PROJECT SURECLEAN
TEAM F: COBOT

Conceptual Design Report

Avinash Hemaeshwara Raju
Joshua Ra'anan
Atulya Ravishankar
Fan Yang

Sponsor: David Wettergreen
Advisors: Dimitrios (Dimi) Apostolopoulos, John Dolan

December 8, 2018

Table of Contents

1. Project Description

There are currently two primary methods of cleaning beaches, either people do it by hand or expensive tractors rake the entire beach for garbage. The first solution is immensely time consuming and is highly impractical for larger beaches which can be miles long[i]. The latter solution, though less time consuming, still takes many hours and is additionally very expensive as the cleaning equipment costs anywhere from tens of thousands to hundreds of thousands of dollars. Additionally, the latter solution has been shown to be very bad for the biome of the raked beach[ii]. This is an industry ripe for automation.

The Cobot team aims to create an autonomous beach cleaner that can pick up litter lying on the dry sand of the beach. The beach cleaning system uses an unmanned aerial vehicle (UAV)-unmanned ground vehicle (UGV) combination to clean the beach with commands originating from the central server.

2. Use Case

Mr. Elsner works for a Massachusetts Cape Cod resort and just purchased a new Cobot Sureclean robotic beach cleaning system. A major part of his job is cleaning the resort's 300 yards of beaches, a job which takes over an hour and uses a machine which ranges from tens of thousands of dollars to hundreds of thousands of dollars. The Sureclean system is designed to autonomously identify and pick up discarded litter on the dry part of the beach, effectively replacing this expensive machine and freeing up time in Mr. Elsner's day.

The Sureclean system is delivered by a Cobot technician. Upon delivery the technician creates a map of the beach for the system's RTK GPS localization. The technician then shows Mr. Elsner how to define the region of the system's operation. The system comes with a base station for recharging, an RTK GPS station, a UAV for scouting the beach, and a UGV for picking up the litter. The technician sets up the RTK GPS followed by the base station and allows the UGV and UAV to charge, as shown in figure 1.

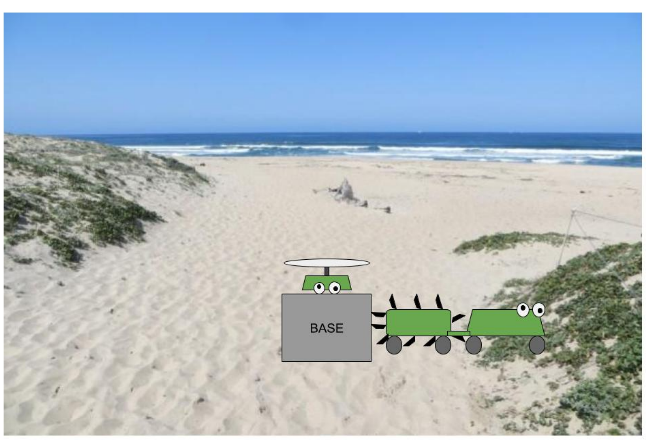

Figure 1: System waiting for activation

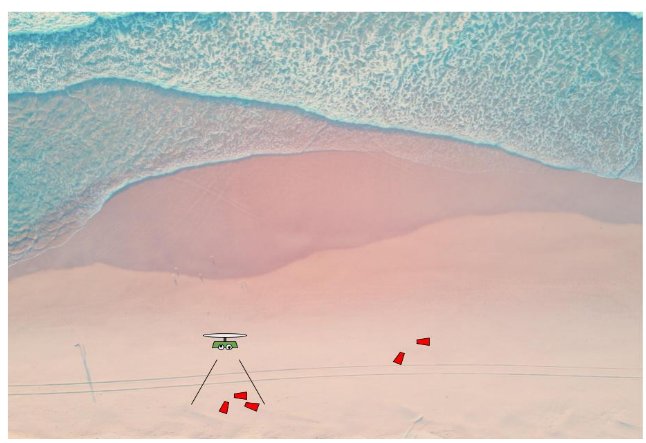

Figure 2: UAV scouting the beach for litter

The next morning at sunrise, when the beach is empty, Mr. Elsner walks over to the Sureclean base station which has green indicator light to show that the system is charged and ready to go. Mr. Elsner pushes a button launching the system, and the Sureclean system begins its routine. First the UAV deploys and performs a scout routine, flying 20m above the ground safely above the height of any people and in accordance with FAA regulations. Along its route, the UAV takes pictures localized by the RTK GPS of the beach that can be seen in figure 2. Upon its return, the UAV lands by the base station and begins recharging, it also uploads all of the images it took to the base station, which begins processing the images.

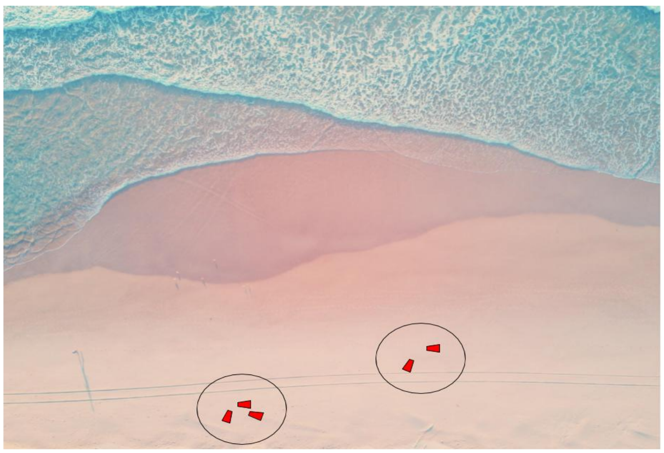

Figure 3: Identified regions of interest

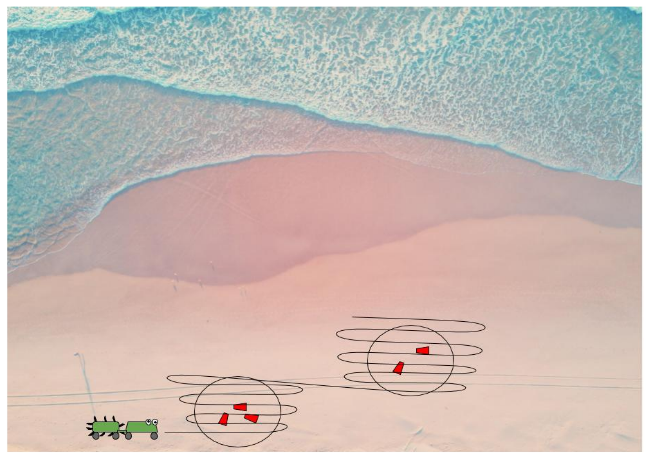

Figure 4: UGV covering the planned path

The base station finishes processing the images and has identified litter regions of interest (ROI) as shown in figure 3. The Sureclean system then deploys the UGV to go out and pick up the litter at the ROI. As the UGV approaches the first ROI, it enters activates its pickup raking mechanism and enters into a full coverage pattern to clean up the entire ROI which can be seen in figure 4. The UGV then repeats this process until it has picked up all of the litter ROI. At which point the UGV returns to the base station. When the UGV returns to the base station as shown in figure 5, Mr. Elsner collects the litter from the UGV and places it in a dumpster as shown in figure 6.

Figure 5: UGV returning to base station after task completion

Figure 6: System waiting for use to empty litter from UGV

3. System Level Requirements

The system level requirements were selected to create an end to end proof of concept beach cleaning robot. To achieve this goal, the Sureclean system must be capable of both locating and picking up litter. Locating litter requires that the system be able to see all the litter on the beach and identify it as litter. The Sureclean system must be able to localize litter in the world accurately in order to navigate to and pick up the litter.

3.1 Functional requirements

At a high level, the system must be able to identify where in the environment litter exists. Once that is done, it must be able to follow a path to the litter and collect it off the ground. Next, it must return to its base so that the litter can be disposed. The operating environment may be grass or sand, for testing purposes. These have been compiled into a list of functional requirements below:

The system shall
M.R.1 Locate litter in the operating environment.
M.R.2 Plan a path to both locate and collect litter.
M.R.3 Collect and store litter from the surface of the ground.
M.R.4 Return to base upon completion of the mission.
M.R.5 Operate on sand and grass environments.
D.R.1 Identify and avoid obstacles
D.R.2 Monitor the status of the system in real time

3.2 Non-functional requirements

The functional and performance requirements highlight the high-level tasks of a machine and how well those tasks are achieved based on measurement criteria. But there are few other requirements – the Non-functional Requirements – that the system has to fulfill for it to work harmoniously on a whole.

The system shall
M.N.1 Be easily maintainable
M.N.2 Be within budget excluding given resources
M.N.3 Have an easily accessible emergency stop
M.N.4 Adhere to Federal Aviation Administration (FAA) regulations
D.N.1 Monitor the litter capacity in real time
D.N.2 Alert people in vicinity of system by making sound
Note: M.N – Mandatory non-functional requirement. D.N – Desired non-functional requirement.

3.3 Performance requirements

The system will
M.P.1.1 Scout an area of 128 sq. meters.
This is the size of standard sand volleyball court, which is our planned testing site.

M.P.1.2 Identify 50% of litter in scout area.
The system must be able to identify litter to perform its primary task. A 70% detection rate and a 70% identification rate are reasonable to expect from current algorithms, which compounds to 50% identification.

M.P.1.3 Identify litter with a profile of at least 65 sq. cm, at most 13 cm tall.
This is the profile of a coffee cup or solo cup, which are some of the most common litter found on a beach.

M.P.1.4 Correctly locate to within 0.7m of ground truth.
The system's pickup mechanism requires that it drive over the litter, so it's very important that the system know the litter's location within width of the UGV.

M.P.2 Plan a successful path 80% of the time.
A high level of navigation accuracy is required, and this is a suitable goal for testing.

M.P.3.1 Collect 70% of the identified empty coffee cups and solo cups.
The ability to collect identified litter is vital to the system's primary functionality.

M.P.3.2 Hold at least 0.05 cubic meters of litter.
The system must be able to hold litter to perform its primary responsibility, this capacity matches the size of the pickup trailer to the size of a Husky UGV.

M.P.4 Successfully return to base within 20 minutes of last litter pickup.
Bringing the litter off the beach to a known location is an important part of the user experience.

M.P.5 Operate on flat terrain.
The system must be able to operate in its primary operating environment, which for most beaches is flat.

D.P.1 Identify obstacles of profile greater than 1m2
Avoiding obstacles would increase the resilience of the system to uncertain situations.

D.P.2 Navigate around obstacles within 5 min
Navigating around an obstacle in a reasonable amount of time will make the system more useful in uncertain situations.

D.P.3 Monitor the sensor status, battery status at real time and log the data
Additional sensor data are necessary to add more advanced functionality.

Note: M.P – Mandatory performance requirement. D.N – Desired performance requirement.

4. Functional Architecture

Our system consists of three major physical entities: The UAV, the UGV and a central server. Outside of these physical entities, our system also has a communication subsystem, which is spread across all agents. Additionally, our localization subsystem will also be operating across all agents. The server contains the mapping and vision subsystems, the outputs of which are broadcasted to the UAV and UGV accordingly.

The UAV is responsible for covering the operating environment and scouting for litter. The central server defines waypoints for the UAV to cover the area and communicates them to the UAV. The UAV's onboard controller takes those waypoints and follows the intended trajectory. Along it's scout path, it periodically collects data about the environment (images, locations etc.). Once this scout task is done, the UAV returns to its base and then transmits the data it collected back to the central server.

The server is responsible for defining and managing the tasks being done by the agents. One of its primary purposes is to compute waypoints for the UAV and UGV for their respective jobs (scouting and collection). In addition, the server takes the data collected by the UAV and analyzes it for litter in the environment. Using that information, plus the other metadata collected by the UAV, the server builds a map of the litter in the environment. This map is used to define the collection task performed by the UGV.

The UGV's role is to traverse the operating environment and collect litter that was identified by the UAV. The UGV receives waypoints from the server and follows the intended trajectory. It also has a litter pick-up mechanism attached to it which is capable of retrieving litter (solo cups and coffee cups) off the ground and storing it for the duration of its collection task.

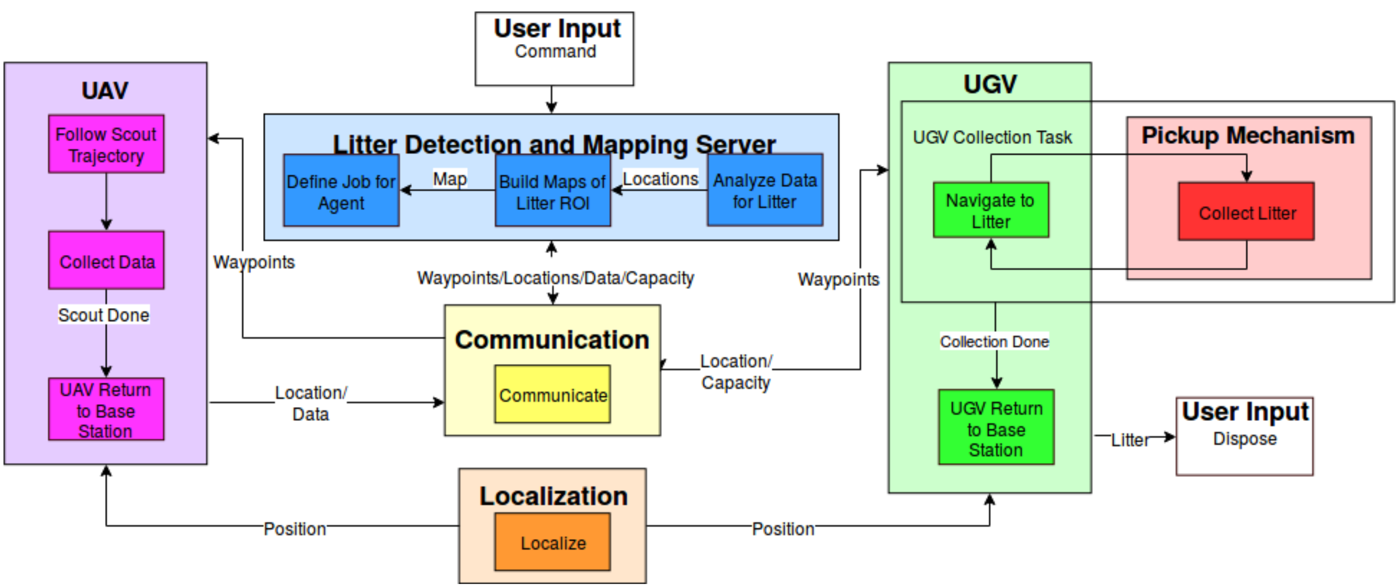

Figure 7: Functional Architecture

Figure 7 is the functional architecture for our system. It depicts the agents and subsystems outlined above, as well as the critical information flowing through the system.

5.Trade Studies

5.1 System Configuration Trade Study

The first step was to decide on a platform configuration that can best achieve the system requirements. Three possible combinations of vehicles were considered and each was evaluated based on various measures of effectiveness and cost.

Table 1: System configuration trade study

Requirements	**Map to Require-ments**	**Weights**	**Norm Weights**	**UAV**		**UGV**		**UAV + UGV**	
Criteria				**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Capacity	M.P.1.1, M.P.3.2	8.00	0.21	1.00	0.21	5.00	1.03	5.00	1.03
Speed	M.P.1.1	9.00	0.23	5.00	1.15	2.00	0.46	4.00	0.92
Energy Cost	M.P.1	7.00	0.18	1.00	0.18	5.00	0.90	4.00	0.72
Operational Complexity	M.P.3.1, M.N.1	7.00	0.18	3.00	0.54	4.00	0.72	2.00	0.36
Effectiveness	M.P.3.1, M.N.1	8.00	0.21	4.00	0.82	3.00	0.62	5.00	1.03
Total Score		39.00	1.00		2.90		3.72		4.05

5.2 Pickup Mechanism Trade Study

The next step was to select a pickup mechanism, as successfully picking up litter is a central requirement of the system. Again, several possible combinations of vehicles were considered and each was evaluated based on various measures of effectiveness and cost.

Table 2: Pickup mechanism trade study

Criteria	Map to Require -ments	Weights	Norm Weights	Rake		Arm		Sweeper		Scoop	
				Score	Weighted Score	Score	Weighted Score	Scor e	Weighte d Score	Score	Weighte d Score
Effectiveness	M.P.1.1	9	0.225	5	1.125	2	0.45	4	0.9	1	0.225
Operational Complexity	M.N.1	8	0.2	3	0.6	1	0.2	1	0.2	2	0.4
Cost	M.N.2	4	0.1	2	0.2	4	0.4	2	0.2	3	0.3
Weight (Husky DP)	M.N.1	5	0.125	1	0.125	3	0.375	2	0.25	4	0.5
Dimensions (Navigation)	M.P.3.1	7	0.175	2	0.35	4	0.7	4	0.7	4	0.7
Testing Ground Type Versatility	(Demo request)	7	0.175	4	0.7	4	0.7	4	0.7	1	0.175
Robustness	M.P.1.1	9	0.225	4	0.9	3	0.675	3	0.675	3	0.675
Total Score		40	1		4		3.5		3.625		2.975

5.3 Vision Algorithm Trade Study

Another key trade study was comparing various vision algorithms for successfully identifying litter. Several alternatives were compared on the criteria of speed, needed training data, computational load, ease of implementation, and dependence on camera[iii, iv].

Table 3: Vision algorithm trade study

Criteria	Map to Requirements	Weight	HoG/SVM	R-CNN	YOLO
Amount of training data required	M.N.1	0.25	4	2	2
Speed (testing)	(Demo request)	0.25	1	1	5
Computation	M.N.2	0.1	4	2	2
Ease of Implementation	M.N.1	0.25	5	2	3
Dependence on camera	M.N.2	0.15	1	3	3
Total		1	3.05	1.9	3.15

5.4 Communication Trade Study

A trade study comparing various methods of communication was also performed to determine how best to get information from one of our agents to another. The evaluation criteria were: ease of modification, cost, operational complexity, range and robustness.

Table 4: Server to UAV communication trade study

SERVER TO UAV									
Criteria	**Map to Require-ments**	**Weights**	**Norm Weights**	**Local WIFI station**		**Radio modem**		**DJI inner communication system(UAV) – 2.4 GHz**	
				Score	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Ease of Hardware Modification	M.N.1	4.00	0.12	5.00	0.59	4.00	0.47	2.00	0.24
Operational Complexity	M.N.1	8.00	0.24	3.00	0.71	2.00	0.47	5.00	1.18
Cost	M.N.2	6.00	0.18	5.00	0.88	5.00	0.88	5.00	0.88
Range	M.P.1.1	7.00	0.21	1.00	0.21	4.00	0.82	5.00	1.03
Robustness	M.P.1.1	9.00	0.26	4.00	1.06	4.00	1.06	5.00	1.32
Total Score		34.00	1.00		3.44		3.71		4.65

Table 5: Server to UGV communication trade study

SERVER TO UGV							
Requirements	**Map to Requirements**	**Weights**	**Norm Weights**	**Local WIFI station**		**2.4GHz radio modem**	
Criteria				**Score**	**Weighted Score**	**Score**	**Weighted Score**
Ease of Hardware Modification	M.N.1	4.00	0.12	5.00	0.59	4.00	0.47
Operational Complexity	M.N.1	8.00	0.24	3.00	0.71	2.00	0.47
Cost	M.N.2	6.00	0.18	5.00	0.88	5.00	0.88
Range	M.P.1.1	7.00	0.21	1.00	0.21	4.00	0.82
Robustness	M.P.1.1	9.00	0.26	4.00	1.06	4.00	1.06
Total Score		34.00	1.00		3.44		3.71

5.5 Localization Trade Study

The next important trade study to perform was a localization trade study comparing alternative methods of specifying the location of litter in the world. The trade study compared accuracy, cost, adaptability, operational complexity, and robustness.

Table 6: Localization trade study

Criteria	Map to Require-ments	Weights	Norm Weights	GPS		GPS with RTK station		GPS with local SLAM		Local SLAM	
				Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Accuracy	M.P.1.4	9.00	0.25	1.00	0.25	5.00	1.25	4.00	1.00	1.00	0.25
Cost	M.N.2	4.00	0.11	5.00	0.56	3.00	0.33	4.00	0.44	4.00	0.44
Adaptable - Does it fit on System	M.N.1	6.00	0.17	4.00	0.67	3.00	0.50	4.00	0.67	4.00	0.67
Operational Complexity	M.N.1	8.00	0.22	5.00	1.11	3.00	0.67	1.00	0.22	2.00	0.44
Robustness	M.P.1.1	9.00	0.25	3.00	0.75	5.00	1.25	4.00	1.00	2.00	0.50
Total Score		36.00	1.00		3.33		4.00		3.33		2.31

6. Cyberphysical Architecture

As mentioned in the Functional Architecture, our system can be split up into three different agents: the UAV, UGV and server. We have expanded on our functional architecture to a cyber physical architecture. This cyber physical architecture is motivated by the subsystem (and in some cases component) trade studies.

All our major entities will be using 2.4GHz radio to communicate with each other. Our localization subsystem will be implemented using RTK GPS.

The UAV, which will be a DJI Matrice 100 drone, will have its own onboard microcontroller and flight controller. These will be used to fly the vehicle and collect data from the camera and localization subsystem. The major software components of the UAV will involve a trajectory planner and an image collector to interface with the camera.

The UGV, which will be a Husky, will also have its own onboard controller. In addition to that, we will have a microcontroller (Arduino Uno) to control the pickup mechanism and a microprocessor (NVIDIA Jetson) to handle the other high-level decision-making responsibilities while the UGV is on its collection task.

The server itself will have both a CPU and GPU to support computationally intensive computer vision algorithms for litter detection and localization.

Below, we have included our cyber physical architecture. We have split it up into two diagrams to make it easier to track. The one on the top is our software architecture while the one on the bottom is our hardware/electrical architecture. Both the diagrams below, as well as the functional architecture diagram are color-coded so that the functions can be mapped to the subsystems/components that will be performing specific tasks.

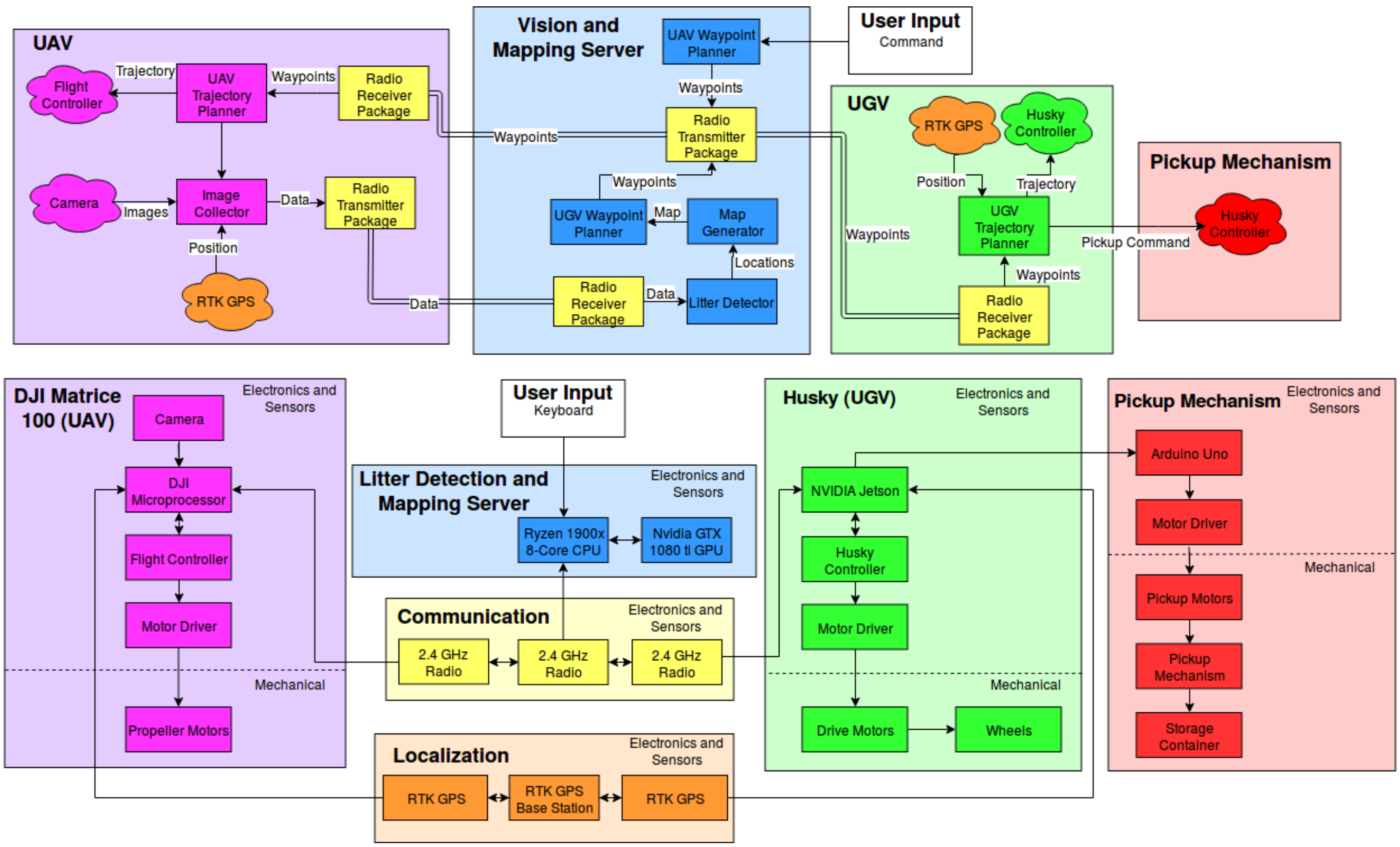

Figure 8: Cyberphysical Architecture

The top figure represents Software Architecture, the bottom figure represents the Hardware Architecture

7. Subsystem Descriptions

7.1 Vision

Based on our vision subsystem trade study, it appears that a learning algorithm (You Only Look Once, or YOLO) is the best way to accomplish our goals. This algorithm allows us to detect objects in a scene in almost real-time. Training the model involves learning the weights to multiple convolutional layers. In order to have a properly trained system, we will need to obtain/procure a sizeable training data set of litter on sand and grass. The model will be trained before the system is deployed. While the system is in operation, it will use the pre-trained weights to classify objects in the scene. The algorithm will be capable of looking at an image and identifying the location of specific objects (in our case, litter) in the scene. The location of the pieces of litter will be used by the server to define a collection task for the UGV.

In the event that our learning algorithm is unable to perform to the desired level, or if we are unable to acquire sufficient training data, we will revert to conventional vision techniques i.e. non-neural-network algorithms. An example of such an algorithm would be using Histogram of Oriented Gradients (HoG) features and an SVM to identify objects in the scene. Since the objects we're trying to identify (solo cups and coffee cups) have distinctive colors and shapes, purely geometric or color-based approaches should be able to identify these objects.

7.2 Pickup

The pickup mechanism will collect and store litter from the beach. The subsystem will be built as a trailer for the Husky pull along. The mechanism will pick up litter using a rotating conveyor driven by at least one DC motor. The conveyor belt will have teeth to help collect litter and ensure it is pulled into the conveyor. The mechanism will be located such that it will capture litter which the system drives directly over. Below is the figure[v] of the pickup mechanism model.

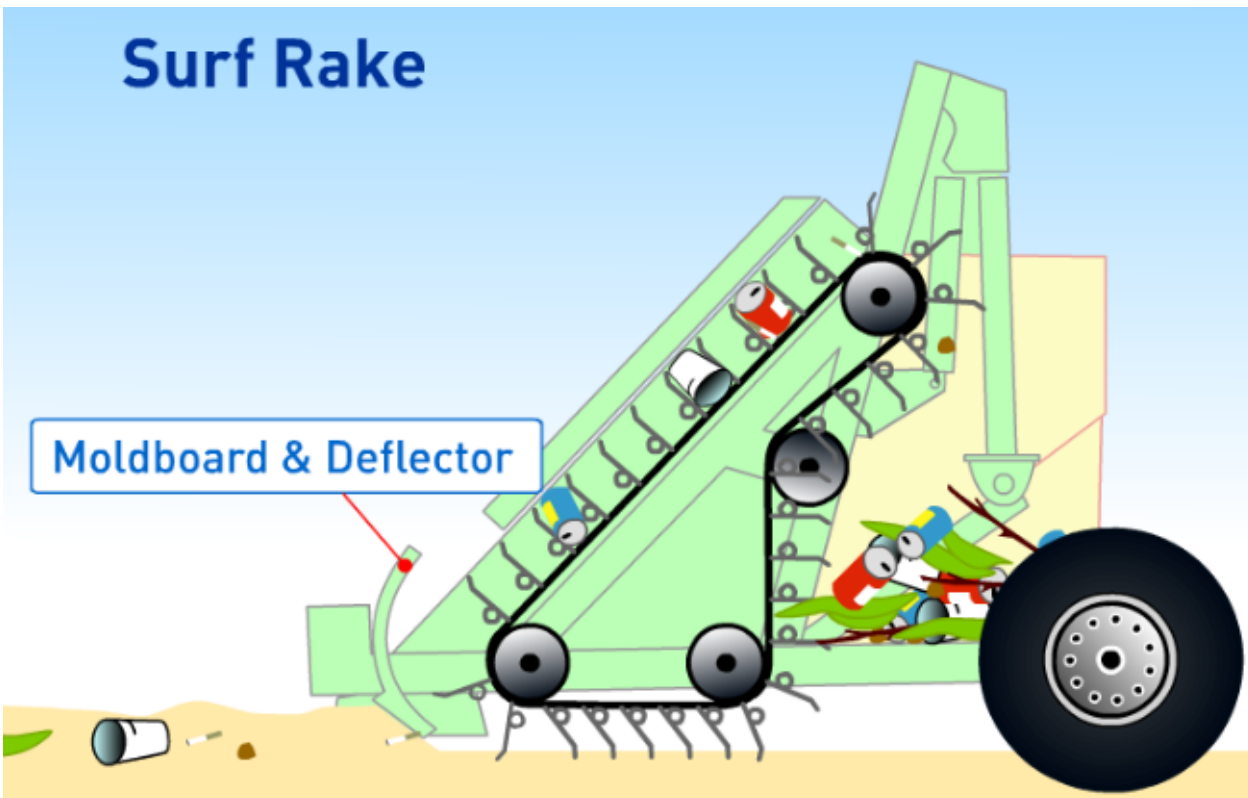

Figure 9: Pickup subsystem

7.3 Localization

The central localization subsystem will allow all the agents (UAV, UGV and server) to share the same coordinate frame, which will enable the map and litter coordinates to be easily shared and calculated. This subsystem will track each agent's location as well as the location of the detected litter on the map.

7.4 Communication

A central server will be the main device commanding the other subsystems. It hosts the entire process and subsystem algorithms. It first sends a path via radio signals to the UAV to perform scout task. The data from the UAV scout task is autonomously transferred to server via radio signals. This data is used to build a litter map and a path that are communicated via radio signals to the UGV for the litter pickup task.

7.5 Server (planning and mapping)

The server's planner will take the litter map as input (which was built by the servers) and generate a valid path for the UGV to follow in order to pick up all the litter. The path shall direct the UGV to navigate towards litter clusters. Additionally, this subsystem is made aware of the operating environment through the form of a pre-determined map, which means it can prevent the UAV and UGV from flying/travelling to areas that are out of bounds (water, obstacles etc.).

7.6 UAV

A DJI Matrice 100 will act as the UAV for our system. This platform includes a camera. The UAV subsystem will scout the area of operation for litter collecting images and location data and passing the data on to the central server for processing.

7.7 UGV

A Clearpath Husky will act as the UGV for our system. The UGV's role in the system will be transporting the trash pickup mechanism to litter clusters. The UGV will also be the hub for communication with the Server.

8. Project Management

8.1 Work Plan

8.1.1 WBS

A bottom-to-top approach was applied for planning out the work packages in the Work Breakdown Structure[vi]. The lowest level work packages correspond to component level tasks, the mid-level work packages correspond to subsystem level tasks. Level 2 and level 1 of the WBS correspond to major subsystems and the entire system respectively. The work packages in the WBS tree, referenced in the link at the end of the document, are color coded to be in tandem with the color coding in Functional and Cyberphysical Architectures. The work packages with red outline indicates desired tasks.

Table 7: Work Breakdown Structure

ID	Deliverables	Work Packages
1	Litter Detection	1.1 Procure training data – 1.1.1 Litter on grass 1.1.2 Litter on sand 1.2 Train aerial vision model 1.3 Test aerial vision model 1.3.1 Test on grass 1.3.2 Test on sand 1.4 Integrate aerial vision to server 1.5 Implement air to ground homogeneous-transform
2	UAV	2.1 Communicate path 2.2 Implement localization 2.3 Capture aerial images 2.3.1 Capture image meta data 2.4 Data transfer to server 2.5 Integrate into system 2.6 Test UAV module 2.6.1 Test on grass 2.6.2. Test on sand
3	Server	3.1 Implement ROS communication architecture 3.2 Build pre-determined map 3.3 Implement UAV path planning 3.4 Collect images form UAV 3.5 Build litter map generator 3.6 Implement UGV path planning 3.7 Integrate into system 3.8 Test server module
4	UGV	4.1 Establish communication with server 4.2 Communicate path 4.3 Test path traversal 4.3.1 Test on grass 4.3.2 Test on sand 4.4 Integrate hardware 4.4.1 Arduino for motor controls 4.4.2 Nvidia jetson for onboard processing 4.4.3 RTK GPS for real time ground position 4.5 Implement localization 4.6 Integrate pickup trailer 4.7 Test UGV module 4.7.1 Test on grass 4.7.2 Test on sand
5	Pickup Mechanism	5.1 Research mechanism specifications 5.2 Design CAD model 5.3 Build prototype 5.3.1 Build CAD model

		5.3.2 Build prototype rig to finetune design 5.4 Test prototype 5.4.1 Update CAD model with prototype results 5.5 Procure parts and materials 5.6 Fabricate and assemble mechanism 5.6.1 Build chassis 5.7 Test pick-up mechanisms 5.7.1 Test chassis with Husky 5.7.2 Build and test pickup 5.8 Integrate 5.8.1 Integrate pickup to chassis 5.8.2 Integrate pickup trailer to UGV
6	Project Management	6.1 WBS Work package tracking 6.2 Schedule tracking 6.3 Risk Tracking 6.4 Budget tracking

8.1.2 Schedule

From the WBS, a schedule was generated by taking into consideration the importance of each work package and a best estimate of man-hours needed for each work package. A Gantt[vii, viii] chart is utilized for tracking the schedule and major milestones.

8.1.3 Progress Review

Table 8: Progress review table

Date	**Work Package**
Jan-19-2018	1.1.1 2.1 2.1.1
Jan-26-2018	4.1 5.1
Feb-2-2018	1.2 2.2 2.3 4.2 5.2
Feb-9-2018	1.3.1 2.4 4.4.1 5.3.1
Feb-16-2018	1.4 2.5 3.4 4.3.1

	4.3.2 5.3.2
Feb-23-2018	2.6.1 Aerial system milestone 5.4.1
Mar-2-2018	3.1 3.2 4.3.4 5.5
Mar-9-2018	3.5 3.6 4.5
Mar-16-2018	3.7 3.8 Server system milestone 5.6.1
Mar-18-2018	Preliminary Design Review
Mar-24-2018	5.7.1
Mar-30-2018	4.7.1 5.7.2
Apr-6-2018	4.7 5.8.1 5.8.2 Ground system milestone
Apr-13-2018	Complete system test
Apr-20-2018	Complete system test
Apr-24-2018	Spring validation experiment
Apr-30-2018	Spring validation experiment encore
May-6-2018	Critical design review
Sep-2019	Finish unfinished work from spring
Oct-2019	Full system integration
Nov-2019	Full system integration test
Dec-2019	Final testing and Fall Validation Experiment

8.2 Work Plan

8.2.1 Spring Validation Experiment

The Spring Validation Experiment (SVE) will demonstrate the functionality of the major subsystems.

Test 1: Litter Detection Test
Location: The Cut at Carnegie Mellon University
Equipment: UAV (DJI Matrice 100), Server, Solo cups/coffee cups
Procedure (and relevant requirements):

1. Place Solo cups/coffee cups at random locations on the Cut.

2. Manually fly the drone over the area and capture images of the environment.
3. Run the captures images through the litter detection algorithm.
4. Use a visualizer to verify that the algorithm is able to identify the litter in the images. (M.R.1, M.P.1.2, M.P.1.3)

Note: This test can be performed before the actual SVE and the results can simply be displayed at the demo.

Test 2: Litter Collection Test
Location: The Cut at Carnegie Mellon University
Equipment: UGV (Husky), Server, Solo cups/coffee cups, RTK GPS System
Procedure (and relevant requirements):

1. Calibrate/setup RTK GPS system
2. Deploy the UGV at a base location.
3. Place Solo cups/coffee cups at predetermined locations on the Cut (use RTK GPS coordinates)
4. The server computes a trajectory for the UGV to collect the litter and communicates it to the UGV. (M.R.2, M.P.2)
5. The UGV follows the trajectory, picking up litter off the surface along the way and storing it in its onboard container. (M.R.3, M.R.5, M.P.1.4, M.P.3.1, M.P.3.2, M.P.5)
6. Once all the litter has been collected, the UGV returns to its base location. (M.R.4, M.P.4)

8.2.2 Fall Validation Experiment

The Fall Validation Experiment (FVE) will demonstrate the full system operation. The goal of the FVE is to verify that all system requirements have been met.

Test 1: Full System Test
Location: The Cut at Carnegie Mellon University
Equipment: UAV (DJI Matrice 100), UGV (Husky), Pick-up mechanism, RTK GPS, System Server, Solo cups/coffee cups (10).
Procedure (and relevant requirements):

1. Calibrate/setup RTK GPS system.
2. Place Solo cups/coffee cups at random locations within the operating environment.
3. Deploy UAV and UGV at a designated base location.
4. Command the system to begin cleanup task.
5. Server will compute waypoints for the UAV scout trajectory and communicate those waypoints to the UAV. (M.R.2)
6. The UAV will take-off, follow the scout trajectory, capture information about the environment and return to base location. (M.R.4, M.P.1.1)
7. The UAV will transmit this data to the server, which will then proceed to identify the location of litter in the environment. (M.R.1, M.P.1.2, M.P.1.3)
8. The server will build a map of the litter locations in the predetermined area , plan a trajectory for the UGV to collect the litter, and communicate this trajectory to the UGV. (M.R.2, M.P.2)

9. The UGV will follow the trajectory, picking up litter from the surface as needed and storing it in an onboard container. (M.R.3, M.R.5, M.P.1.4, M.P.3.1, M.P.3.2, M.P.5)
10. Once finished, the UGV will return to base location. (M.R.4, M.P.4)

8.3 Team Responsibilities

This table contains the preliminary team responsibility matrix, where 1 and 2 represent primary and secondary responsibility.

Table 9: Team responsibilities

Task	Josh	Avinash	Atulya	Fan
Vision		2	1	
Litter Pickup	1			2
Coordination		1	2	
Localization	2			1

8.4 Risk Management

8.4.1 Risk Details

Table 10: Risk details

ID	Risk	Likelihood	Consequence	Mitigation
1	UAV identification failure (drops below 70%)	2	5	Switch to April tags or other easily identifiable object
2	UAV crash	2	3	Buy new drone (budget)
3	Litter visual location drift (error beyond 1 meter)	3	3	Extend ROI boundaries
4	Husky cannot move on sand (UGV)	3	3	Change tires Try and borrow another UGV Change use case to grass
5	Pick up Mechanism failure (cannot pick up litter)	3	5	Buy alternative (must identify)
6	Mechanism stuck	2	4	Sensor for this Have reverse functionality
7	Communication failure	3	5	Manual data transfer
8	UAV going off course (demo)	2	4	Manual switch
9	UGV localization failure	2	4	Manual switch

10	Algorithm fails to reach solution	2	4	Have alternative (more reliable) algorithm as backup
11	Sand damage	4	4	

8.4.2 Risk Matrix

Table 11: Risk matrix

Likelihood	**5**					
	4				11	
	3			3,4		5,7
	2			2,8	6,9,10	1
	1					
		1	**2**	**3**	**4**	**5**
Consequence						

8.4.3 Risk Table for High Level Risks

Table 12: Pickup mechanism failure risk

Risk ID	**Risk Title**	**Risk Owner**
5	Pick up Mechanism failure (cannot pick up litter)	Joshua
Description		
Litter pick-up mechanism fails to retrieve litter off the surface and place it in the UGV's litter container.		
Consequences		
The beach is not cleaned i.e. the litter is not removed. The system failed to perform its most basic function. A human must now manually scout the beach and pick up the litter.		
Action Plan	**Success Criteria**	**Risk Type**
1. Redesign failing component (if minor).	1. Modified mechanism is able to pick up litter without cause excessive schedule slip	Schedule, Cost
2. Identify and purchase off-the-shelf mechanism as replacement	2. Mechanism is able to pick up litter while staying within budget	**Risk Level**
		95%

Table 13: Communication failure risk

Risk ID	**Risk Title**	**Risk Owner**
7	Communication failure	Avinash
Description		
The Server is not able to communicate with the UAV or UGV at any point in time.		
Consequences		
The system is unable to collect relevant data or perform collection task. The system is also unable to guarantee safe operation if it cannot communicate with its agents.		
Action Plan	**Success Criteria**	**Risk Type**
1. Reduce scout area for demo (if the issue is range)	1. Reliable communication channel established between server and agents at all points within scout area	Schedule, Cost
2. Modify system operation to include manual data transfer (with wires etc.)	2. UAV scout data is made available to server to enable UGV to perform its task	**Risk Level**
		90%

Table 14: Sand damage risk

Risk ID	**Risk Title**	**Risk Owner**
11	Sand damage	Joshua
Description		
Sand from the beach enters the system in some way.		
Consequences		
Sand particles interfere with mechanical operation and potentially damage motors and other electrical components.		
Action Plan	**Success Criteria**	**Risk Type**
1. Buy a device (like a leaf blower) to regularly blow sand out of system, preventing buildup	1. Insufficient sand buildup to seriously affect electrical components	Schedule, Cost
2. Replace damaged components with replacement units	2. Electrical components are fully functional	**Risk Level**
3. Change use-case to grass cleanup	3. System operates without this issue on grass	90%

Table 15: UAV identification failure risk

Risk ID	Risk Title	Risk Owner
1	UAV Identification Failure	Atulya
Description		
The visual system fails to identify litter or the recognition accuracy drops below 70%		
Consequences		
Fail to build the litter map		
Action Plan	**Success Criteria**	**Risk Type**
1. Change searching item	1.The system shall meet the performance requirement P.R.6	Schedule, Cost
2. Implement different recognition algorithm in the same time		**Risk Level**
		95%

8.5 Budget

Table 16: Budget table

Functional Group	Item	Details	Cost
Localization	RTK GPS	Emlid	$800
Pickup	Chassis	Extrusion, miscellaneous fasteners wiring etc., used grounds bot as example	$1,000
	Pick up Motors	2 x 12 V	$250
	Motor Drivers	2x 5v to 12v	$100
	Microcontroller	Raspberry Pi	$60
	Microprocessor		$20
	Battery		$200
Communication	2.4GHz receiver and transponders	5x (3 required 2 spare)	$100
	Miscellaneous	Antenna etc..	$100
Litter Detection and Mapping Server	Additional Processors		$500
25% Buff			$658
Rainy Day Fund			$1,000
Total			**$4,788**

9 References

[i] Wimbrow, Fred [Town of Ocean City Public Works Maintenance]. (2018, October 24). Personal interview.

[ii] Tidal range and recovery from the impacts of mechanical beach grooming Caroline Griffin, Nicola Day, Hanna Rosenquist, Maren Wellenreuther, ... André S. Gilburn Pages 66-71

[iii] Grover, Prince. "Evolution of Object Detection and Localization Algorithms." *Towards Data Science*, 15 Feb. 2018, http://towardsdatascience.com/evolution-of-object-detection-and-localization-algorithms-e241021d8bad

[iv] Gandhi, Rohith. "R-CNN, Fast R-CNN, Faster R-CNN, YOLO - Object Detection Algorithms." *Towards Data Science*, 9 July 2018, http://towardsdatascience.com/r-cnn-fast-r-cnn-faster-r-cnn-yolo-object-detection-algorithms-36d53571365e

[v] Team, Barber. "How It Works." *Barber*, http://www.hbarber.com/Cleaners/SurfRake/HowItWorks.html

[vi] Cobot, Team. "WBS Tree." *Sureclean Google Drive*, 2018, https://drive.google.com/file/d/1b4BaPO0fYwGiCQUCwDIFCj2hO9okfJCT/view?usp=sharing

[vii] Cobot, Team. "Sureclean Spring 2019 Gantt Chart from CoDR." *Instagantt*, 7 Dec. 2018, http://instagantt.com/shared/5c04be9447b2d83b433c102d

[viii] Cobot, Team. "Fall 2019 Sureclean Schedule." *Google Drive*, 7 Dec. 2018, https://docs.google.com/spreadsheets/d/1kuTaJJxByHAvOwLWyM45lP-A4mhspEMveJBMTfs32Vo/edit?usp=sharing

10 Appendix A

Table of figures

Table of tables

11 Appendix B

Risk ID	Risk Title	Risk Owner
2	UAV Crash	Fan, Avinash
Description		
The UAV crashes and sustains critical damage		
Consequences		
The time spent to fix the system will delay the schedule and may cost extra money for repairs		
Action Plan	**Success Criteria**	**Risk Type**
1. Add safety components when testing (e.g. propeller guards)	1. The UAV can fly again	Technical
2. Borrow or purchase another UAV	2. Our new UAV is operational and we are still within budget	**Risk Level**
		60%

Risk ID	Risk Title	Risk Owner
3	Litter visual location drift (error beyond 1 meter)	Fan, Atulya
Description		
The visual system cannot give the location of trash within the desired precision		
Consequences		
The litter map will not have the location accuracy required for the UGV to pick up litter		
Action Plan	**Success Criteria**	**Risk Type**
1. Modify UGV path planning parameters to account for increased uncertainty	1. The localization accuracy meets M.P.1.2	Technical
2. Change the localization strategy to GPS + SLAM	2. The localization accuracy meets M.P.1.2	**Risk Level**
		80%

Risk ID	Risk Title	Risk Owner
4	Husky cannot move on sand (UGV)	Joshua
Description		
The ground cannot traverse on sand, one of its primary operating environment		
Consequences		
The UGV may not be able to properly move on sand, making it incapable of performing its mission tasks		
Action Plan	**Success Criteria**	**Risk Type**
1. Change tires of the ground vehicle	1. The UGV's performance meets M.P.5	Technical, Sechdule
2. Try and borrow another UGV		**Risk Level**
3.Change the use case to only include grass		80%

Risk ID	Risk Title	Risk Owner
6	Pickup mechanism gets stuck	Joshua
Description		
The pickup mechanism gets stuck during the validation experiment due to the litter		
Consequences		
The pickup will be incapable of picking up the remaining litter on its path		
Action Plan	**Success Criteria**	**Risk Type**
1. Add sensors to sense if the mechanism is stuck	1. The pick-up system performs normally	Technical, Schedule
2. Have the ability to reverse the pickup mechanism to remove jammed litter	2. Pick-up system meets M.P.3.1	**Risk Level**
		80%

Risk ID	**Risk Title**	**Risk Owner**
9	UGV localization failure	Fan, Atulya
Description		
The RTK GPS on the UGV fails and it does not know where it is		
Consequences		
The UGV cannot find the ROI and finish the rest of the task		
Action Plan	**Success Criteria**	**Risk Type**
1. Set different locaization system for the system	The system is able to meets M.P.1.3	Technical
2. Switch to a full coverage pickup of the area		**Risk Level**
		85%

Risk ID	**Risk Title**	**Risk Owner**
10	Algorithm fails to find a solution	Fan, Atulya
Description		
The system or subsystem algorithm fails to get a solution		
Consequences		
The whole system or part of the system will become stuck and fail to fininsh the rest of the task		
Action Plan	**Success Criteria**	**Risk Type**
1. Have alternative (more reliable) algorithm as backup	1.All algorithms return solutions	Technical
2. Print algorithm log		**Risk Level**
		85%

Risk ID	Risk Title	Risk Owner
8	UAV going off course (demo)	Avinash
Description		
The UAV flies off the range of searching area		
Consequences		
The UAV fails to search certain area and will face the risk of drone loss		
Action Plan	**Success Criteria**	**Risk Type**
1. Set electric fence for flying	1.UAV tracks the pre-built path	Schedule, Budget
2. Switch to manual control	2. Meet requirement M.P.1.1	**Risk Level**
		60%