location
6. ***Navigate to the rescue location carrying the rescue package***
7. ***Drop the rescue package***
8. Complete the search within limited time

Targeted Subsystems

Autonomous Flight System

Signature Detection System

Package Drop System

Sensing System

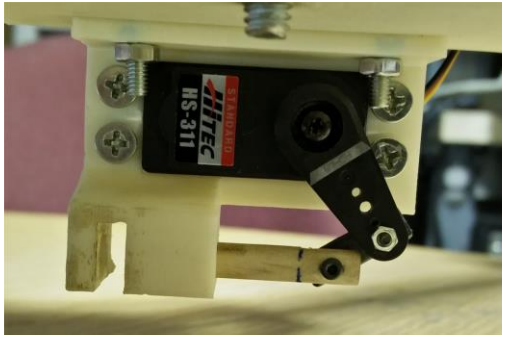
Teaser Video

[Rescue Rangers]

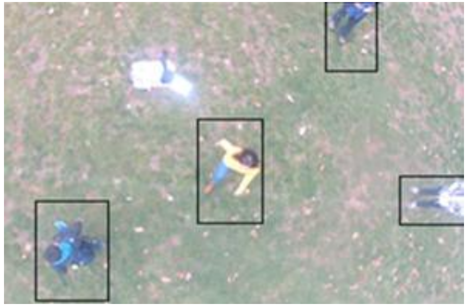
Overall System

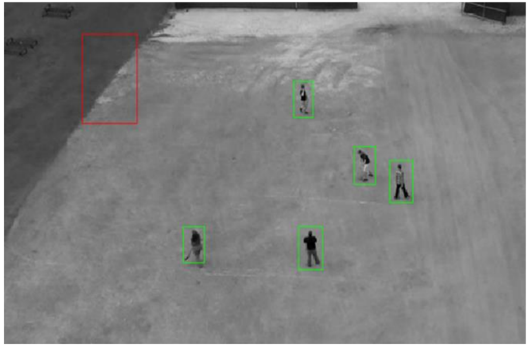
Waypoint Navigation

Package Drop



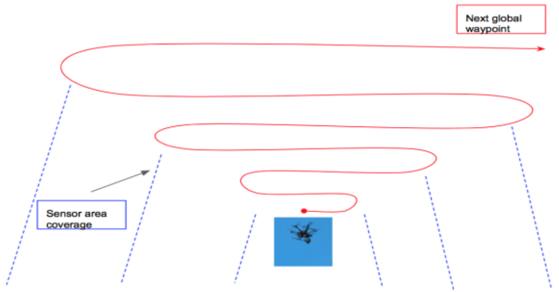
Human Detection





Autonomous Flight System - Description

Defining the navigation strategy:



- Terrain considerations
- How can we optimize the search
- Trade-off time, resolution and coverage
- Optimal altitude / speed

First pass at navigation strategy design:

- Reach LOI at altitude of 15 m, speed ~5 m/s
- Spiral up to an altitude of 30 m, complete one circle of radius 6 m, speed ~2m/s
- Move to the next location of interest while reducing the altitude to 15 m

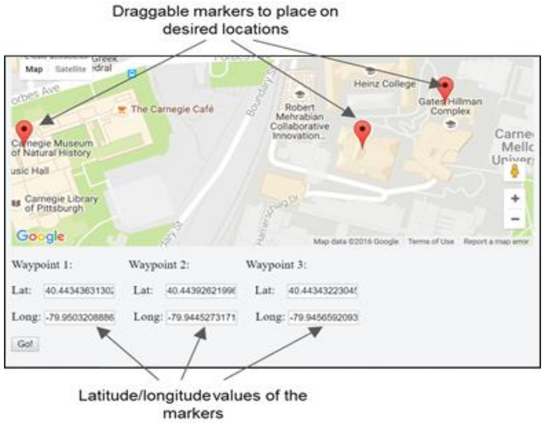
Theoretically, it can achieve:

- >98% overlap between two frames for both thermal and RGB cameras - ***good stitching***
- ***Well detailed imagery***
    - Ground sampling distance: 0.5 cm/pixel for RGB, 2.7 cm/pixel for thermal

Autonomous Flight System - Implementation

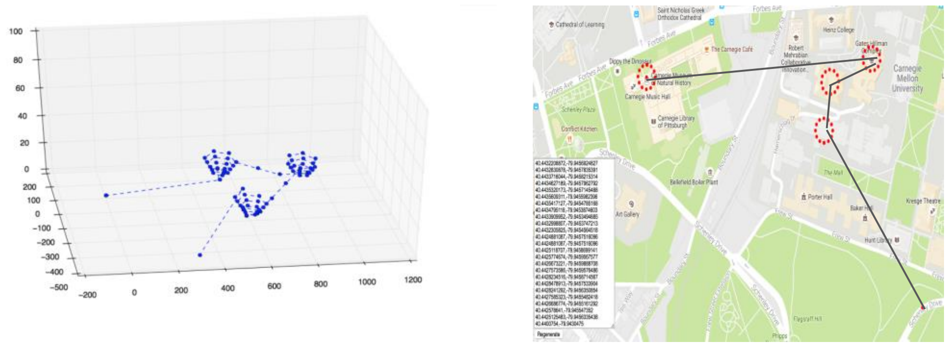
Generate Location of Interests

- Implemented UI/interface for operator to specify locations of interest and convert to GPS coordinates



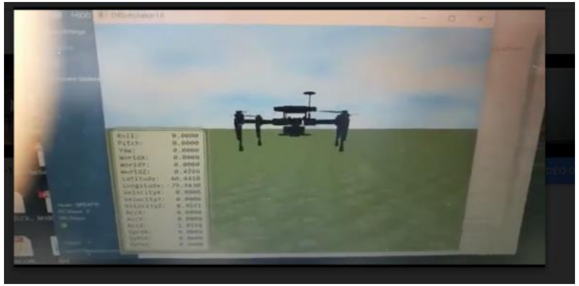
Generate Waypoints

- Implemented software to generate intermediate waypoints



Intermediate Waypoint Generation

Autonomous Flight System - Implementation and Testing



Implementation

- iOS app using DJI mobile SDK and sample code
- Changes to accept and display waypoints as GPS coordinates.

Test/Validation

- Test working of app on DJI Simulator
- Validate GPS location of drone and coordinates with iOS based API for multiple waypoints.
- Validate GPS random error by plotting std deviation of drone and phone GPS logs for multiple waypoints.

Autonomous Flight System - FVE Performance Evaluation

Test A	***UAV Waypoint Navigation Test***	
Description	Validates the autonomous flight control and waypoint navigation capability of the UAV	
Location	Open 50m x 50m area with GPS access and normal wind conditions	
Equipment	UAV, Laptop for waypoint control	
Steps	**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	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)

Evaluation Results

A.1. iOS App to provide input GPS

A.2. Height provided = **5M.** Min height = **4.8M**, Max height = **5.3M**

A.3 Accuracy : **<3M** from each waypoint

A.4 Back to start location : **<3M**

Autonomous Flight System - Conclusions

Strengths

- Rich SDK API that provides functions to control the drone

Weakness

- UX Needs improvement to show exact distance of drone from input waypoint.

Future Work

- Integrate waypoint pattern generation into app.
- Real time navigation for rescue drop.

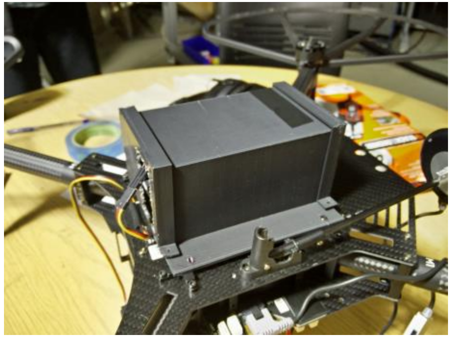
Package Drop Mechanism - Description

Mechanism:

- Simple servo actuated mechanism
- Package easily attached by hanging using a string

Control:

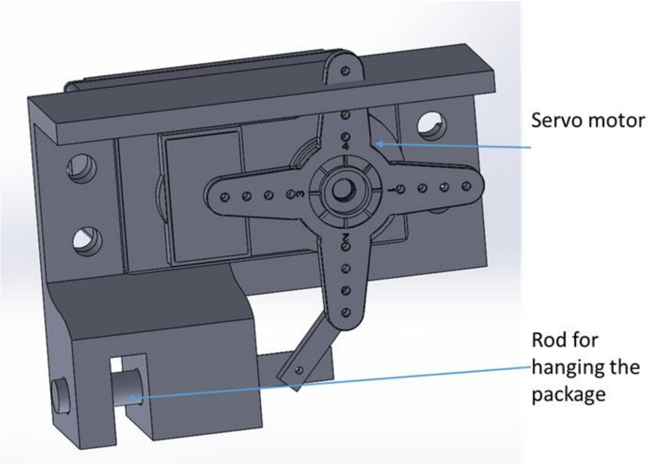
- Implemented using Raspberry PI
- Http call to R-pi server with servo angle



Package Drop Mechanism - Modeling and Testing

Modeling was done in SolidWorks:

- To test feasibility
- To finalize exact design specifications of different components to be manufactured
- To estimate the angles the servo motor needs to rotate to open/close the mechanism



Testing:

- Done on a package of ~160g to ensure the robustness of the mechanism
- Grip testing: on multiple flights with drone speed upto 2 m/s
- Package attach and release testing: 20-25 times in total, 5-10 times in flight

Package Drop Mech. - FVE Performance evaluation

FVE Test C	***Package drop mechanism prototype test***			
Steps	**Step Description**	**Performance Measures**	**FVE**	**FVE - Encore**
C.1.	Validate package size and weight. Secure the package in the mechanism	Should be able to hold package of weight 100g, and size 10cmx10cm	**Successful (package weight ~160g)**	**Successful (package weight ~160g)**
C.2.	Subject the mechanism to accelerations in x, y and z directions manually	Should not lose grip of the package for drone velocities under 2 m/s	**Successful**	**Successful**
C.4.	Manually demonstrate the mechanism's ability to release the package	Should release the package safely without any damage, 3 times in a row	**Successful**	**Successful**

Successful on all the three performance measures!

Package Drop Mechanism - Conclusions

- **Strengths:**
    - Simple and easy to control
    - Compact and lightweight
    - Grip on package not dependent on any electrical system, but rather on structural strength

- **Weaknesses:**
    - Package is hung, not held firm in place
        - Not an issue for our system requirements

- **Further work:**
    - Create a mount to enable its mounting on sponsor’s Matrice 600 drone
    - Evaluate the need for metal fabrication

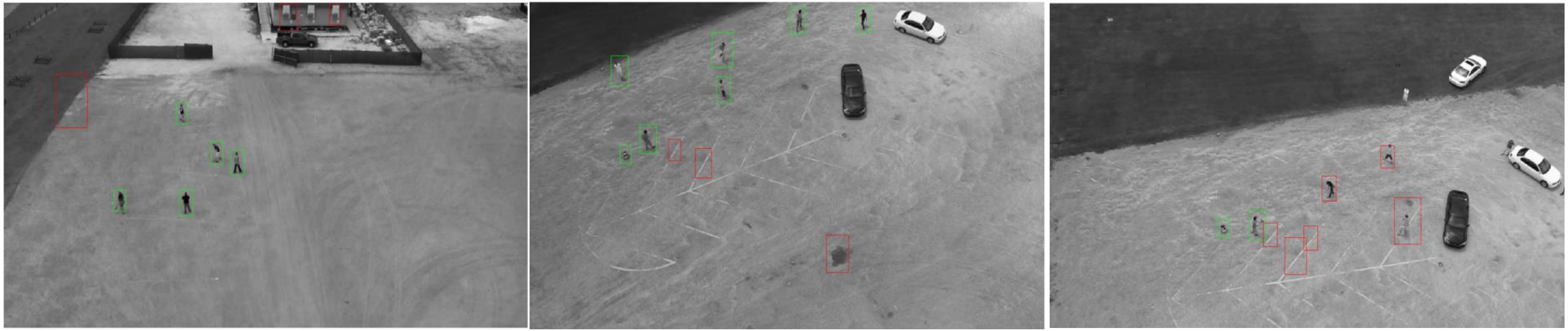
Signature Detection System - Description

Motivation

Use RGB-based signature detection algorithm to detect human beings in aerial images

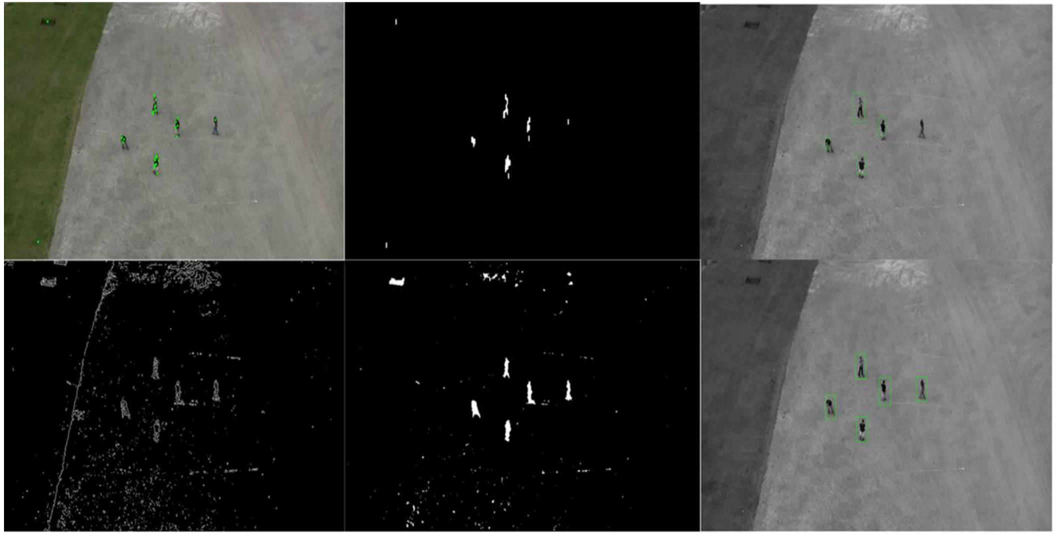
Method

- Edge detection for finding potential human candidates
- Background Subtraction to detect moving human candidates
- HoG+SVM for classification

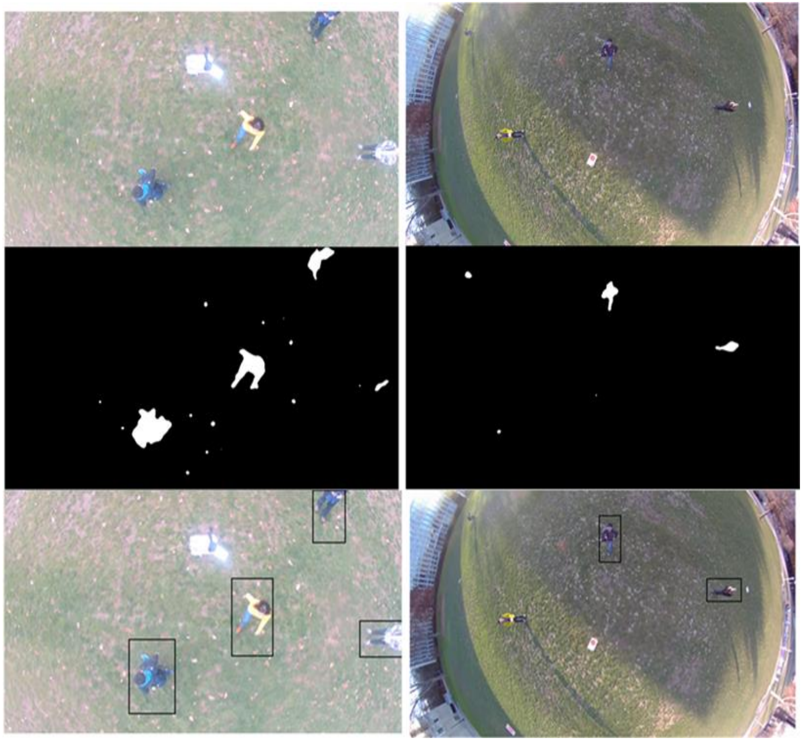


Signature Detection System - Modeling & Analysis

Edge detection and Blob detection



Background Subtraction Strategy



Signature Detection System - Modeling & Analysis

HoG+SVM for classification

- Training set:
  299 positive images, 372 negative images
- Test set:
  111 positive images, 108 negative images
- Result:
  PPV: 85/(26+85) = 76.6%
  NPV: 98/(98+10) = 90.7%

	Negative (predicted)	Positive (predicted)
Negative (Actual)	98	10
Positive (Actual)	26	85

Signature Detection - FVE Performance Evaluation

Test B	*Human detection algorithm test*	
Description	Validates the capability of the algorithm to detect human signatures in RGB images	
Location	Lab	
Equipment	Laptop to run the detection algorithm, pre-stored images with relevant human signatures	
Steps	**Step Description**	**Performance Measures**
B.1.	Run the algorithm on the set of images	Ability to detect at least 60% of valid human signatures in images

Evaluation Results:

- For 20 images from 2 different online videos, there are 64 humans in those images, and 42 of them are detected. Accuracy:**65.6%**
- For 20 images from 2 our collected videos, 42 of 65 humans in those images are successfully detected. Accuracy:**64.6%**
- Overall accuracy for 40 test images: **65.1%**

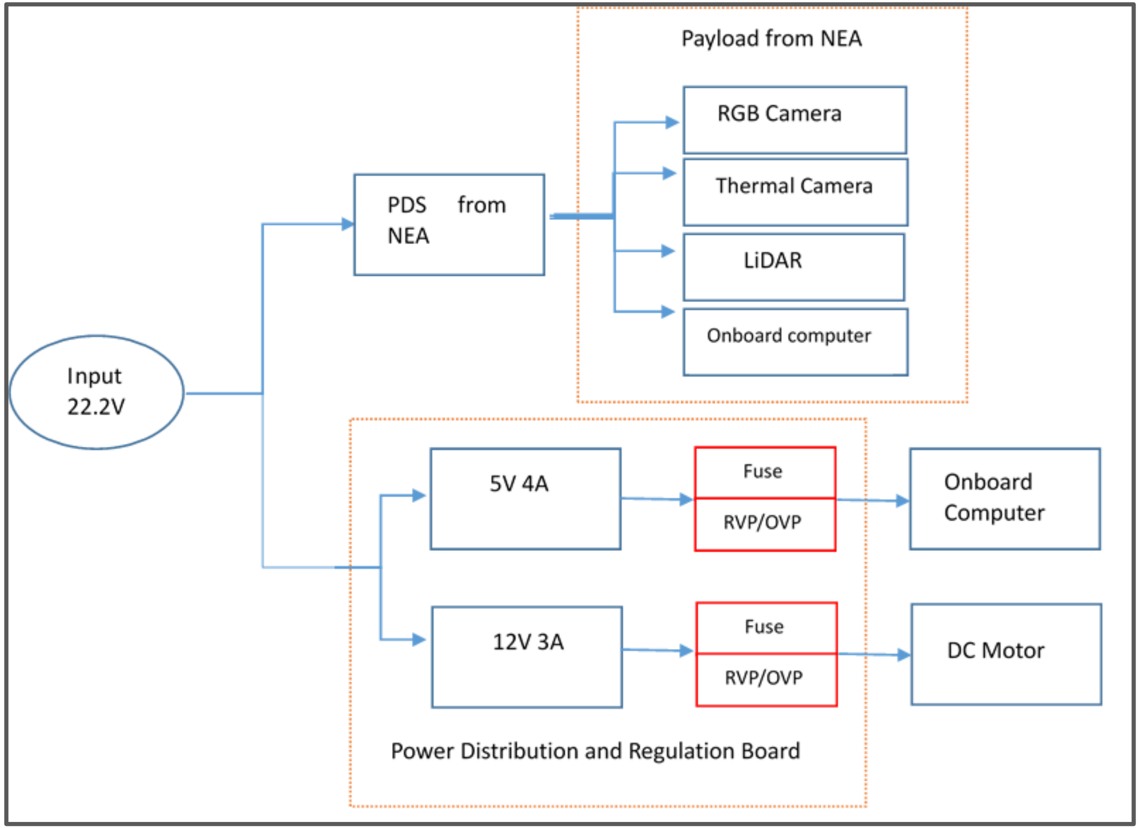
Signature Detection System - Conclusions

- **Strengths**
  - Efficient in finding potential human candidates in an image.
  - Ability to detect both in moving and motionless human beings

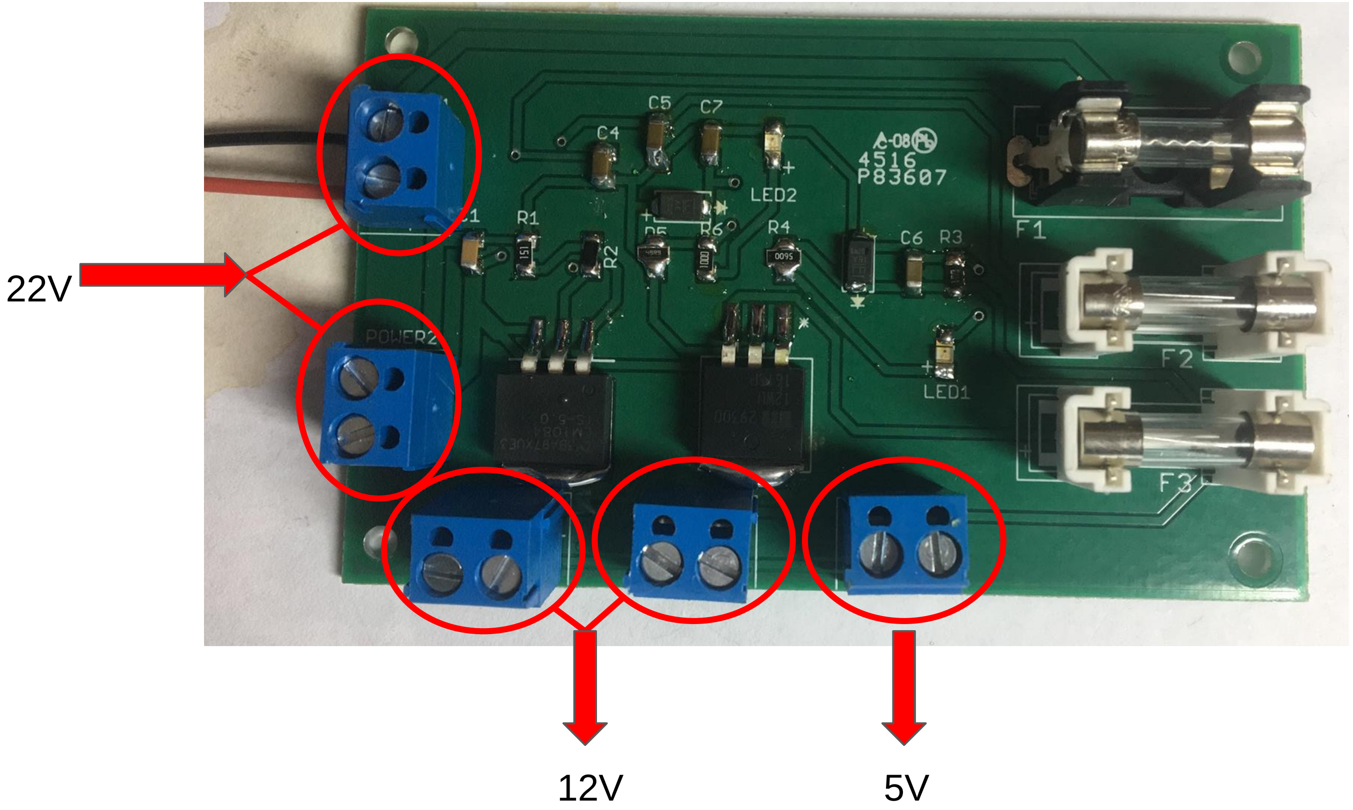
- **Weaknesses**
  - Lower accuracy when dealing with human beings who are not vertical.
  - Does not cover all poses

- **Further work**
  - Improve the training set to include humans with different poses.
  - Use more advanced methods for finding human candidates and classification

Power Distribution Board - Description



PDB - FVE Performance Evaluation



Power Distribution Board - Conclusions

- **Strengths:**
  - Is able to protect the circuit from misoperation
  - Compact and lightweight
  - Have additional connectors for backup use

- **Weaknesses**
  - The input power voltage can only be lower than 25V

- **Further work:**
  - Add step-down transformer before the power input.
  - Change the type of the regulator

Project Management

Work Breakdown Structure (High-level)

Rescue Rangers
Search and Rescue Assistance System

1. Autonomous Flight System

1.1. Set up Matrice 100

1.2. Set up Matrice 600

1.3. Implement autonomous waypoint navigation

1.4. Implement Local Search strategy

2. Sensing

2.1. Finalize sensors

2.2. Test individual sensor performance

2.3. Software: process NEA payload data

2.4. Software: process specific sensor data

2.5. Design sound sensor mounting

3. Rescue assembly system

3.1. Mechanical structure

3.2. Actuation system

3.3. Integrate mechanical structure & actuation system

4. Signature detection and analysis

4.1. Finalize human signatures to detect

4.2. Basic visual signature detection

4.3. Visual+Thermal signature detection

4.4. Human sound detection

4.5. Optimize/scale Performance

5. System Integration and Testing

5.1. Test flight

5.2. Build SDPD payload; integrate

5.3. Data collection pipeline: UAV to base

5.4. Test end to end system

6. Project Planning

6.1. Initial Planning

6.2. Project Continuity

6.3. Project Delivery

6.4. Risk Management

Schedule

Plan	
Not finished	
Finished	

	Tasks	Sems	Hours
1	**Autonomous Flight System**		**117**
1.1	Matrice 100 setup	FV	17
1.2	Matrice 600 setup	FV	5
1.3	Implement autonomous waypoint navigation	Both	46
1.4	Implement Local Search strategy	SV	49
2	**Sensing**		**110**
2.1	Finalize sensors	Both	20
2.2	Test individual sensor performance	Both	18
2.3	Process NEA payload data	SV	16
2.4	Process specific sensor data	Both	48
2.5	Design sound sensor mounting	FV	8
3	**Rescue assembly system**		**70**
3.1	Design mechanical system	FV	16
3.2	Prototype mechanical system	FV	6
3.3	Procure mechanical/electronic components	FV	4
3.4	Fabricate mechanical system	SV	24
3.5	Develop electronics	SV	12
3.6	Integrate mechanical assembly + electronics	SV	8

Schedule

Plan	
Not finished	
Finished	

	Tasks	Sems	Hours	Oct,2016			Nov,2016				Break	Jan,2017			Feb,2017				Mar,2017				April,2017				
				10/17/2016	10/24/2016	10/31/2016	11/7/2016	11/14/2016	11/21/2016	11/28/2016		1/16/2017	1/23/2017	1/30/2017	2/6/2017	2/13/2017	2/20/2017	2/27/2017	3/6/2017	3/13/2017	3/20/2017	3/27/2017	4/3/2017	4/10/2017	4/17/2017	4/24/2017	5/1/2017
4	**Signature detection and analysis**		**150**																								
4.1	Finalize human signatures to detect	FV	10																								
4.2	Develop basic visual signatures' detection algorithm	FV	60																								
4.3	Develop visual+thermal signatures' detection algorithm	Both	60																								
4.4	Performance optimizations/scaling (as per SVR)	SV	20																								
5	**System Integration and Testing**		**107**																								
5.1	Test flight: waypoint navigation; NEA payload	FV	10																								
5.2	Test flight: waypoint navigation + basic hover; no payload	FV	10																								
5.3	Build SDPD payload; integrate into the syatem	Both	51																								
5.4	Data collection pipeline from UAV to base	SV	6																								
5.5	Test end to end system: waypoint navigation + search; NEA	SV	10																								
5.6	Test end to end system for the whole operation	SV	20																								
6	**Project Planning**		**143**																								
6.1	Initial Planning	FV	30																								
6.2	Project Continuity	Both	56																								
6.3	Project Delivery	Both	40																								
6.4	Risk Management	Both	17																								

Spring 2017 Milestone/Test plan

Milestone	***Date***	***Capability***
PR7	**Late January**	- Test software for planning localized waypoint navigation
PR8	**Mid-February**	- Test Revised RGB based human detection algorithm
PR9	**Late February**	- Test finalized design for integrating sound sensor - Test rudimentary detection algorithm for thermal and sound
PR10	**Mid-March**	- Test software to collect and process NEA payload data
PR11	**Early April**	- Test final signature detection algorithm using data collected from NEA payload
PR12	**Mid-April**	- Test end-to-end system for the whole operation

Spring Validation Experiment 2017

Test D: Full system test (1/3)

Objective:

To validates 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	UAV; Laptop; Rescue package; 3 Representations of human signatures: Mannequins (filled with hot water)/red clothes/speaker/fire

Spring Validation Experiment 2017

Test D: Full system test (2/3)

Steps	*Step Description*	*Performance Measures*
D.1.	Place UAV on the ground. Feed GPS locations for 8 LOIs	
D.2.	UAV takes off and reaches the desired altitude for navigation	Accuracy in reaching desired height (+-1m tolerance)
D.3.	UAV reaches the first LOI and performs localized search	Accuracy in reaching the LOI (+-5m tolerance)
D.4.	UAV Flies from one LOI to another performing localized search	- Accuracy in reaching the LOI (+-5m tolerance) - 80% coverage of the planned search area
D.5.	UAV flies back to the starting point after covering all the waypoints	Accuracy in reaching the starting point (+-5m tolerance)

Spring Validation Experiment 2017

Test D: Full system test (3/3)

Steps	Step Description	Performance Measures
D.6.	Transfer data from the UAV to base station	Ability to collect the three types of perceptual data
D.7.	Process the data to identify any human signatures	Ability to identify at least 67% of the locations with human signatures
D.8.	Based on the identified human signatures, select correct location for rescue	Ability to identify at least one correct location for rescue
D.9.	UAV flies to the selected rescue location	Accuracy in reaching the rescue location (+-5m tolerance)
D.10.	UAV releases the rescue package	Ability to safely release the package
D.11.	UAV flies back to the base station	Accuracy in reaching the starting location (+-5m tolerance)

Budget

Part List 1 , Sponsor Provided

Description	Manufacturer	Model	Unit	Weight (g)	Cost
LWIR	FLIR	Tau 2	1	72	$7000
RGB Camera	Pointgrey	Grasshopper	1	520	$2,399
Lidar	Velodyne	VLP-16	1	590	$7,999
Flying platform	DJI	Matrice 600	1	9,600	$4,599
Panorama video camera	360fly	360fly 4k video camera	1	172	$399

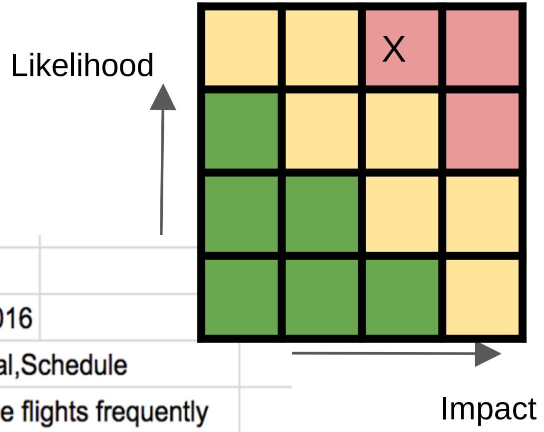
Part List 2, Not provided by Sponsor

Description	Manufacturer	Model	Unit	Weight (g)	Cost
Aerial Platform	DJI	Matrice 100	1	680	$3250
Battery Heater	DJI	Inspired 1	1	100	$20
Battery Sticker	DJI	Inspired 1	1	0.2	$2

Key points

- Total Budget = $5000
- Total Cost = $3272
- Major items
  - DJI Matrice 100
- Percentage spent to date = 65.4%

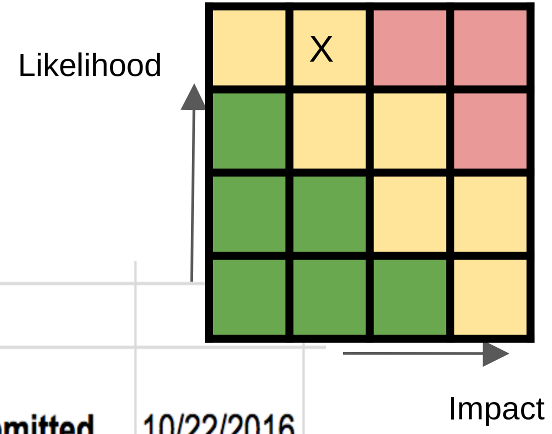
Risks and Mitigation



RISK SUMMARY			
Title	Unavailability of drone for frequent testing	**Date Submitted**	10/19/2016
Owner	Karthik/Sumit	**Risk Type**	Technical,Schedule
Description	Sponsor requires drone to remain in their premise and may not be able to schedule flights frequently		
Consequence	Will impact ability to iterate quickly on various navigation strategies/sensing evaluation and rescue strategy		

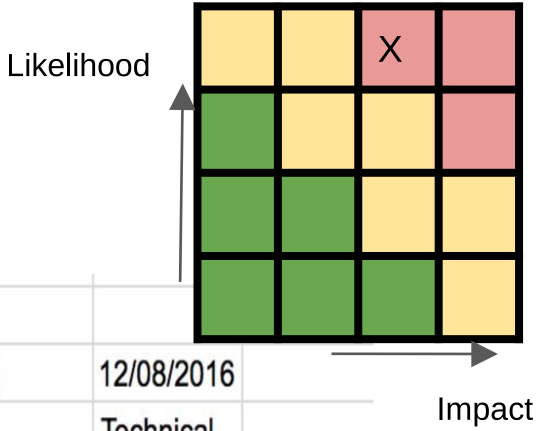
RISK MITIGATION			
Action	**Date**	**Success criteria**	**Risk level**
Order dev drone	10/25/2016	Ability to test and run navigation strategies iteratively	60
Validate using sensor payload manually to generate data	11/10/2016	Ability to generate sensor data very similar to aerial flight	50
Use data from flights scheduled for other projects	11/10/2016	Validate if data matches what we expect	40
Device sensor mounting strategy for dev drone	11/20/2017	Ability to use rgb and thermal camera for sensing on dev drone	30

Risks and Mitigation



RISK SUMMARY					
Title	Inability to achieve high accuracy in signature detection			**Date Submitted**	10/22/2016
Owner	Juncheng/Sumit			**Risk Type**	Technical
Description	Sensor data especially sound might be very noisy and could generate inaccurate results				
Consequence	Will impact accuracy with which system can detect signatures				
RISK MITIGATION					
Action	**Date**	**Success criteria**			**Risk level**
Evaluate design for suspended microphone sensor	1/20/2017	Ability to suspend microphone 10 feet below the drone and fly the drone safely			10

Risks and Mitigation



RISK SUMMARY						
Title	Drone battery not working in cold weather conditions			**Date Submitted**	12/08/2016	
Owner	Karthik/Sumit			**Risk Type**	Technical	
Description	We noticed on our flight tests that the smart battery has a safety check to turn off when exposed to sub zero temperatures for long periods of time.					
Consequence	Cannot fly the drone					
RISK MITIGATION						
Action	**Date**	**Success criteria**			**Risk level**	**Status**
Have a spare pre-heated battery	12/8/2016	Procurement of another battery			50	

Conclusions

Key Fall lessons

Requirements should be as clear as possible:

For ex, Human detection requirements for us

Give time to discussions: There will always be varied opinions, it’s better to discuss them ahead of time

Keep things simple:

Package drop mechanism - faced no issues

Carefully consider all the spares required

Although expensive, a spare pre-heated battery for drone could have worked well for FVE Encore

Key Spring activities

Requirements should be as clear as possible:

- *Define human detection requirements properly*
- *Define area coverage requirements properly*
- *Think about ways to validate them*

Give time to discussions:

- *Set aside time to discuss whenever starting on a new thing*

Keep things simple:

- *Keep this in mind whenever designing something new*

Carefully consider all the spares required:

- *Order a new battery for the drone*
- *A spare pre-heated battery is a great idea for flights in cold weather conditions*

Thank you!