FlySense
Team C

Critical Design Review

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Who’s who on FlySense

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Difficult or dangerous flying situations…

Flying in low visibility environments or night

Flying at low altitude (below 200m), especially takeoff/landing in cluttered environments

Highly congested air traffic

… that may come unexpectedly!

Enhanced situation awareness using Augmented Reality to assist in aerial navigation

Solution

Captain Dolan with FlySense

Pilot assistance system which keeps pilot close to the reality by giving all the necessary information right in front of their eyes

- Display surrounding obstacles
- Warn pilots about possibility of collision (escalating warning)

FlySense Onboard

In Green: Added

Mandatory Functional and Performance Requirements

Feature	The system SHALL	Target Performance
Input	• Receive sensor state variable data (pose estimate, LIDAR input)	• Receive Point cloud from 1 Velodyne VLP-16 • Receive pose estimates from DJI M100
	• Receive Voice commands to toggle through Flysense widgets (Heads-up-display, Bird's eye view)	• 5 commands • 90% recognition without noise • 70% accuracy with noise
Process / Plan	• Detect obstacles in flight envelope	• Projected 5 seconds into future • 2m X 2m in distances less than 10m
	• Generate bird's eye view of obstacles surrounding the vehicle	• Image generated in vehicle frame >=10Hz
	• Color bird's eye view	• Into Red, Yellow or Green based on time to impact, pilot's inputs
	• Recommend feasible trajectory around obstacle	• Avoid obstacle(s) by 1m • Reduce errors by 20% w.r.t. pilot flying w/o FlySense
	• Override pilot commands to prevent collision	• Stop the aerial system 1m before the obstacle
Output / Convey	• Render HUD, horizon	• >10 Hz refresh rate
	• Render Bird's Eye View	• >10 Hz refresh rate
	• Generate Sound warnings	• Obstacle in flight path with least time to impact • Binary audio, Left or Right based on obstacle • Latency less than 1sec

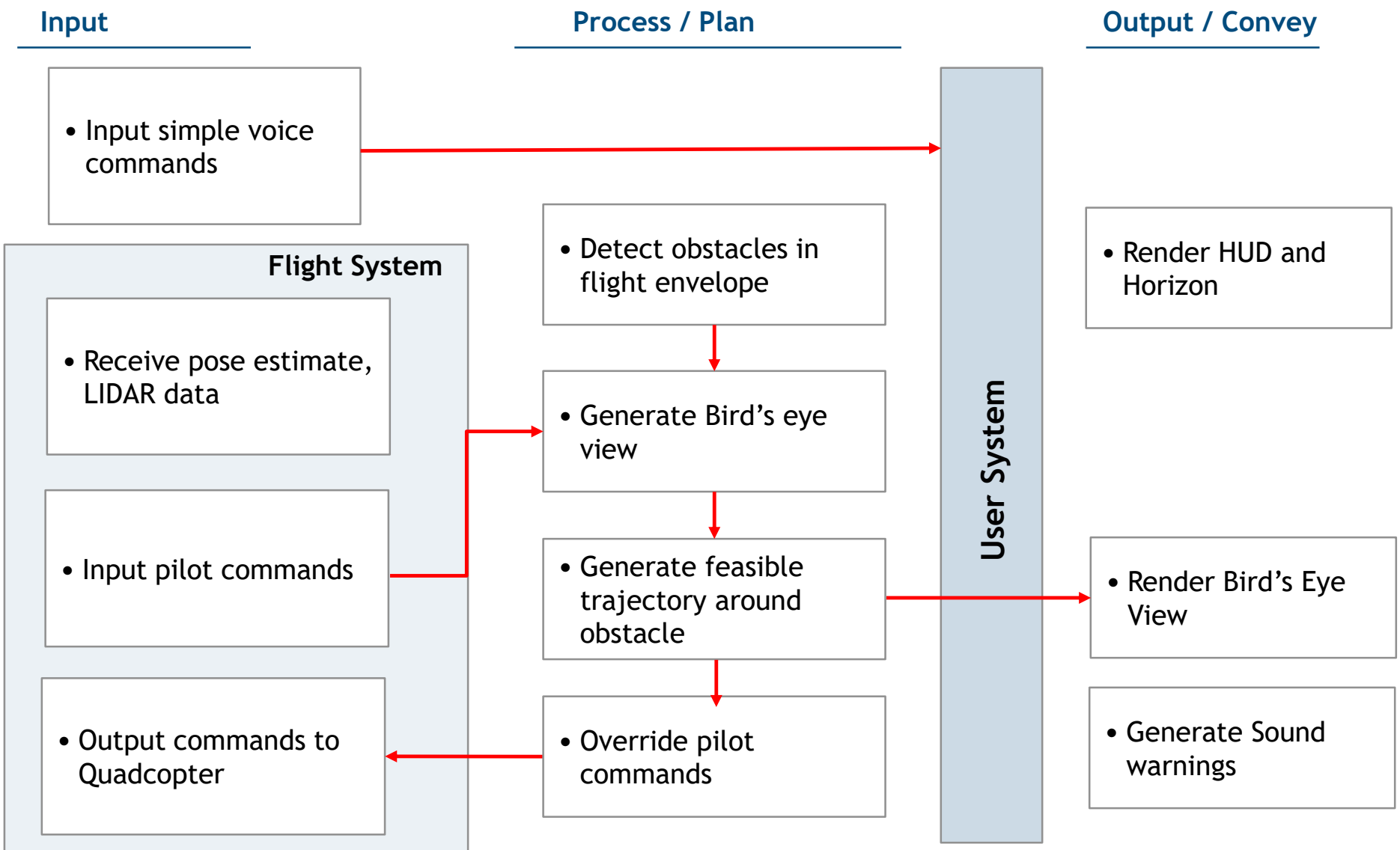
In Green: Added

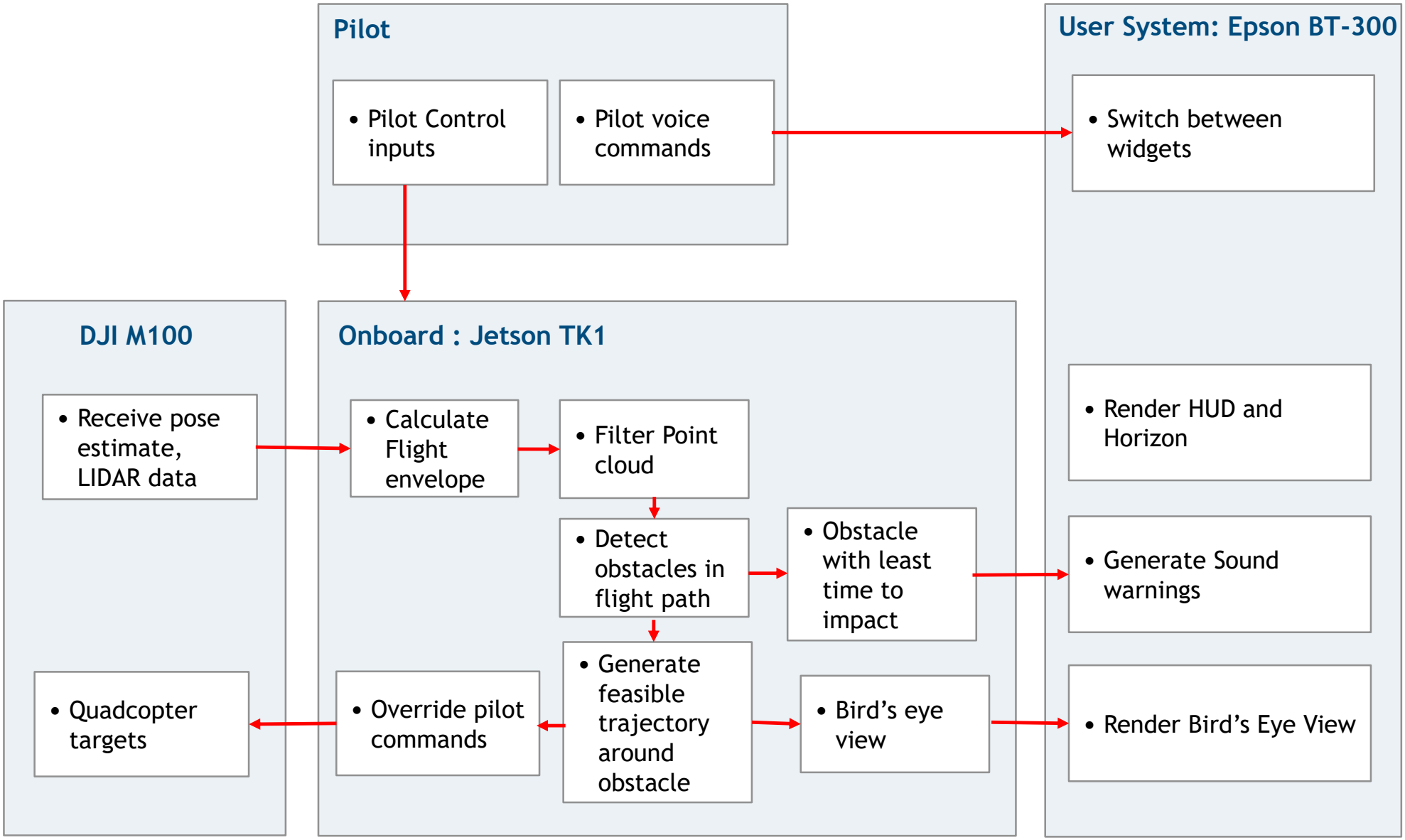
Desired Functional and Performance Requirements

Feature	The system SHALL	Target Performance
Input	• Voice recognition personalized to User	• Voice command personalized to 3 user
Process / Plan	• Override the pilot to avoid obstacles	• Avoid obstacles by with radial clearance of 2m
Output / Convey	• FPV video overlay on Epson • Segment obstacles	• >10Hz frame rate • Into 2 categories (Trees or building)

Updated Non-Functional and Performance Requirements

Segmentation	The system WILL	Target Performance
Installation	• Be easy to setup (hardware and software)	• The system will be set up within 1 minute with a single operator
Interaction with Pilot	• Feel natural to the pilot • Be easy to put/remove headwear • Be comfortable to wear headwear for long periods of time	• Focal distance up to 20 meters • Wearable like normal glasses • Weights less than 1 pound
Information Displayed	• Be clear and simple • Be non intrusive to the pilot • Be non distracting for the pilot	• Focus group with 3 pilots using solution
Other criteria	• Be substantially more affordable than available solutions (e.g. fighter jet pilot helmets)	• Solution hardware cost below USD 5,000

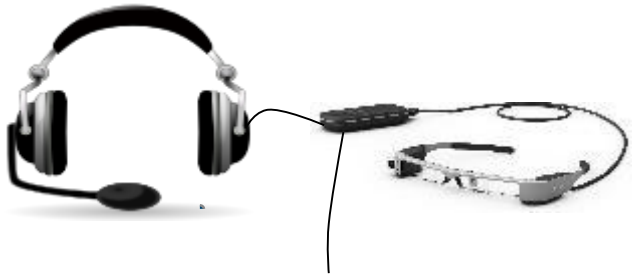




Aerial System

Flight envelope calculation	Project up to 5 seconds into the future ✓
Obstacle mapping	Generate obstacle map at latency <1s for objects of 2 m size located < 10 m ✓
Sound warning generation	Identify closest obstacle, and its location w.r.t vehicle ✓

User System

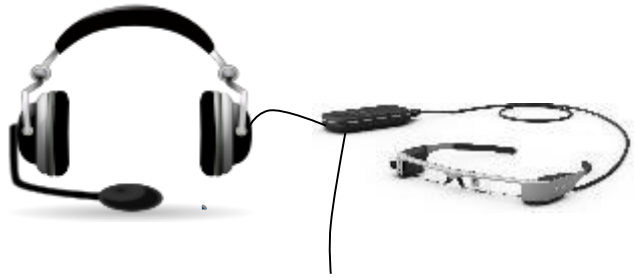


AR interface	Render HUD, Bird's eye view at refresh rate >= 10Hz ✓
Sound warnings	give warnings in left/right ear at latency < 1 second ✓
Voice commands	5 commands with 80% accuracy and no noise ✓

Aerial System

Obstacle mapping	Color obstacles (Red/Yellow/Green) based on time to impact
Override pilot commands	Stop vehicle 1m before the obstacle
Trajectory planning	Maintain 1m clearance from obstacles Reduce close proximity error by 20%

User System



AR interface	Render FPV at 10Hz frame rate or greater
Voice commands	Increase accuracy to 90% without noise, 70% with noise
Personalized Voice commands	Lock voice commands to a single user

The final SVE system will have three major components: Aerial, Communications & User System

Aerial System

- DJI Matrice 100 (mounted with Jetson TX-2 and Velodyne VLP16 Puck, PDB)

Communications

- 5 GHz Dual Radio Base Station with MIMO technology

User System

- Epson BT 300 Augmented Reality headset
- Headset for audio warnings & voice command recognition

Onboard computer interface to DJI Matrice 100 (Implementation/Status)

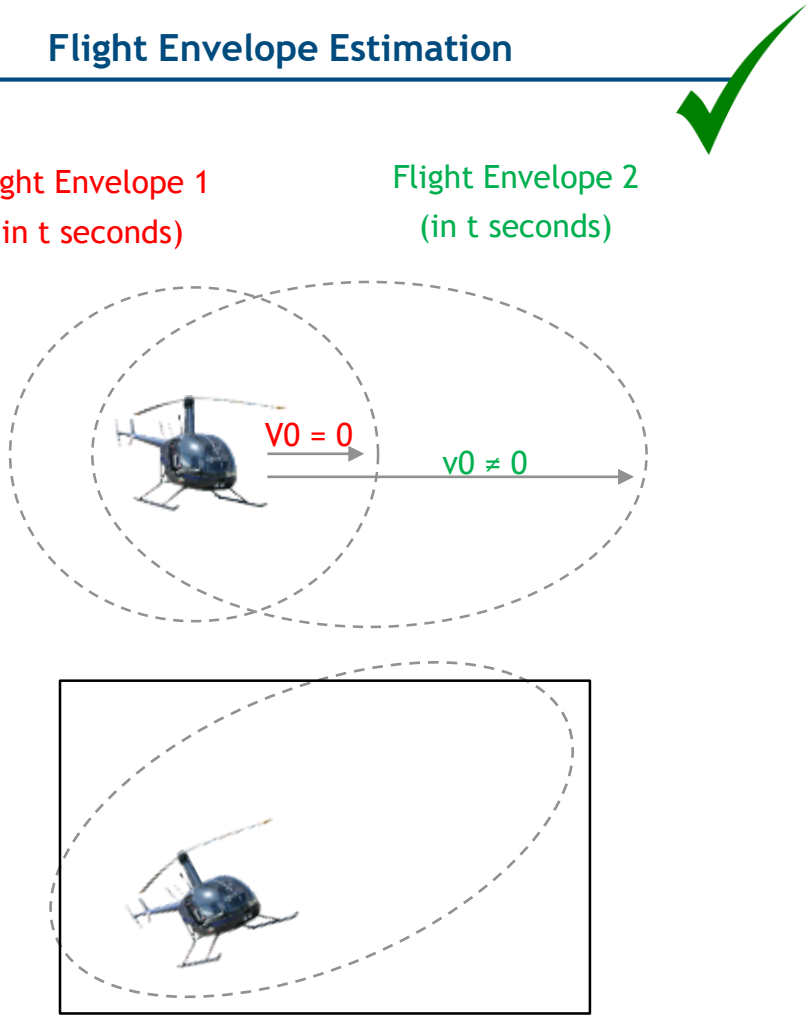
- Attitude Quaternion ✓
- Local position/GPS ✓
- Flight Status ✓
- Pilot inputs ✓

Pilot Override

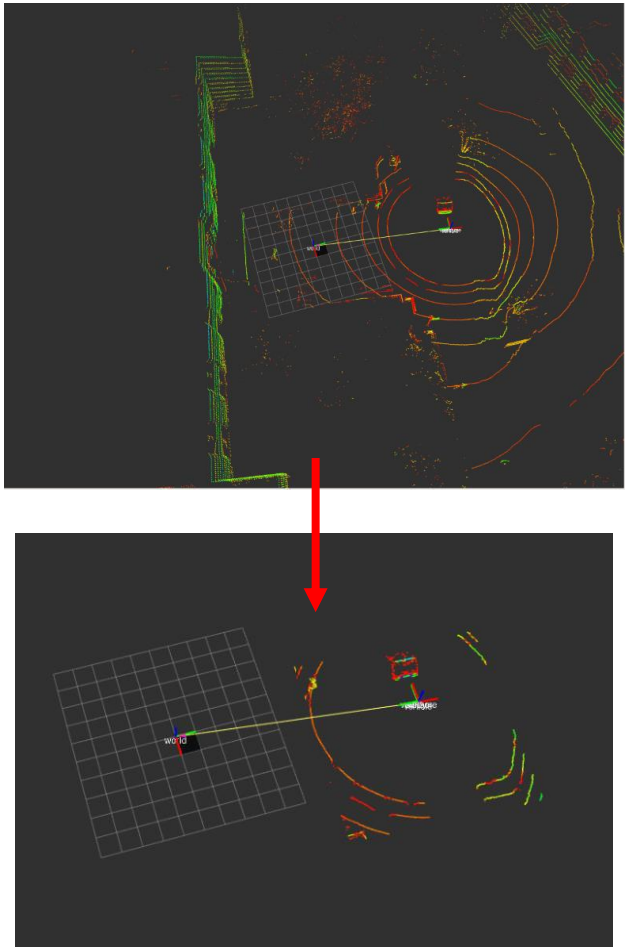
- Publish Roll Pitch Heading in North East Down frame ✓
- Publish TF Tree ✓

Flight Envelope implementation/status

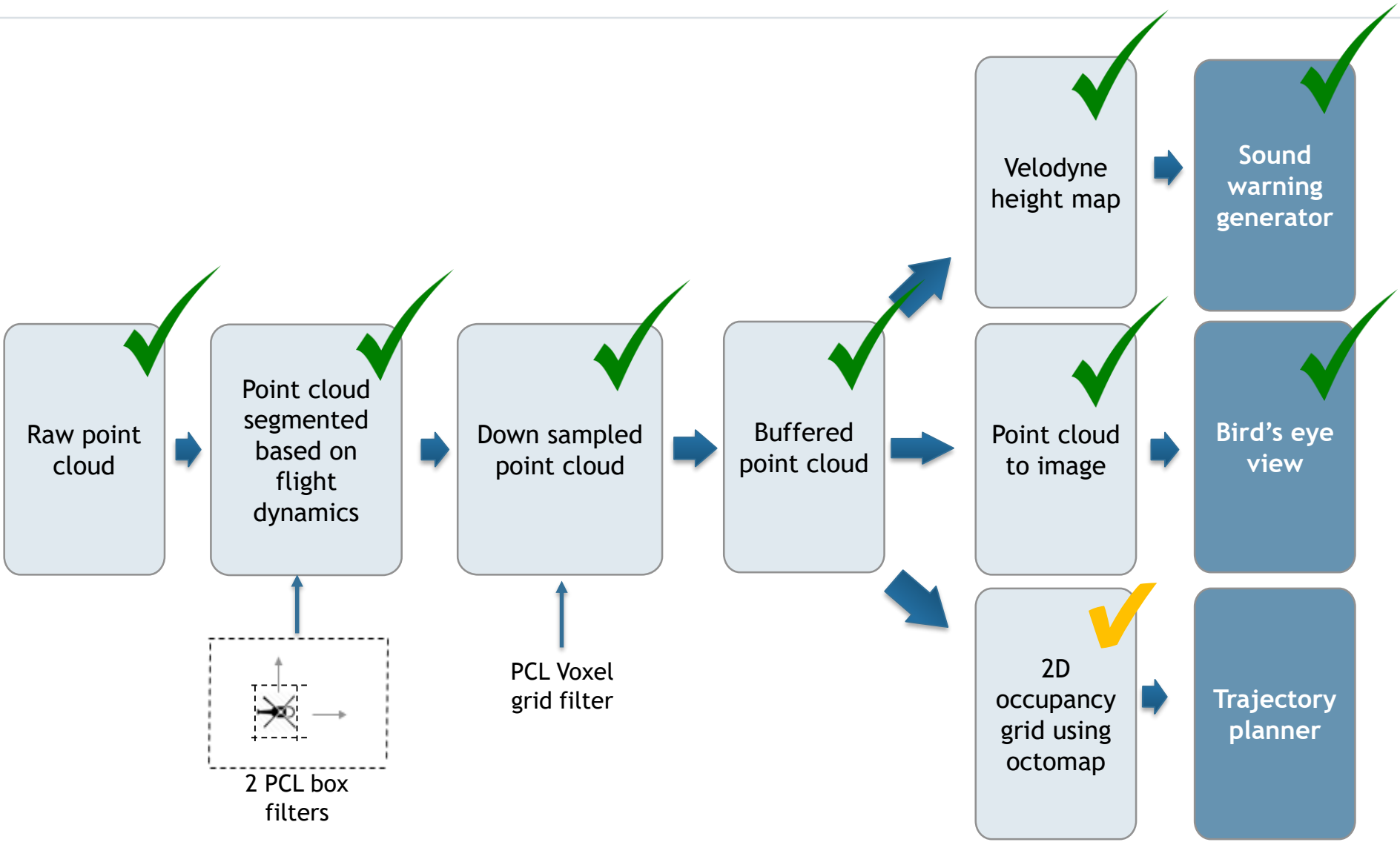
Flight Envelope Estimation



Implementation

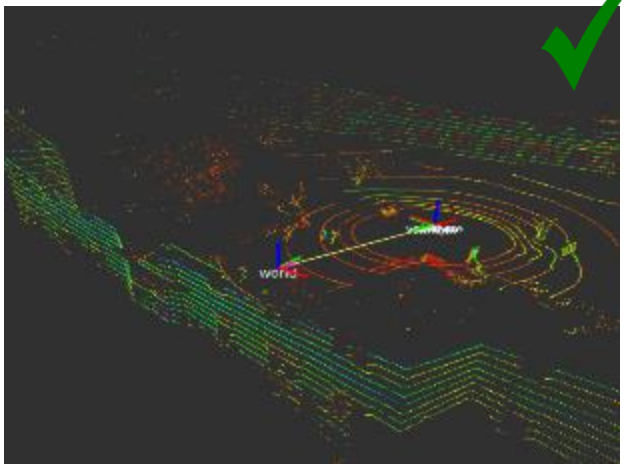


PCL pipeline and mapping implementation/status

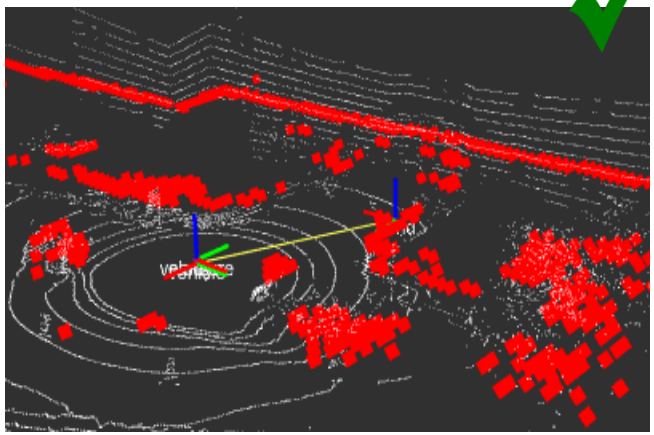


PCL pipeline and mapping (Status)

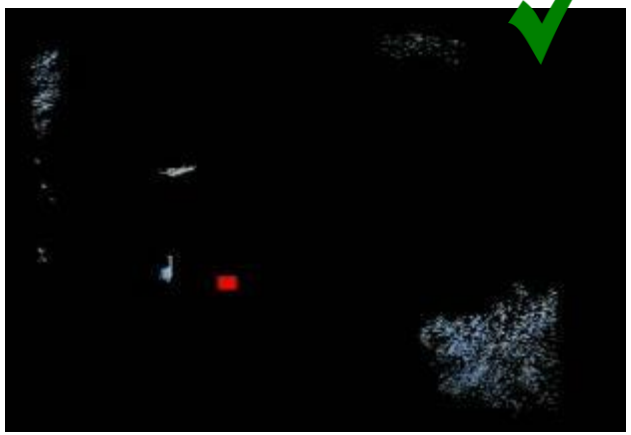
Raw point cloud



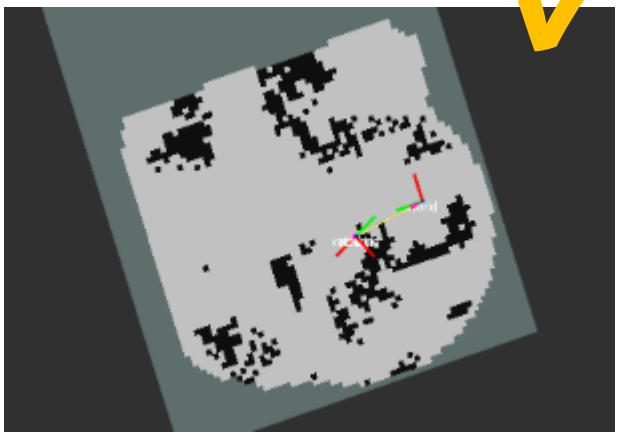
Obstacles for sound warning generator



Bird’s eye view Image in Rviz

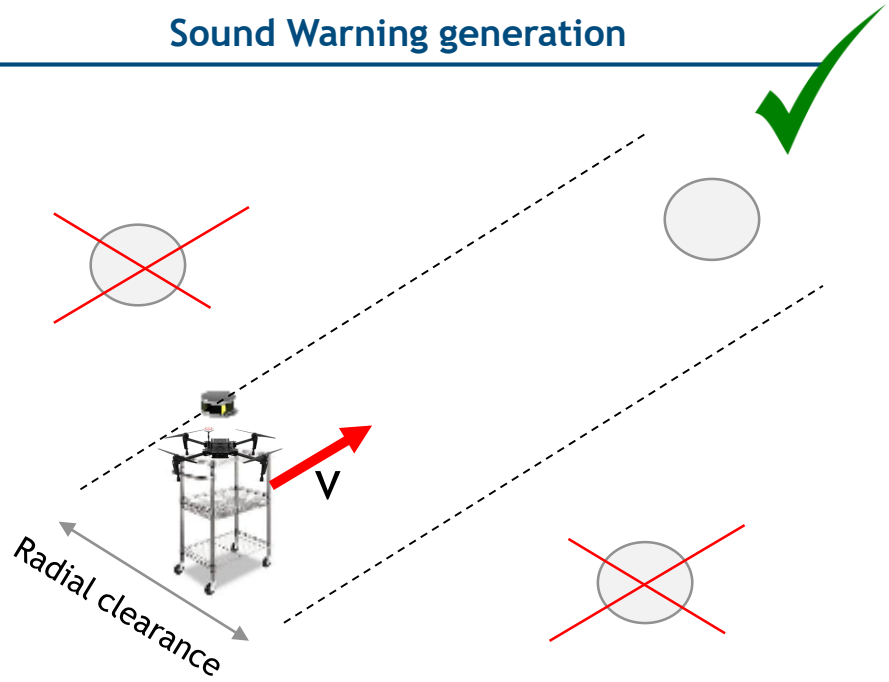


2D occupancy grid map for trajectory planner



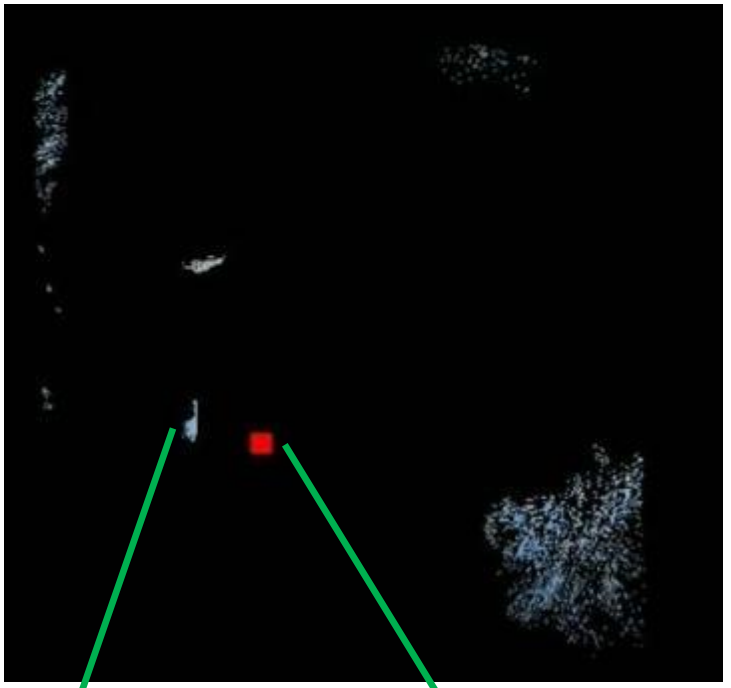
Sound warnings implementation/status

Sound Warning generation



Time to impact	Time between beeps
4 to 5.5 seconds	0.5 seconds
2 to 4 seconds	0.3 seconds
0 to 2 seconds	0.1 seconds

Implementation in Bird's Eye View



Obstacle on left, sound warnings in left ear

Faster beeping as object gets closer

Aircraft in the center

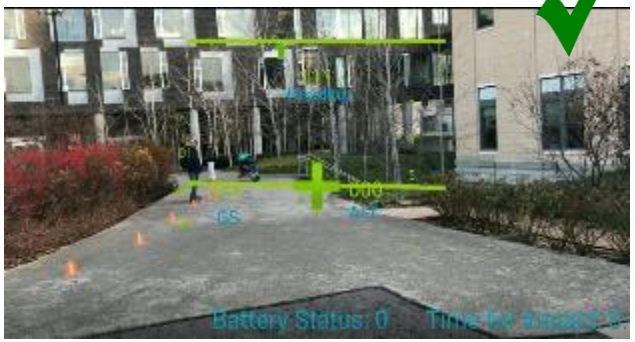
Test Hardware implementation/status

Cart Mechanical setup

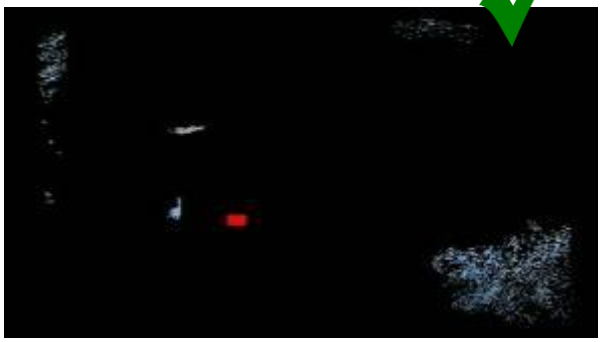
Power Distribution Board PDB

User Interface implementation/status

- Default is no AR display on to prevent cluttering pilot's view



- Information from sensors (heading, roll, pitch, time to impact and ground speed)

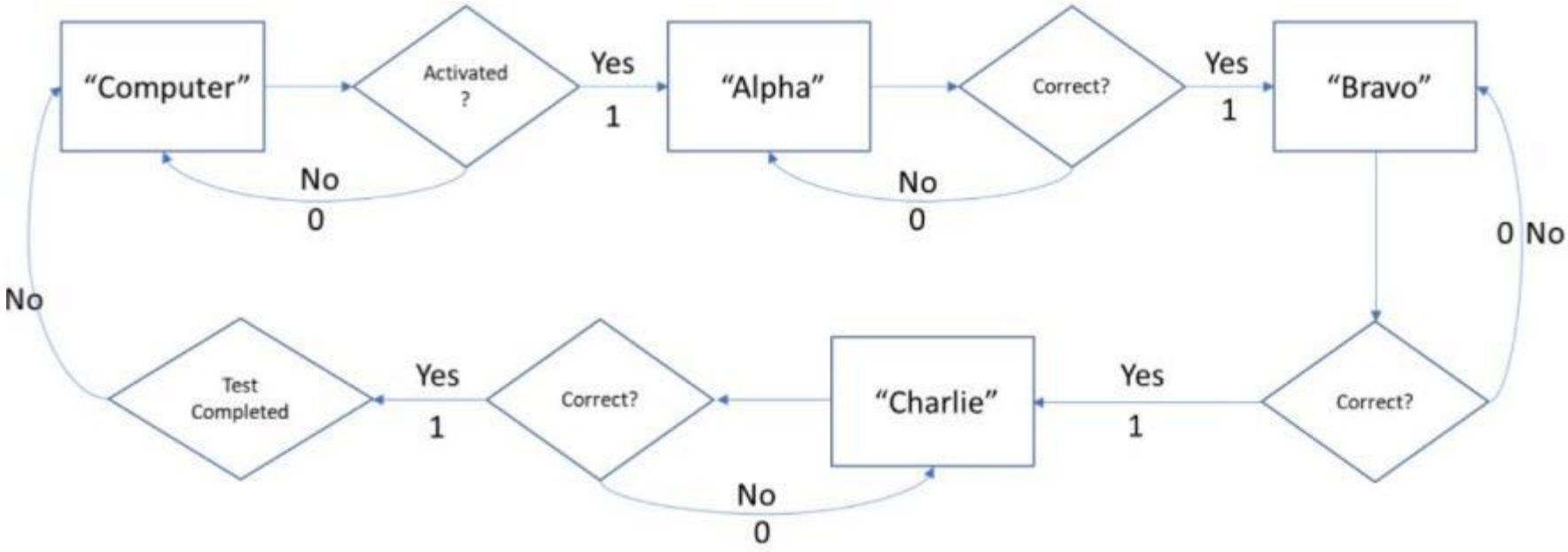


- Obstacles around the quadcopter displayed on Bird's eye view

+ Sound Warnings
(left and right)

+ Voice Commands
(86% accuracy no noise)

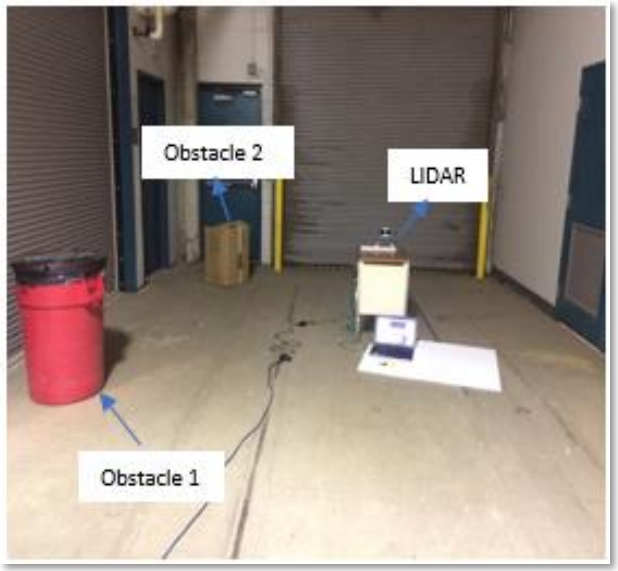
Voice command implementation/status



Results in Noiseless Environment:

- In a noiseless environment, the accuracy of recognizing the activation word is 86%
- The accuracy of recognizing Alpha, Bravo and Charlie is 76%, 92%, and 90% respectively
- The overall mean accuracy is 86%

Static LIDAR tests



VLP -16
Octomap

Moving LIDAR tests

TF tree
PCL pipeline

Tests in SNOW !!!!

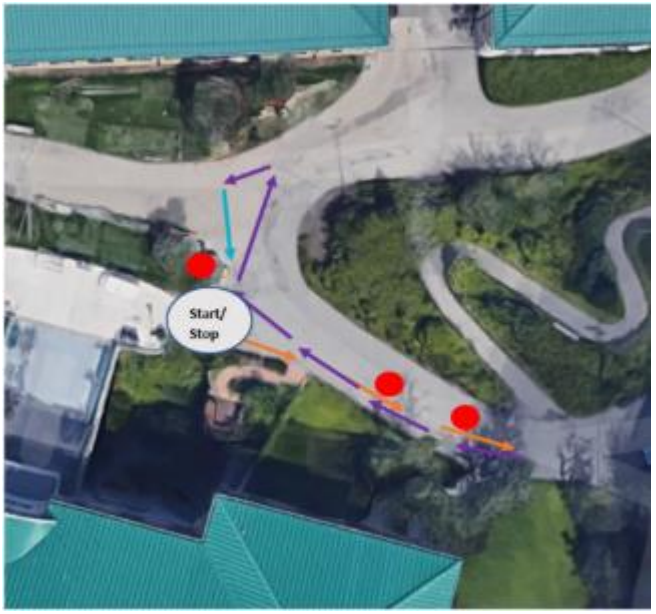
System in drastic weather

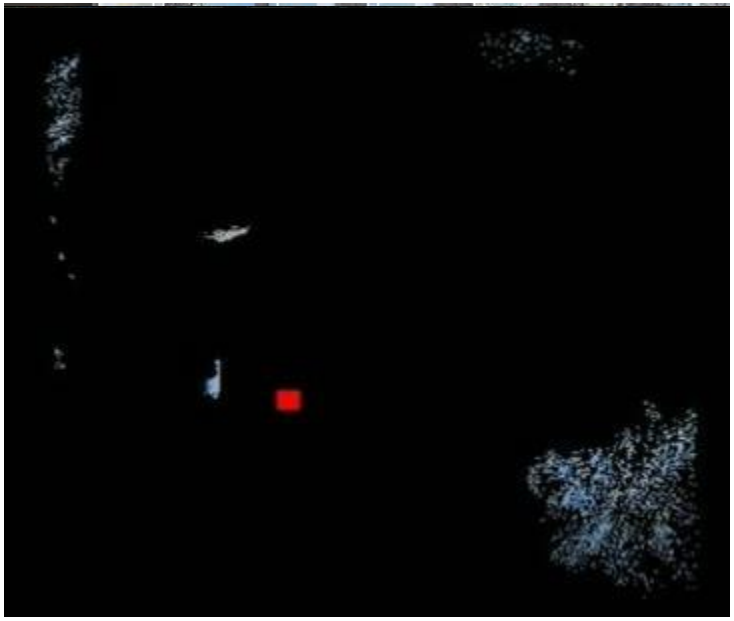
Test procedure 1 – Voice commands test

Computer
Alpha
Bravo
Charlie
Garbage commands

86% accuracy without background noise

Test procedure 2 – HUD and Bird's eye view test





FALL SEMESTER VIDEO TEASER

Strengths

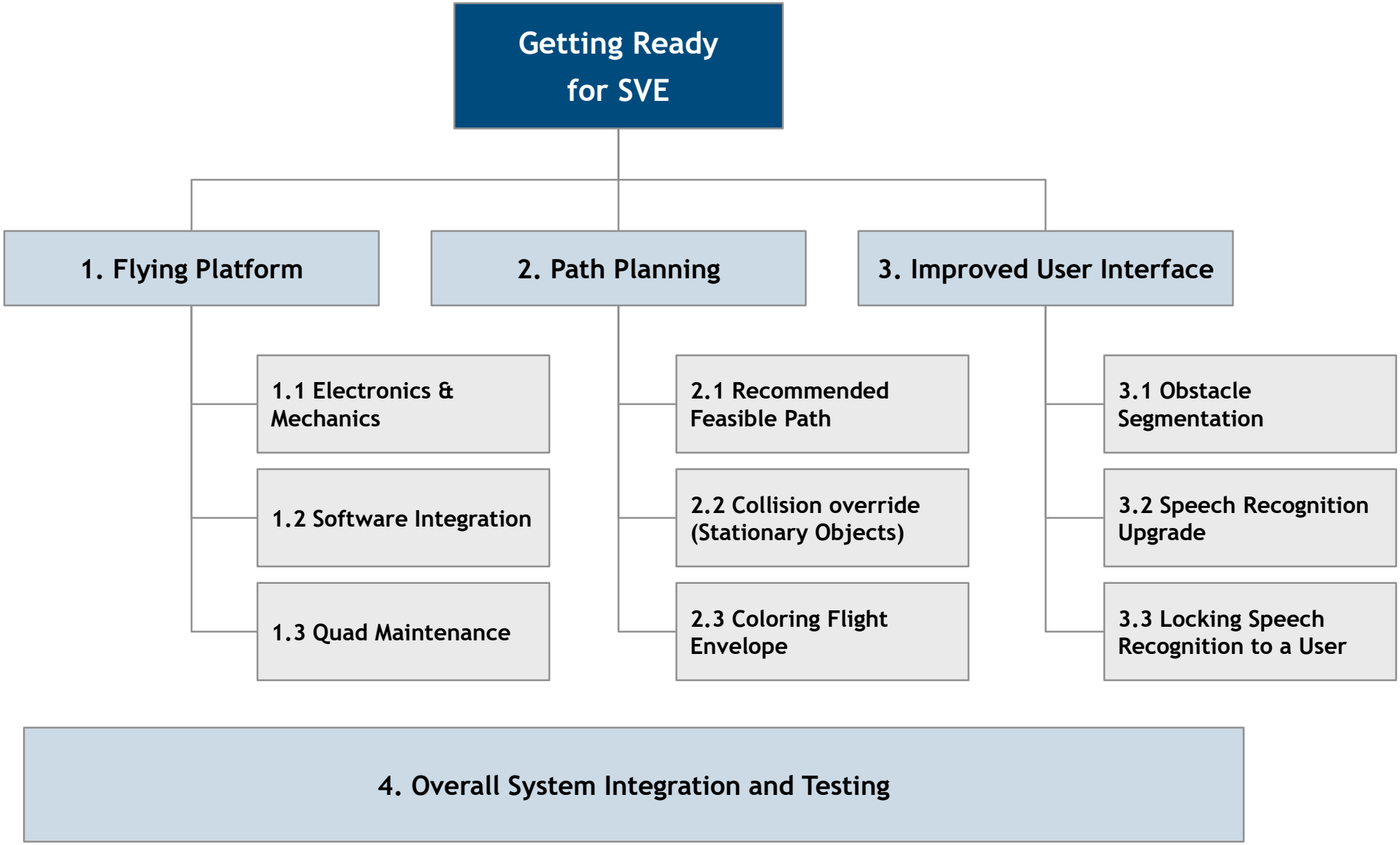
- AR Headset robustness
- Sound Warnings accuracy
- Ease of user interfacing
- Detail of visual map

Areas of improvement

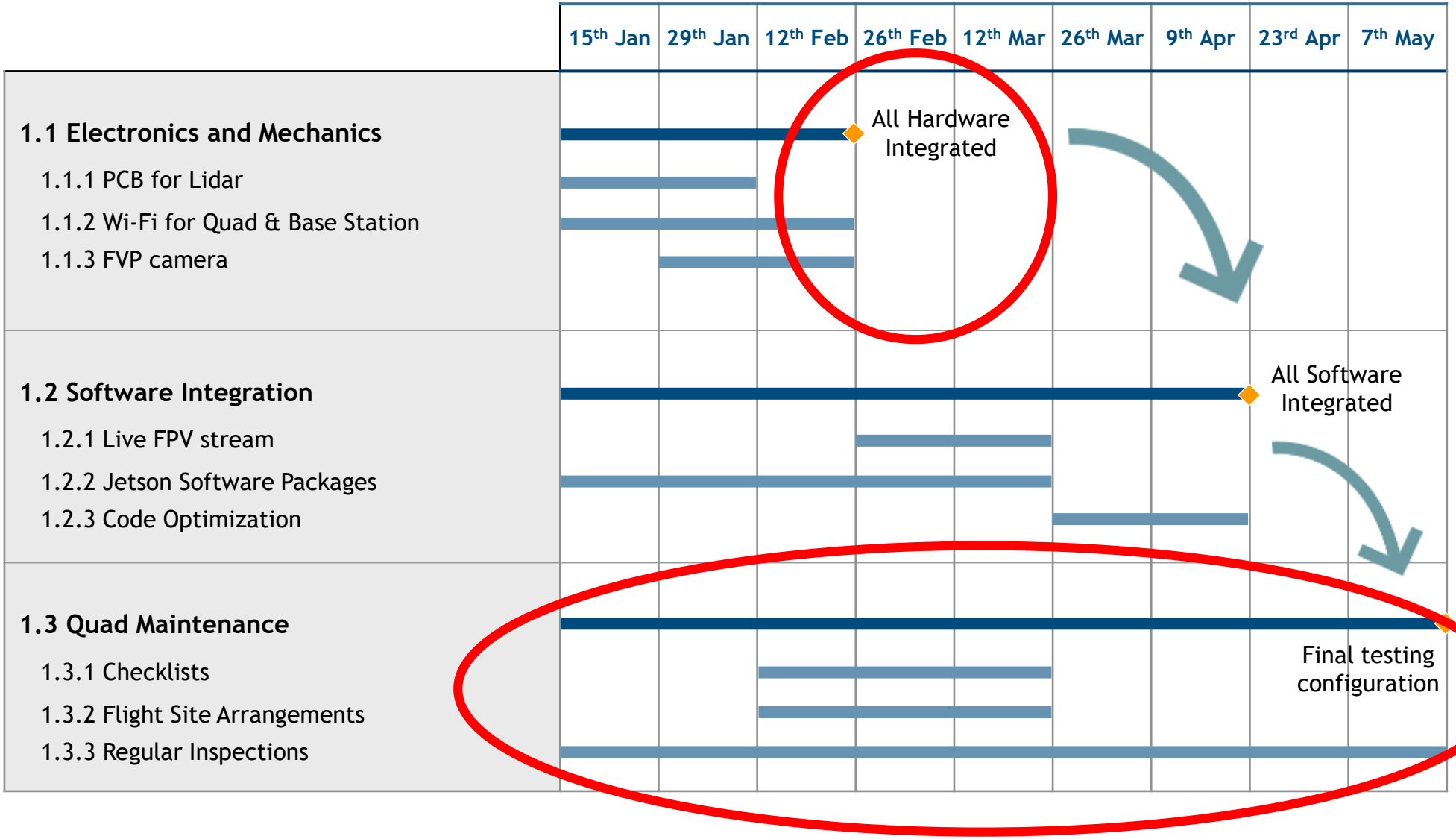
- Voice Commands accuracy with background noise
- Bird’s Eye View visualization does not convey easy to understand symbology
- System only works in 2 dimensions
- Point cloud registration
- Occupancy grid map cluttered, and poor update rate

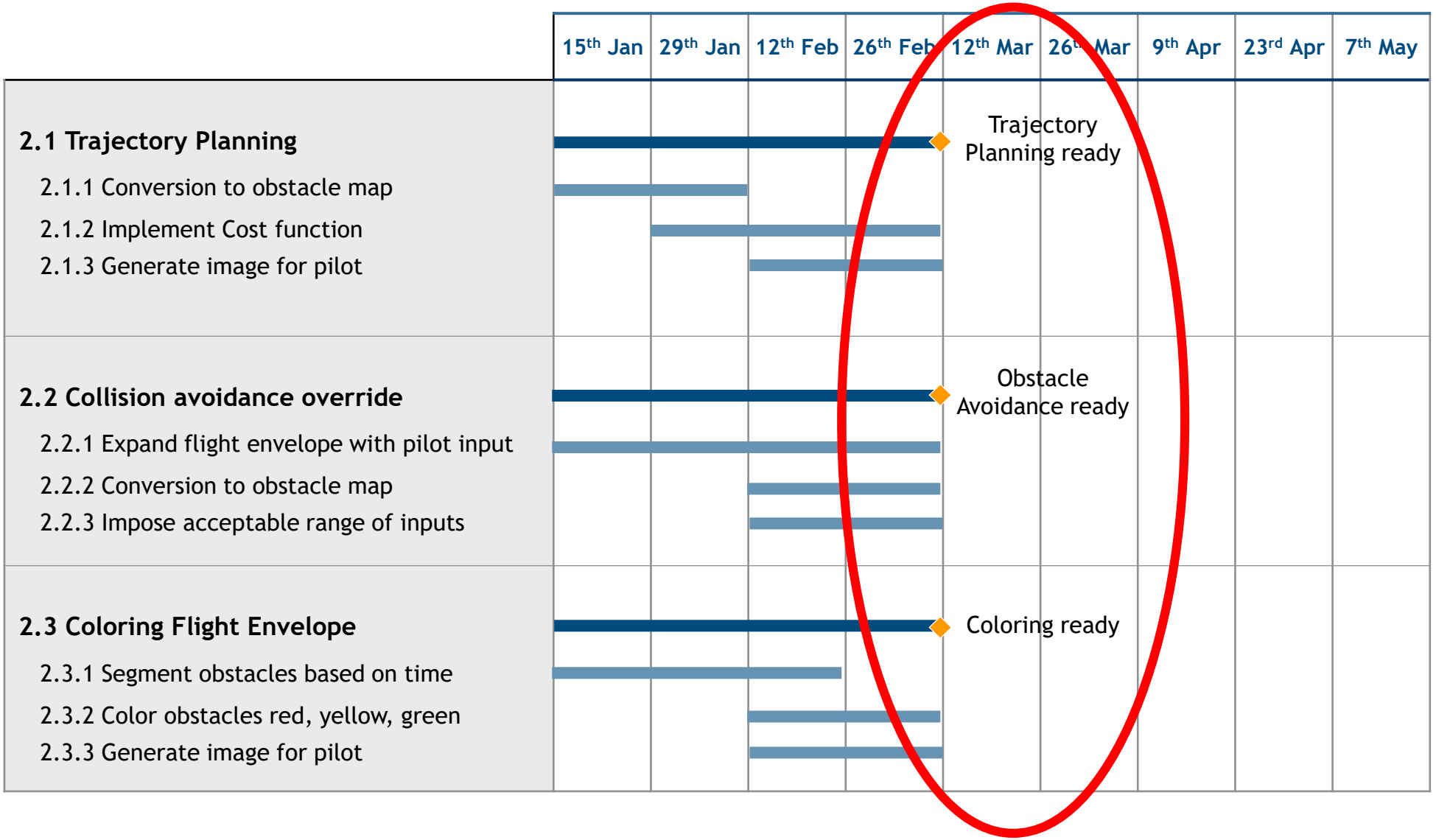
WORK BREAKDOWN STRUCTURE: FALL

	Sensing	UI/UIX	FlySense Validation
Algorithm	• 3D mapping ✓ • Flight envelope ✓ • 2D obstacle map ✓	• Sound warnings ✓ • Speech recognition (with noise cancellation) ✓	• N/A
Software	• Interface to AR ✓ • Interfacing with sensors ✓ • Mapping implementation ✓ • Bird's eye view image generation ✓	• Generate Sound Warnings ✓ • Render Bird's Eye view ✓ • Render Std. Instruments ✓ • User Interface (~~Buttons, pop-up~~, speech) ✓	• N/A
Hardware (procure, setup, test)	• PDB ✓ • LIDAR ✓ • Jetson ✓ • INS-GPS ✓	• Augmented Reality Headset up and running (Epson) ✓	• Flying Quadcopter with sensors ✓ ~~• Jetson to Helicopter computer~~
Integration	• Jetson -> AR ✓ • Jetson+LIDAR ✓ • Jetson+GPS-INS ✓	• Jetson communication protocol ✓ • AR -> Jetson ✓	• Integrate with NEA LIDAR Datasets ✓ • Integrate with Quadcopter ✓ ~~• Integrate with NEA Flight System~~
Testing	• LIDAR Static ✓ • LIDAR Moving ✓ • GPS/INS test ✓ • PDB test ✓	• AR connected with PC ✓ • AR connected with Jetson ✓	• Test with NEA LIDAR dataset ✓ • Test with Quadcopter ✓ ~~• Test with NEA Flight System~~

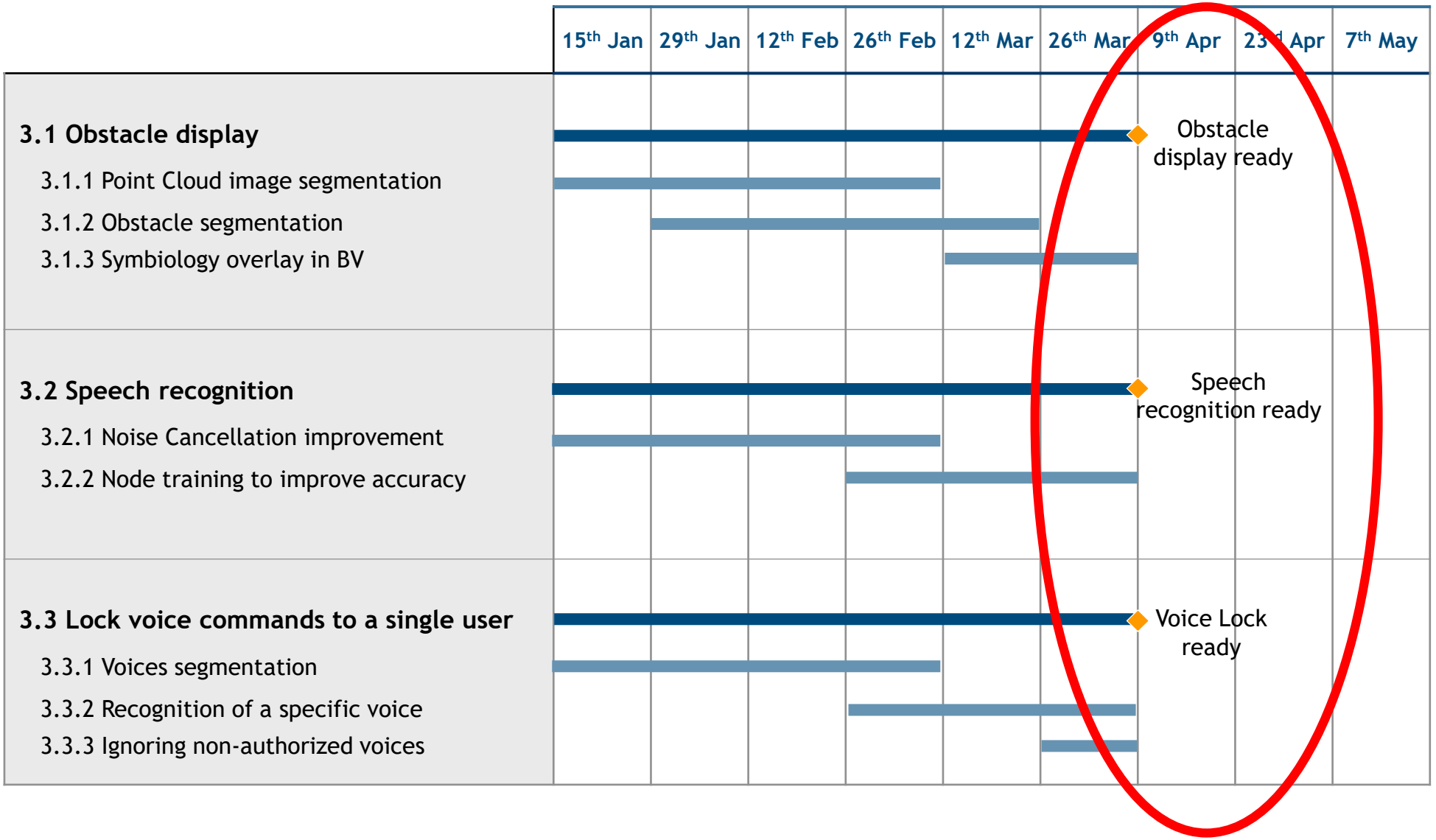


SCHEDULE: FLYING PLATFORM



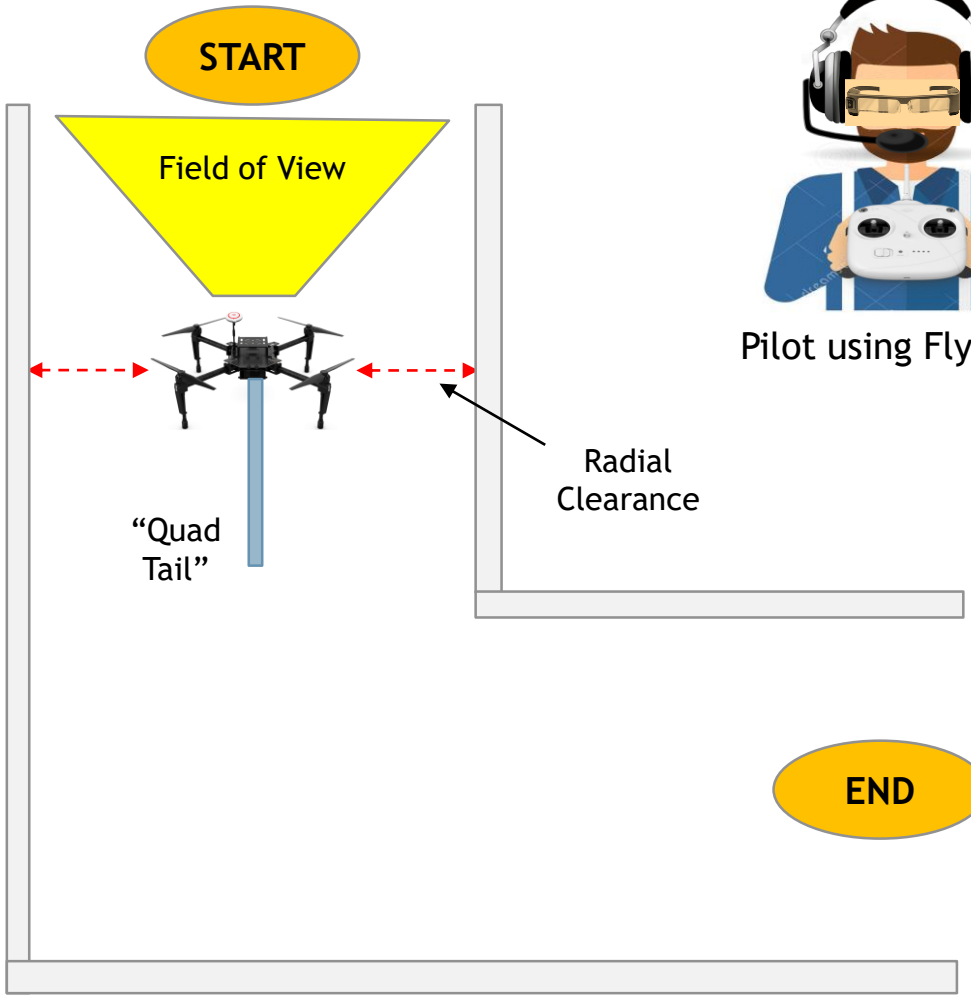


SCHEDULE: IMPROVED USER INTERFACE



Milestone	Desired Functionality	Test Method
Late January	• Quad flying with FPV video transmission	• Fly quad at NREC • Live data transmitted to AR glasses
Mid February	• Recommended feasible trajectory v1 • obstacle avoidance v1	• Testing done in simulation
Late Feb	• Quad flying with trajectory generation and obstacle avoidance • Personalized Voice command v1	• Testing live with aerial platform at NREC • Round one of user feedback from focus group
Mid March	• Trajectory generation v2 • Obstacle avoidance v2	• Testing live with aerial platform at NREC • Round two of user feedback from focus group
Early April	• Full System integration with AR	• Test at NEA flight testing location • Flight testing with AR
Mid April	• More integration and testing	

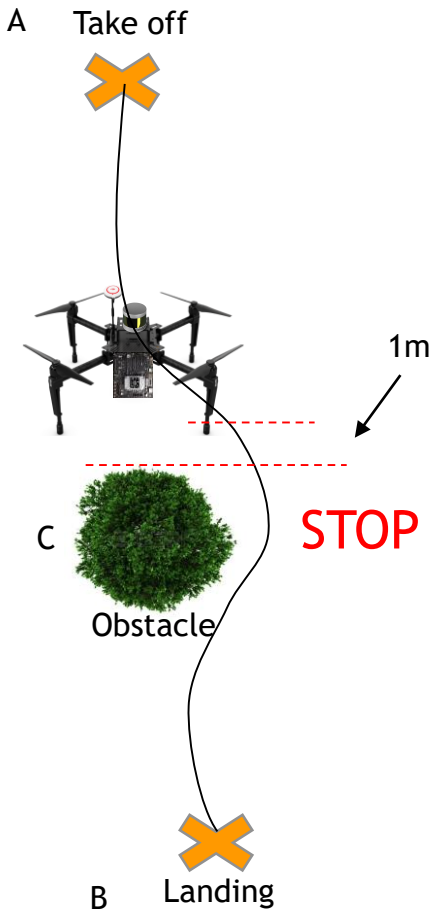
Test 1



Pilot using FlySense

Test location	NEA field testing area with specially designed environment

Test 2



Test location	NEA field testing area / NREC

Equipment	DJI Matrice 100 Quadrotor mounted with Velodyne VLP-16, FPV camera, and communication module, Epson BT300 AR headset and headphones

Test Procedure	Performance Evaluation
1. Pilot flies the Quadcopter from start to end using only FPV video feed and no FlySense	• Maneuvering time and number of errors (< 1 m away from wall) measured
2. Pilot wears FlySense, gives voice commands in both quiet and noisy environments	• 90% accuracy without noise • 70% accuracy with noise
3. Gives command in RC for Quadcopter to start, switches AR to BV mode	
4. Follows feasible trajectory shown in the AR interface to reach end position	• Trajectory maintains 1m clearance from obstacles • Sound warnings generated in the correct ear • Maneuvering time and number of errors (< 1 m away from wall) reduced by 20%
5. Pilot removes FlySense, and gives feedback of the complete system	• Comfort, relevance to reality, extent of assistance

Equipment	DJI Matrice 100 Quadrotor mounted with Velodyne VLP-16, FPV camera, and communication module, Epson BT300 AR headset and headphones

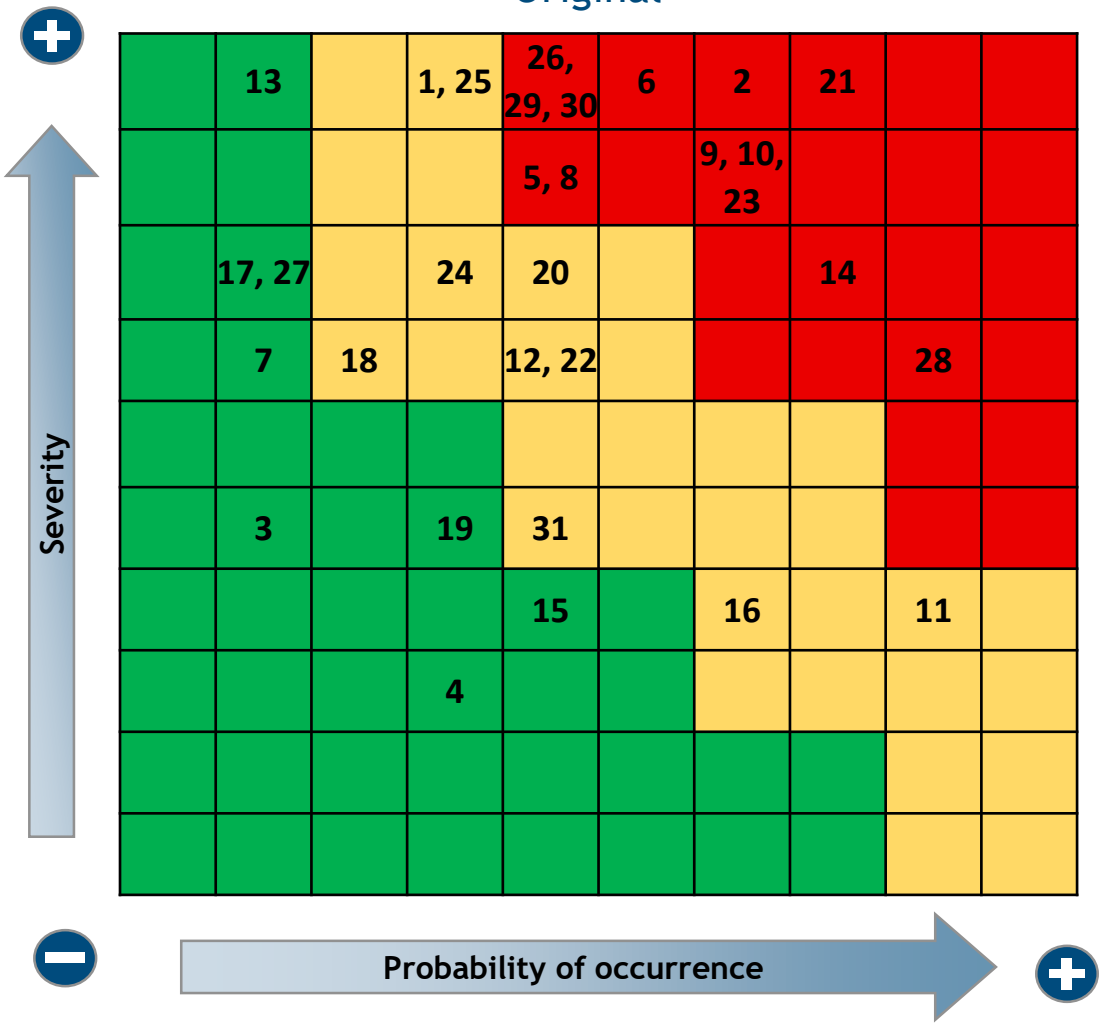
Test Procedure	Performance Evaluation
1. Pilot wearing FlySense gives RC command to take off at A	
2. Quadcopter follows the feasible trajectory seen on AR toward B through C	• Trajectory maintains 1m clearance from obstacles
3. Quadcopter reaches closer to C, but still less than 1m	• Obstacle shows color transition (green-yellow-red) based on time to impact • Sound warnings generated in correct ear when time <5.5 seconds
4. Quadcopter diverts from feasible path, moves 1m close to the obstacle but stops immediately	• Quadcopter stops at distance less than 1m

Type of Budget item	Supplier	Description	Unit cost($)
Borrowed Equipment	NEA	Velodyne VLP16	8,000
Borrowed Equipment	MRSD Lab	DJI Matrice 100	2,847
Confirmed Budget	Amazon	Epson BT 300	799
Confirmed Budget	-	Miscellaneous stuff	656
Confirmed Budget	NVIDIA	Jetson TX2	599
Projected Budget	TBD	Communication system	600
Projected Budget	MRSD Lab	Quadcopter stuff	600
Projected Budget	Amazon	Headset with MIC	300
Projected Budget	Real Flight	Drone flight simulator	100
Projected Budget	E-con systems	FPV camera	250

- Borrowed Equipment (Lidar + DJI M100): $10,847
- Amount spent from MRSD Budget: $2,054
- Projected Budget: $1,850
- Reserve Budget: $ 1,100

Risk Mitigation Effect is an ongoing process…

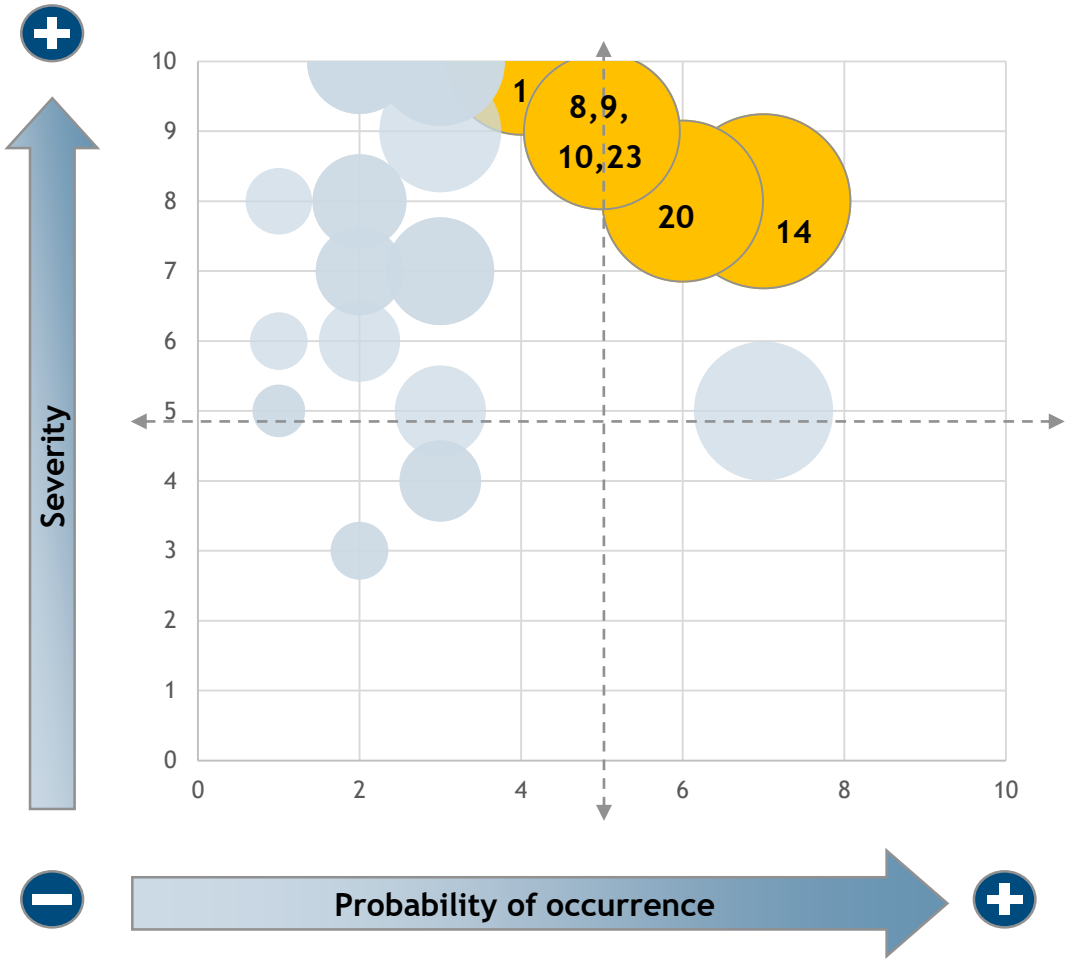
Original



Mitigated (current status)

	2, 25, 26	21, 29, 30	1						
		5		8, 9, 10, 23					
13	16, 24				20	14			
	12, 15, 27	6, 22							
17									
3, 7		31				28			
		11, 18							
	4, 19								

… and we will keep monitoring closely the major risks identified so far



Note: 19 risk identified so far

Risk mitigation strategies

Hardware

1. Budget Constraints: Monitor budget closely, steal budget from other teams
8. AR headset gives pilots headaches: Adjust refresh frequency rate, adjust focal distance
9. Jetson data processing constraints: Segment data, or test with just one LIDAR, get the most powerful hardware for the available price, sample data
10. Wifi communication with drone: Test multiple solutions early, buy base station with enough range
14. Velodyne Lidar too heavy for drone: Take weight out from other areas

Performance

20. Weather prevents testing: Schedule multiple tests
23. Voice commands do not work properly: multiple mics, use Android libraries

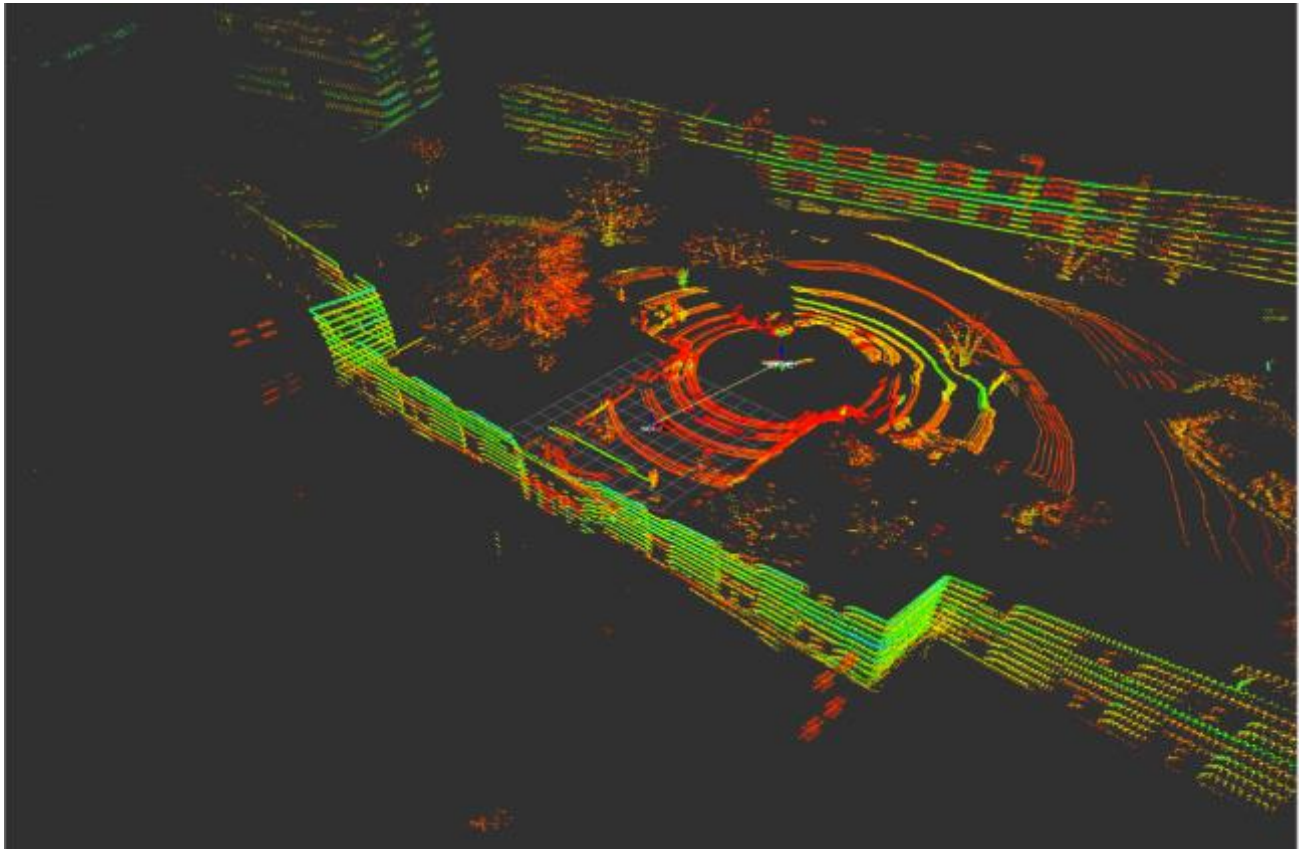
Technical

- Testing a system is much more demanding than testing a single sub-system (e.g. network)
- Designing for a human is substantially different from designing for a robot (e.g. mapping)
- Sometimes the simplest possible solution works well (e.g. direct from LIDAR)

Team

- Time is an extremely scarce resource that needs to be well managed from the beginning
- Cross-functional tasks need to be planned as early as possible to ensure work bandwidth
- Requirement ownership is crucial for success (demand vs “sell them to someone else”)

- Transfer ground based system to air
- Improve voice commands
- Deploy additional planning features and benchmark safety warning features



Thank You!

PROJECT MANAGEMENT: DETAILED RISKS (1/3)

Group	Risk item	Description	Consequences	Causes	Mitigation Strategies	Occ	Sev	RPN	Risk Owner
Hardware	1. Budget	Run out of money / cost overruns	Cannot buy any more things and/or have to beg John/ NEA for more money	Expensive sensors, can't get hardware donated, lack of budgetary restraint	Win the lottery, monitor budget closely, steal budget from other teams	4	10	40	Nick
Hardware	2. Flight hardware procurement	Difficulty in obtaining drone for flight testing	Cannot meet key test parameters for SVE	expense of drone, cannot get hardware sponsored	Get flight hardware from NEA	7	10	70	Nick
Hardware	3. IMU procurement	Can't get a hold of a functional IMU in reasonable time	Delays in developing sensor fusion and dynamic displays	products out of stock	Consider alternative IMUs	2	5	10	Shivang
Hardware	4. UI research	Difficulty in getting external help in UI development	Delay in development schedule, incomplete solution impacts non-functional requirements	external stakeholder availability	Schedule in advance, use published work	4	3	12	Joao
Hardware	5. AR Headset	AR headset not robust to changes in light	Cannot meet key functional requirements	not designed for helicopter lighting conditions	Design shade, get AR interface that mitigates this problem	5	9	45	Nihar
Hardware	6. Flight hardware	Flight hardware breaks during testing	Can't test or perform SVE	user error, weather	Meet with NEA to negotiate flight hardware, have assitance on flying, use simulations	6	10	60	Shivang
Hardware	7. CPU	Nvidia Jetson breaks	Can't process sensor data on real hardware	Electrostatic discharge, dropped	Handling procedure, package on test appartus, have backup plan for cpu	2	7	14	Shivang
Hardware	8. AR Headset	AR headset gives pilots headaches	Can't meet key non-functional requirements	Humans are not evolved enough	Adjust refresh frequency rate, adjust focal distance	5	9	45	Nihar
Hardware	9. Hardware cannot support all the data coming from sensors	LAN cable, Jetson cannot support the whole point cloud from LIDAR	Cannot process data with desired latency and accuracy	data too complex, hardware not powerful enough or too expensive	Segment the data, or test with just one LIDAR, get the most powerful hardware for the available price, sample data	7	9	63	Hari
Hardware	10. Wifi communication issues with drone	Can't communicate between drone and AR	User system doesn't work, can't validate requirements	Range, DJI interference	Test multiple solutions early, buy base station with large enough range	7	9	63	Shivang
Hardware	12. LiDAR data storage	LiDAR data takes up too much space	Cannot process to much data because of storage limits	Not enough disk space on a computer	Buy a external drive for processing	9	4	36	Hari

PROJECT MANAGEMENT: DETAILED RISKS (2/3)

Group	Risk item	Description	Consequences	Causes	Mitigation Strategies	Occ	Sev	RPN	Risk Owner
Hardware	13. LIDAR	LIDAR data is too coarse to do effective obstacle mapping	Cannot generate effective obstacle map, impacting requirements	We only have access to a VLP-16	Buffer data in the obstacle map	5	7	35	Hari
Hardware	14. LIDAR	LIDAR breaks	Can't do point cloud mapping	Drone falls out of sky	Secure LIDAR for protection, maximize use of simulation	2	10	20	Nick
Hardware	15. Velodyne LIDAR	Velodyne Lidar is too heavy for drone	Can't test on a flying quadcopter	Velodyne VLP-16 is too heavy	Take weight out of other areas	8	8	64	Nick
NEA	16. Reduced access to NEA dataset	Limited or no access to NEA dataset	Cannot build extensive simulations/mapping system from flight data	Government regulations, deep in relationship with NEA	Train US Person(s) on data if there are ITAR/US gov limits, plan to generate own data	5	4	20	Nick
NEA	17. NEA Dataset	Difficulty visualizing NEA data for use in mapping	Cannot build extensive simulations/mapping real flight data	lack of direction on how to process the data	Get direct help on the data from NEA engineers	7	4	28	Nick
NEA	18. NEA relationship	Total loss of NEA support	Lack of resources, data, and potential funding	funding issues at NEA, breakdown of relationship	Engage NEA actively, have backup plan to get access to substitutes at all times for sensors, data, and flight hardware. Talk to John, Basti and Dimi if funding/access to materials becomes an issue	2	8	16	Nick
NEA	19. NEA simulation data	NEA data not useful	Unable to build accurate simulation/model	available dataset does not include tail rotor data, data is too coarse	Work to get more data sets from nea, collect data with Velodyne puck that we have access to	3	7	21	Hari
Perfor-mance	20. UI testing	Limits on human ui testing	Delay in development schedule, incomplete solution	human testing regulations	Test on ourselves, don't collect personal data	4	5	20	Joao
Perfor-mance	21. Limits on real-flight testing	Weather prevents flight testing	Unable to perform validation experiments	pressure differences, rain, God, etc	Schedule multiple tests	6	8	48	Nick
Perfor-mance	22. Octomap	Octomap lags when processing LiDAR data in real time	Cannot meet latency functional requirement	octomap is too slow	Decrease resolution of the occupancy grid	8	10	80	Hari
Perfor-mance	23. CPU development	Difficulty in working with CPU SDK	Delay in development, potentially can't meet FVE/SVE requirements	lack of OEM support	Work with other teams, pair up on development, recruit help from NEA/other CMU	5	7	35	Shivang

PROJECT MANAGEMENT: DETAILED RISKS (3/3)

Group	Risk item	Description	Consequences	Causes	Mitigation Strategies	Occ	Sev	RPN	Risk Owner
Perfor-mance	24. UI/UX voice commands	Voice commands do not work properly	Cannot change modes in flight, do not meet some functional requirements	voice command detectin not robust to helicopter noise	Use only a few words, multiple mics, use Android system to avoid rewriting code	7	9	63	Joao
Perfor-mance	25. AR headset processing	AR headset does not have computation ability for handle rendering data	Can't meet requirements in FVE/SVE	lack of processing power	Package AR software to be offloaded to external CPU	4	8	32	Nihar
Perfor-mance	26. CPU performance	CPU cannot handle LIDAR data	Cannot meet requirements	Processor speed/RAM	Have backup plan for CPU, have a 2nd processor ready, work with NEA on what they have on board their drones	4	10	40	Shivang
Team	27. AR development	Can't get full user interface on headset	Cannot meet key functional requirements	Difficult API, scheduling	Work on interface early and often, with specific milestons	5	10	50	Nihar
Team	28. Lose a team member sickness/personal	Team member is unavailable due to injury, sickness, personal matter, etc	Reduced work force	Sickness, team difficulties	Team up on many tasks, have a lead and second for each functional area	2	8	16	Nick
Team	29. Team overworked in other classes	Lots of classwork conflicting with project schedule	Delays in working on project, increased risk of health deterioration	Taking 5 classes in a difficult Masters program	Schedule to map out assignments, monday meeting to schedule work, calender to track events, team up to help on assignments	9	7	63	Shivang
Team	30. Too many requirements	Have too many requirements to meet for FVE and SVE	Objective of project not met	Overambitious targets, lack of proper planning, underestimation of work involved for each requirement	Limit mandatory requirements, prioritize or consolidate requirements	5	10	50	Nick
Team	31. Integration	Project does not work when is put together	Cannot meet key functional requirements	lack of planning, non-robust components	Unit testing, start early	5	10	50	Nick
Team	32. Simulation	Simulation sucks time from real-hardware development	Delays in schedule	misalignment of priorities, delays in hardware prioritizes software sim	Set specific goals for simulation, limit scope, make it easy to use for functional requirement purposes	5	5	25	Nick

User Subsystem

Non-Functional Requirements Status

User can see things much farther than 20 meters

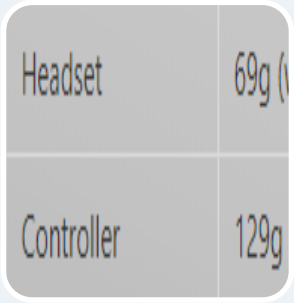
Status:

Requirements Satisfied

The system can be worn for long periods without any issues

Status:

Requirements Satisfied



The system weighs 198 grams

Status:

Requirements Satisfied

The system costs $780 which is way less than $5000

Status:

Requirements Satisfied

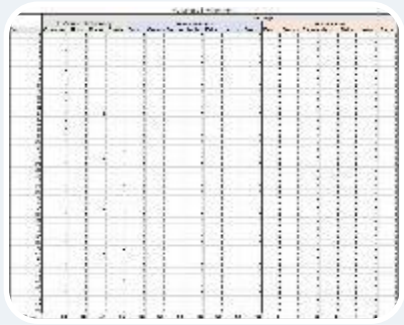
Vehicle roll, pitch, yaw, time to impact and ground speed data displayed on screen

Status:

Requirements Satisfied

User Subsystem

Functional Requirements Status



The system can recognize “Computer”, “Alpha”, “Bravo” and “Charlie” at 86% accuracy in noiseless environment

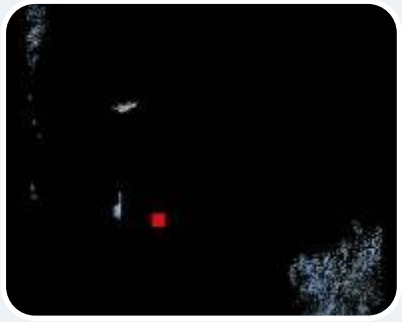
Status:

Requirements Satisfied

The system displays information at exactly 10Hz

Status:

Requirements Satisfied



Audio warnings are generated based on the location on obstacle

Status:

Requirements Satisfied

- medscape.com
- nvidia.com
- flyingmagazine.com
- archive.jsonline.com/news
- dji.com
- velodyne.com
- murrayjob@slingshot.com
- heliguy.com
- jasperproject.github.com