FIELDROID

Conceptual Design Review

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1. Project Description

1.1. Overview

A beautiful and meticulously painted field is the pride of every major soccer & football team in the world. It is an enormous spectacle which requires constant care and maintenance. Currently, this maintenance implies several laborers spending many painstaking hours in an effort to paint across more than an acre of grass every week. The Fieldroid is an autonomous field painting system that will transform any field of grass into a professional grade sports arena.

While current solutions are time, labor and resource intensive, Fieldroid paints field markings and graphics with superhuman precision and efficiency. The excessive use of paint is an unnecessary cost which damages grassy fields. Fieldroid can control the amount of paint used at any point on the field so that it limits these damages, all while saving paint. Furthermore, time is money in the fast paced sports industry. One field may have to be repainted more than once in a single day to accommodate multiple events. Fieldroid paints a field in under two hours allowing for faster turnover times between events. It also operates at all times of day or night so that field managers have one less thing to worry about when they wake up. We present advanced technologies in the form of an easy to use robot so that the only simple step between a plot of grass and a professional grade sports field is Fieldroid.

Figure 1. Illustration of Fieldroid capabilities; painted field markings and text

1.2. Use Case

Here is the brief story of Bob Corley.

Bob Corley has had a long day. The first big game of the season is tomorrow, Steelers vs The Cowboys at home. Bob is the groundskeeper for The Heinz Stadium which is considered one of the most beautiful Football fields in the nation. His team has been hard at work all day making sure the field is in perfect condition. They spend much of the day making the final touches to the turf before they could let the Fieldroid loose.

At about 3pm, Bob was able to give the okay on the turf and he let his project manager, Erica, get the robot out of the storage facility and start it up for the first round of paint. She takes it out to the corner of the field, pulls out her phone, and starts tapping the screen. Bob knew very well the interface she was messing with, it was a well-designed app in which she could pull up a pre-programmed line set for a standard NFL field. Bob asks if she had charged Fieldroid since the last use and she stated the battery was at 100%. He grabbed the paint from the storage area and poured it into the cartridge on the robot. For the lines, he knew the robot would only need white and due to its efficient use of paint, he only needed to fill it once for the whole field. Erica double checked the paint and the settings on the phone. She set up the survey beacon and tapped the calibrate button on the App. The Fieldroid was waiting for the okay to start.

Bob was always amazed at the reliability of this complex system. The stadium had owned this system for over 2 years and had very few issues. They were one of the first adopters of this technology, and he knew that could have meant real problems.

Erica checked with Bob to make sure everything looked good and she tapped the launch button on her phone. Off the robot went, painting the outline, the cross lines, and then the numbers. It was a tedious task that would normally take his team half a day. The robot would be done in a little over an hour.

At the end of the day, Bob came back to find the robot waiting for its next command, having finished the lines on the field. This next part was Bob's favorite part about this product, but sadly he had to get home to have dinner with his family. The battery still reading over 70%, had plenty left to finish the job. He pulled out the white cartridge and placed in a color one that he filled up with gold and black. He placed the robot on the corner of the field, just like before and tapped the launch key on his phone. This time, he had input the logo design for the center of the field and end zones. He would stick around and watch, but it was getting dark and he really wanted to see his kids before the big game tomorrow.

As he left the stadium, he turned off the lights and wandered out to his car. The robot was still going, as it would take a few hours to complete, but he knew how they used to do it in the old days, another half day of work - just for the logos. Bob remembered the Fieldroid's marketing tactic of "set it and leave it alone." Boy was he happy he made that purchase as he knew full well he could show up in the morning with a perfectly painted field and a robot, The Fieldroid, sitting in the corner waiting to be charged for the next big event.

1.3. System Sketch

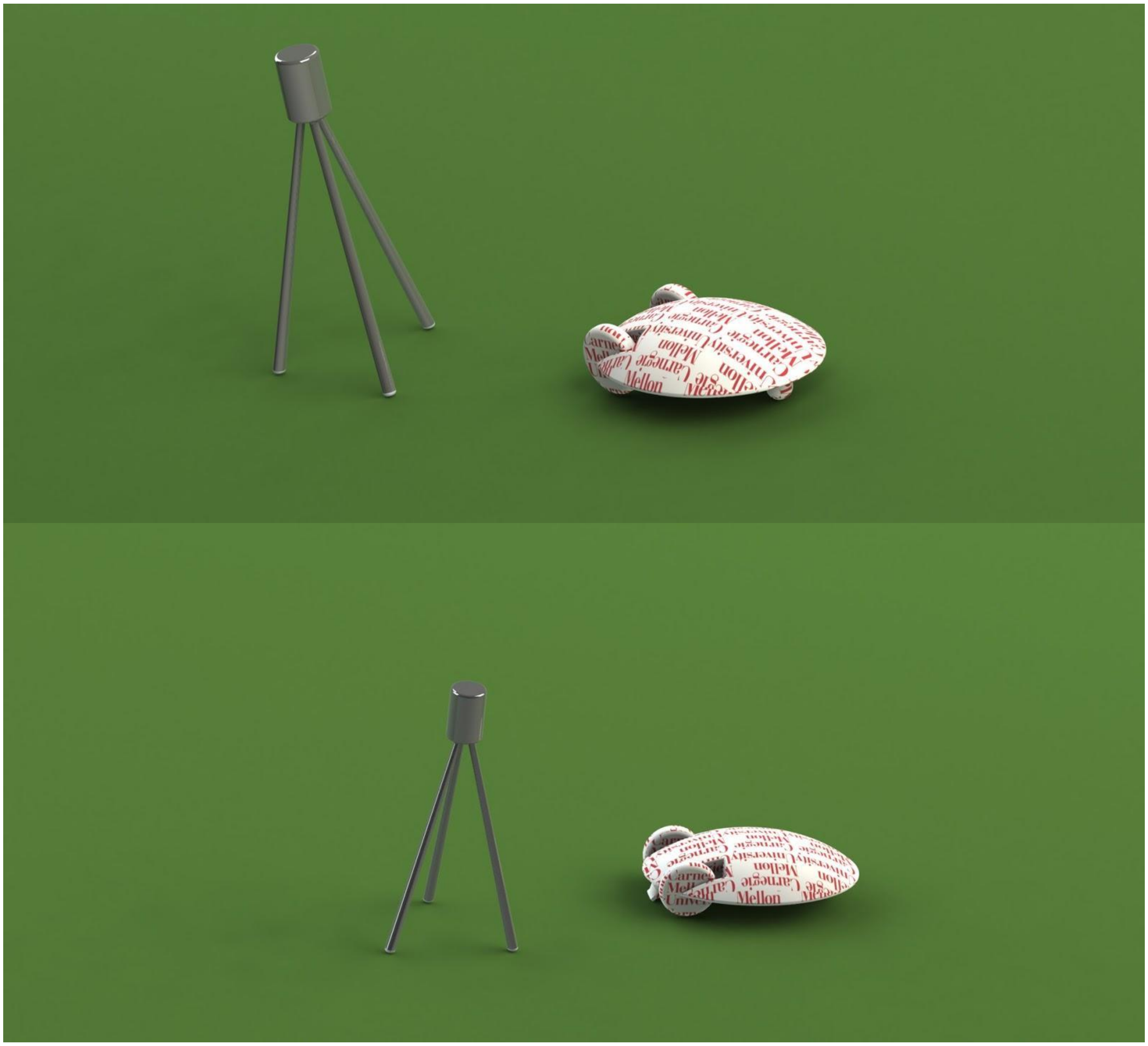

Figure 2. Rough sketch of the overall system. Here you can see a system that resembles a robot and a beacon station separate from the robot.

2. System Requirements

2.1. Mandatory Requirements

2.1.1. Functional

In order for the Fieldroid to succeed, the system:

1. Shall be autonomous
2. Shall paint field markings and graphics

3. Shall interface with the user
4. Shall plan a path given user input
5. Shall respond to the environment

2.1.2. Non-Functional

In order for the Fieldroid to succeed, the system:

1. Will be reliable when autonomously painting the field
   a. Move & Paint within 1cm of the desired path
   b. Paint 100% of regulation soccer & football field markings
2. Will be easy to use
   a. Operable by a 15 year old
3. Will be safe to work around
   a. Avoid obstacles detected within a 3' radius
4. Will be affordable
   a. Cost under $4,000
5. Will save time
   a. Spend at most 2 hours to complete the task
   b. Complete an entire field without requiring a recharge or paint refill
6. Will save Paint
   a. Consume at most 324 oz. of paint per task

2.2. Desirable Requirements

2.2.1. Functional

Ideally, the Fieldroid system:

1. Shall paint complex graphics
2. Shall paint with multiple colors
3. Shall plan the most efficient path given user input settings

2.2.2. Non-Functional

Ideally, the Fieldroid system:

1. Will look appealing
   a. Technology Readiness Level of 6
2. Will be modular
   a. 2 additional tools for seeding & mowing can be installed in under 5 minutes

3. Functional Architecture

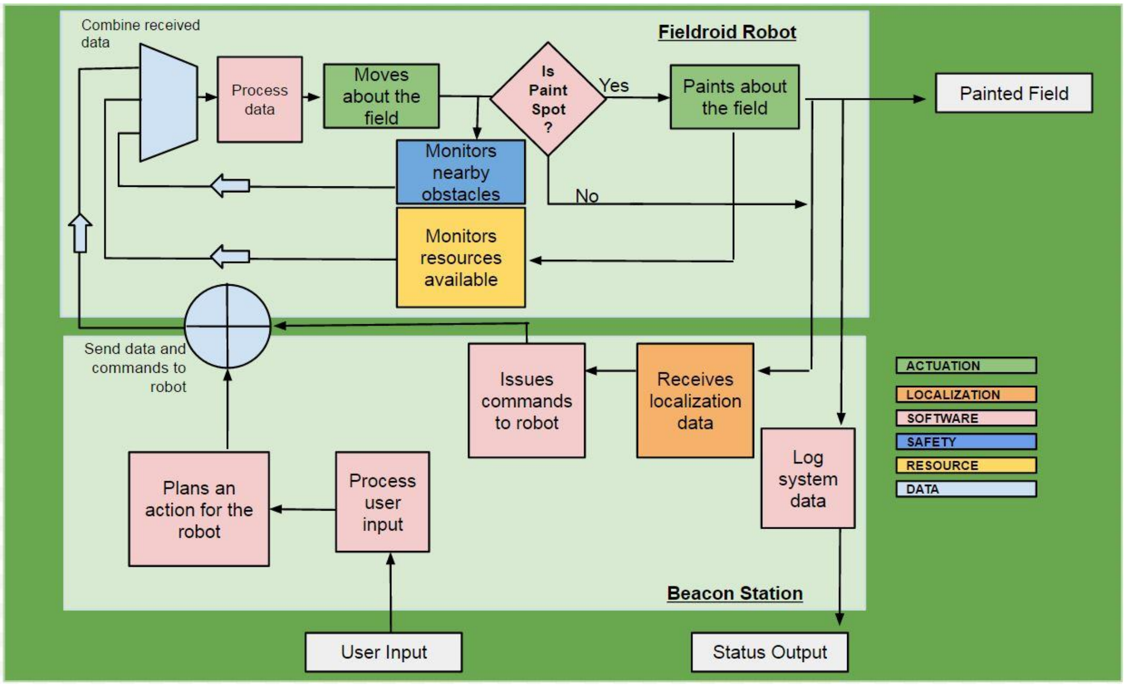

Figure 3. Overview of the functional architecture. This architecture outlines the functions that the system will perform to achieve its task.

Aside from energy needed to power the systems, the primary inputs to the Fieldroid system consist of the user inputs. These inputs are one-time setup inputs where the user can specify all the settings and configurations for Fieldroid.

Once the primary inputs are received, Fieldroid processes all the data and plans the most efficient path to achieve its task. Once it has planned a path, Fieldroid then follows a control system approach to perform its assigned task.

Fieldroid drives according to the plan and dispenses paint on the field according to the given input. If it is not in a place where paint needs to be dispensed, then Fieldroid does not dispense paint. As it is moving and deciding when to dispense paint on the field, Fieldroid constantly receives updates from its localization sensors, obstacle detection sensors, and resource management sensors. Doing so, Fieldroid can correct its current path to realign with the planned path. Fieldroid can also stop in its current position if it detects a hazard on its immediate path or alert the user of decaying resources.

Fieldroid constantly reports its current status to the user so the user can observe the amount of time remaining, amount of resources remaining, and accuracy observed. If desired, the user can also stop or halt commands to the robot. If received, Fieldroid stops moving and stops dispensing paint.

Once the entire task is complete, Fieldroid compiles all the reports and publishes the results of the task. The output of the system ends up being a painted field.

4. System Trades

4.1. Major Systems-Level Trade

SELECTION CRITERIA	Rank	Weight Factor (%)	On Board	Single Beacon	MultiBeacon	Multiple Bots	Gantry Bot
Be reliable when performing autonomous operation	1	28.57	30	70	80	40	85
Paint line markings and graphics on a field	2	23.81	30	50	70	10	90
Interface with user	3	19.05	90	80	55	65	15
Cost	4	14.29	80	70	40	30	10
Plan the most efficient path	5	9.52	50	50	50	80	60
Respond to environment	6	4.76	90	90	90	60	5
		Totals	**53**	**66**	**65**	**41**	**56**

Figure 4. Major System Level Trade. This is the main trade study that will dictate all the subsystems for our robot. Here we only analyzed the deployment of the robot with respect to localization.

The figure above shows the major system-level trade for our system. Here, different deployment configurations were studied and analyzed according to the selection criteria derived from Fieldroid's functional requirements.

<u>On-Board System</u>
The first system consists of a single autonomous mobile platform. This system has all of the subsystems needed to accomplish its overall task. This is the traditional method to constructing an autonomous platform that performs in an outdoor environment. When analyzing this option against the selection criteria, this platform scored well in 'interface with the user', 'cost', and 'response to the environment'. However, the lack of additional localization feedback and the strong reliance on a GPS system drops the reliability of this platform and its capabilities of precisely painting line markings.

<u>Single Beacon System</u>
The second system consists of a single autonomous mobile platform with an added external beacon that would help localize it in the field. For this system, the main localization subsystem consists of the single beacon. The beacon gathers accurate localization error from the robot and relays it back to the robot's computer so that it can correct its path. In terms of reliability and capability to paint lines, this option performs extremely well depending on the type of beacon being used. However, its capabilities of re-planning the path on the flight are not as good as the On-Board option.

<u>Multiple-Beacon System</u>
The next system consists of a single autonomous mobile platform with various external beacons that would help localize it in the field. Sensible Machines, a company that provides autonomous

landscaping robotic services, demonstrates that this is a viable option for localizing in an open field. When compared to the single beacon solution, this system adds more reliability and capabilities to the robot but with an increased cost and reduction to the user-friendly aspect of the system.

Multiple Robots System
The next system consists of multiple autonomous mobile robots painting a field. This system allows for multiple robots to work together to accomplish the task. In theory, this option allows for a fast turnover time between tasks since it has more than one robot simultaneously painting the field. In this configuration, the robots communicate among themselves to update information about their tasks and to calibrate their localization error. This approach, however, shows an unfavorable cost, an undesirable user-friendly system, and an unreliable system to paint line markings. This is because this configuration has more than one moving system that requires constant communication between the platforms and the user.

Gantry-Bot System
This final configuration consists of a gantry system that spans the dimensions of the field. This is similar to a 2D printer as big as a sports field. In theory, this system can consistently paint line markings accurately and with extreme precision. However, setting up this entire system and taking it down requires more labor from the user compared to previously discussed systems. Although this system does not contain single expensive devices, its costs are high due to the costs of raw material.

Major Systems-Level Trade Results
Based on different configuration settings for an autonomous field painting system, the most viable options consist of a multi-beacon or a single beacon system. This aligns with the methods currently being practiced in industry. These systems demonstrate strong capabilities to paint line markings with strong accuracy and precision without having a severe impact to other categories.

4.2. Subsystem Level Trades

4.2.1. Subsystem Level Trade A: Localization

SELECTION CRITERIA	Rank	Weight Factor (%)	Survey Gun (with tracking prism)	Multiple Sensor Motion Capture	Short Range Signal Beacons	Cameras and April Tags
		Examples	Leica, Seco	Vicon, Qualisys	Bluetooth, Sonar	Any USB Webcam
Be reliable when performing autonomous operation	1	25.00	90	90	30	60
Paint line markings and graphics on a field	3	20.00	80	90	40	70
Interface with user	4	15.00	60	40	40	50
Cost	1	25.00	50	0	70	80
Plan the most efficient path	5	10.00	80	90	60	70
Respond to environment	6	5.00	10	30	40	80
		Totals	**69**	**57**	**47**	**68**

Figure 5. Trade study for Localization

Functionally, localization constitutes over 50% of our system. This is because Fieldroid has to autonomously move about the field and dispense paint with extreme accuracy and precision. If our robot cannot be as accurate and precise as the current solutions, our robot will not be a competitive product.

After analyzing some potential options to help Fieldroid localize, we determined that the use of a survey gun or the use of cameras and April tags can present a reliable solution.

4.2.2. Subsystem Level Trade B: Computer Processing Unit (CPU)

SELECTION CRITERIA	Rank	Weight Factor (%)	BeagleBone Black	Rasberry Pi	Arduino Mega	Arduino Uno	TI Launchpad Stellaris	BeagleBoard xM	Linux OS Board	cRIO	32-Bit ARM
CPU Speed	1	22.2%	80	55	30	30	40	90	100	100	90
Programming Interface	2	19.4%	70	80	50	45	50	80	90	95	90
Serial Protocol	3	16.7%	70	50	60	40	95	40	50	60	70
Analog Protocol	4	13.9%	70	30	90	70	100	30	40	60	80
GPIO Capabilities	5	11.1%	90	30	70	40	50	30	50	40	55
Memory	6	8.3%	80	70	40	20	40	60	80	50	80
Power Consumption	7	5.6%	70	60	90	100	50	60	45	10	40
Cost	8	2.8%	60	60	70	80	90	50	60	5	20
		Totals	75.00	54.44	56.94	45.69	62.50	59.44	70.00	68.33	75.83

Figure 6. Trade study for CPU

To perform any action and decision making, our system will require the use of a CPU. For this subsystem, CPU speed, programing interface, and communication protocol are important factors to consider. These factors support the accuracy, precision, responsiveness, and user-friendliness requirements of our system. Other factors considered include hardware and software support.

After analyzing various options, BeagleBone Black, Linux OS Boards, or 32-Bit ARM single-board computers provide strong solutions due to their capabilities and costs.

4.2.3. Subsystem Level Trade C: Operating System Environment

SELECTION CRITERIA	Rank	Weight Factor (%)	Windows OS	Ubuntu 14.04	Arch Linux	Xubuntu 14.04	Mac OS
Freedom of Programmability	1	25.0%	60	85	100	85	80
Hardware Interface	2	21.4%	80	80	60	80	40
Speed	3	17.9%	50	70	100	90	70
Documentation	4	14.3%	70	90	40	70	60
Reliability	5	10.7%	50	80	90	85	60
User Friendly Application	6	7.1%	95	80	45	70	100
Support	7	3.6%	70	95	40	80	70
		Totals	65.71	81.43	75.71	81.43	65.71

Figure 7. Trade study for OS architecture

This subsystem trade study evaluates different options available for deployment in the CPU. Freedom programmability, interfacing with hardware components, and system speed are the three most important factors for this trade. The type of computer chosen must be compatible with the type of operating system that we choose to deploy.

After analyzing the options available, several distributions of Linux OS can provide us with strong capabilities that meet the three most important factors. With this in mind, additional system trade studies must be performed to choose a firmware.

4.2.4. Subsystem Level Trade D: Drive System Configurations

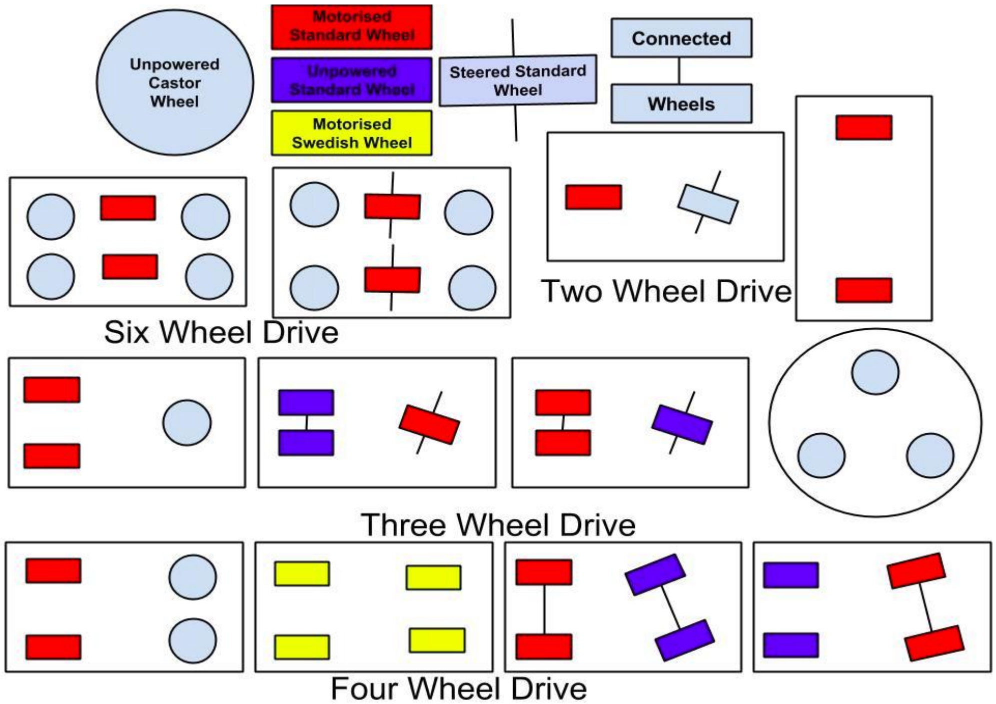

Figure 8. Different wheel configurations.

SELECTION CRITERIA	Rank	Weight Factor	Two Wheel	Three Wheel	Four Wheel	Six Wheel	Tread
STABILITY	1	28.57%	10	40	50	60	80
TRACTION	6	4.76%	10	30	40	50	80
MANUEVERIBILITY	2	23.81%	30	80	50	40	5
CONTROL	3	19.05%	70	40	30	20	20
POWER	4	9.52%	80	60	40	20	30
COST	4	14.29%	80	70	60	40	20
			42.859	**55.239**	**46.191**	**40.476**	**37.3785**

Figure 9. Trade study for drive system configurations.

This subsystem trade study analyzes several wheel configurations. The three most important factors we are concerned with consist of the stability, maneuverability, and speed of the system.

After analyzing current solutions and gathering information about successful drive systems, a three wheel drive system is the best solution. Overall, this option provides great stability and control to our system while reducing costs and simplifying the mechanical design.

4.2.5. Subsystem Level Trade E: Paint System

SELECTION CRITERIA	Rank	Weight Factor (%)	Diaphragm Pump System	Electric Pump System	Pressure vessel units	High Pressure Units	Aerosol spray system
Paint varied lines and patterns	1	28.57%	30	20	40	50	70
Size	6	4.76%	40	40	10	20	70
Cost	4	14.29%	20	50	20	25	60
Speed	2	23.81%	60	30	50	50	70
Paint Storage	5	9.52%	80	20	60	55	10
Reliability	3	19.05%	50	10	20	20	70
		Totals	**44.76**	**25.71**	**36.19**	**39.76**	**62.9**

Figure 10. Trade study for paint systems

This trade study analyzes different options available for dispensing paint. This task is extremely important to implement well and it comprises ~25% of the major system trade study. The main factor to consider here is the adaptability of the system to paint different lines at a speed that is superior to current field painting solutions.

Given the options studied, an aerosol spray paint system allows for the painting of different lines and designs with ease. However, one important factor that we might have to reconsider in the future is paint storage. If our system ends up consuming too much paint, our system would require frequent user interaction for refills. This may decrease Fieldroid's appeal.

4.2.6. Subsystem Level Trade F: User Interface Application

Interface Type	Rank	Weight	Onboard display	Mobile Device	Laptop Interface
Ease of Use	1	27.50%	70	90	60
Size	3	17.50%	50	90	30
Convenience	2	22.50%	80	90	50
Cleanliness	6	5.00%	30	80	90
Cost	5	12.50%	30	90	90
Accessability	4	15.00%	10	60	80
		Totals	**52.75**	**85**	**60.75**

Figure 11. Trade study for user interface applications

Here, we compared the main types of user interfaces that can be integrated with Fieldroid. Smart UI implementation will allow a vast majority of people across all disciplines and ages to use our robot while current field maintenance robots require a trained engineer.

Based on the criteria and options given, a mobile device is potentially the best solution for our system. This allows for intuitive operation of the system with a user-friendly interface

5. Physical Architecture

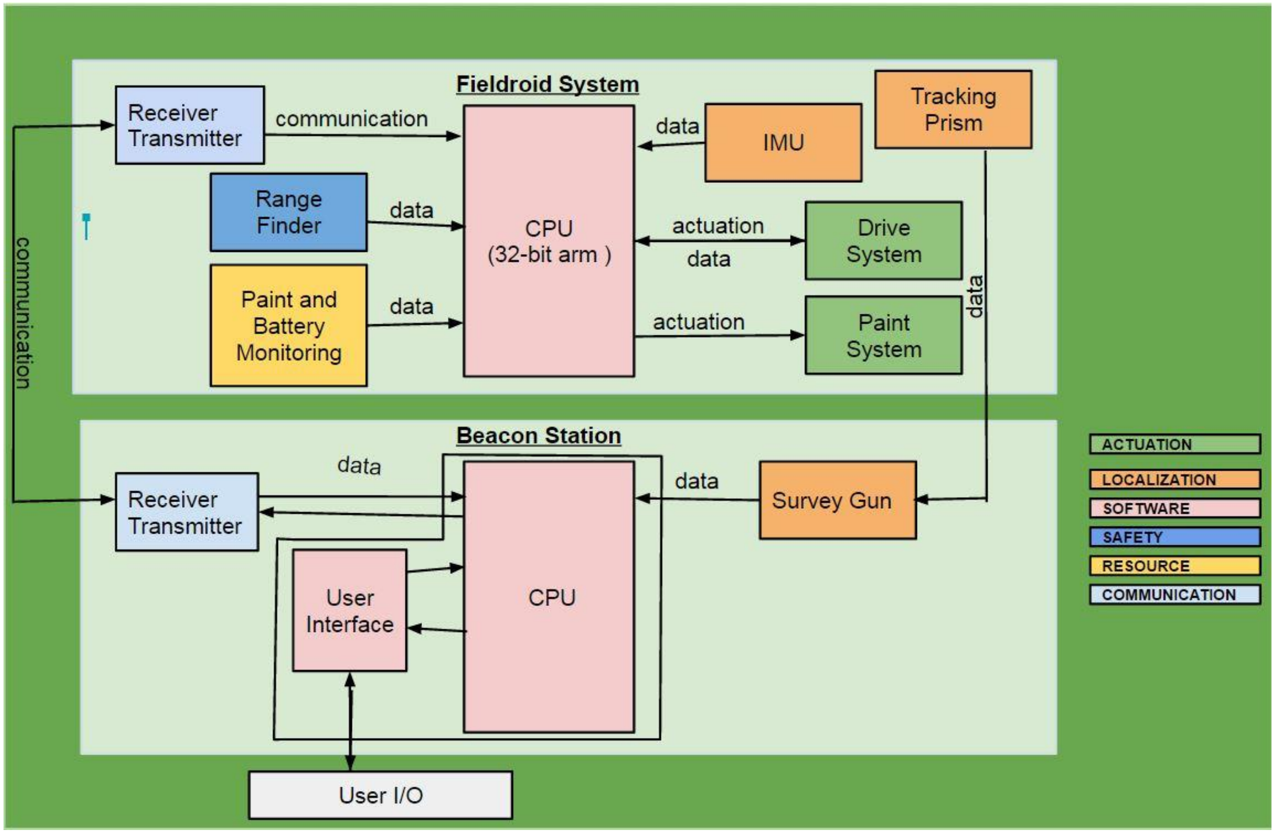

Figure 12. Overview of Fieldroid's physical architecture

The physical architecture of Fieldroid is derived from its functional architecture. The architecture consists of two major subsystems; a Fieldroid robot and a Beacon Station. The Fieldroid robot consists of the autonomous painting system while the Beacon Station consists of the user control station.

The minor subsystems are localization, obstacle detection, user interface, paint system, drive system and resource monitoring system. The physical components of the system are results of the previously discussed trade studies.

5.1. Central Processing Unit

A CPU, a 32-bit ARM processor, is the heart of Fieldroid's physical architecture. It will be the communication hub for all the major physical systems and will manage commands and responses between each particular subsystem. It receives user data which it uses to compute the optimal path for Fieldroid to paint a field. It will be responsible to synchronize the drive and paint systems efficiently resulting in precise locomotion and paint delivery. All system statuses will be delivered to the user via the 32-bit ARM processor.

5.2. User Interface

One of the major non-functional requirements concerns ease of use. With a simple user interface such as a mobile application, the user will be able to send and receive commands from the robot. It can input pre-deployment requirements like image, scale, robot home position etc. and remotely interact with the robot post-deployment. Fieldroid will be able to send real time status updates to user such as:

- The current state of operation
- Task completion status
- Emergency status in case of system failure
- The current location of the robot

5.3. Localization System

The localization system is a critical element that determines the overall system accuracy. A laser based measurement system called a survey gun will be deployed to locate the Fieldroid's current position in the environment. The survey gun will receive information from a tracking prism on board the robot. A processing unit located in the beacon station receives the localization feedback. This processing unit displays the status of Fieldroid to a UI and issues the next motion task to Fieldroid. The localization system will be effectively working in a closed loop with the drive and the paint system.

5.4. Obstacle Sensing

This subsystem is essential from a safety point of view of our robot. Ultrasonic range finders or IR sensors, which are suitable for small distances, will be used to detect hazards close to the robot in the dynamic environment. This way Fieldroid can avoid collisions. In case of hazard detection, sensors will set an alarm to abort the drive system and paint system instantly. The user Interface system will also receive the corresponding failure message.

5.5. Paint System

The paint mechanism will include:

- A diaphragm pump system
    - Delivers a steady stream of high pressure fluid through the hose to the spray gun
- A spray mechanism.
    - Controls the amount of fluid sprayed by using different orifice sizes
    - Orifice shape determines the spray pattern
- A paint storage system
- Purge system

It will have also have a paint system status module to communicate to the CPU, about current resource consumption. In the case of painting a multi-colored field logo it will feed the current color value to the robot.

5.6. Drive System

This subsystem is responsible for robot locomotion. The drive system will receive inputs from the CPU pertaining to the current location of Fieldroid and the path it must follow. All systems, in synchronous, will drive the robot to the desired location to dispense paint.

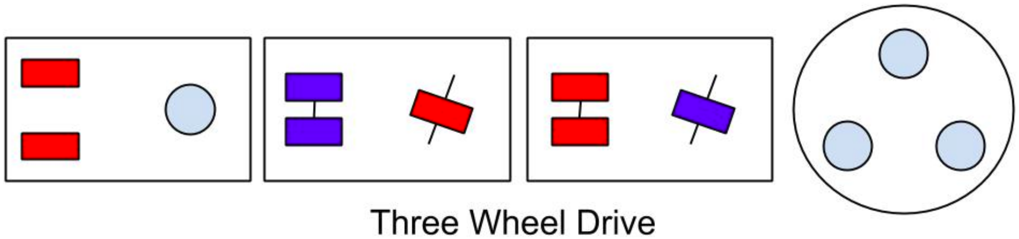

Figure 13. Examples of three wheel drive systems.

Choice of wheels depends upon system maneuverability, stability and traction. Following the trade study, we chose Fieldroid to be a three wheeled robot driven by stepper motors. Critical operations such as synchronizing the drive and paint systems while simultaneously receiving localization information, obstacle detection systems and resource systems will be managed by the on board 32-ARM processor.

5.7. Resource Monitoring System

This subsystem will be responsible for monitoring battery and paint levels. It will give user feedback in case current resources in the system are not sufficient for successful task completion. Also, it will help the user reduce costs by understanding the requirements of its system for future optimization of resources.

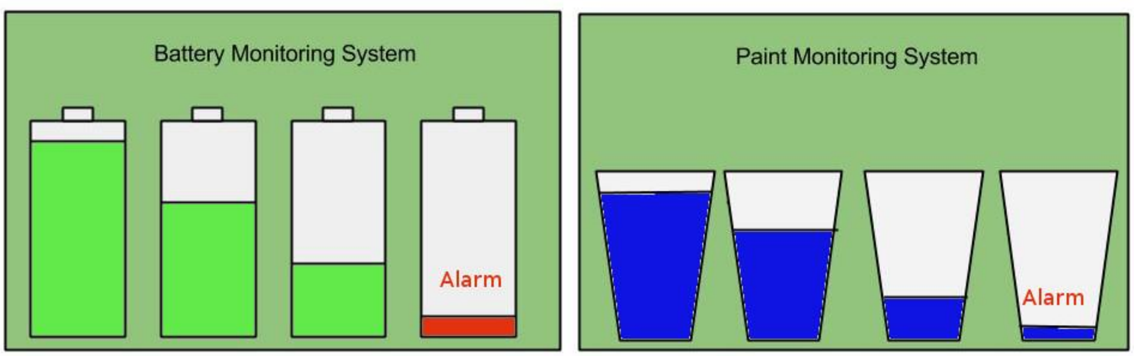

Figure 14. Examples of resource monitor display.

5.8. Wireless RX/TX Communication

This subsystem communicates information between the robot and beacon station. The robot can send information back to the beacon station where it can output status information of the robot to the user. The user can input commands and then this subsystem can send the data from the beacon station to the robot.

More importantly, this subsystem issues the next motion command to the robot after the beacon station receives and process the localization data.

6. Subsystem Descriptions

6.1. Localization

Figure 15. Examples of 3D laser measurement devices for terrain surveying.

Autonomous navigation systems require strong localization systems. This subsystem dictates the overarching physical structure of our system. Sticking to the results of Major System Level Trade A, localization should be performed using a multiple beacon or single beacon system.

According to Subsystem Level Trade A, the system should include one survey gun for absolute localization. With the consideration of Subsystem Level Trade D, an Inertial Measurement Unit (IMU) should also be included. The combination of these two sensors should allow the robot to position and orient itself within the world. This technical capability provides the best chance for success in achieving Fieldroid's functional Requirements

Alternative solutions must be considered and there were clear options presented in the trade studies if problems should arise. The primary downside of the survey gun is cost. If this problem seems too hard to overcome, a camera and April tags solution may be the next most feasible option as it minimizes cost. Also, due to the high importance placed on Functional Requirement 1 & 2, there may be a need to include more additional sensors for validation. Wheel encoders were close to passing in Subsystem Level Trade D and should be considered if a two sensor solution does not meet the requirements.

6.2. CPU

The type of CPU platform and physical architecture depends on the type of system configuration chosen as mentioned in the Major Systems-Level Trade Studies. This subsystem adds to the reliability of the system accurately painting line markings. The criteria for the CPU consists of high speeds with a strong programming interface and capabilities of communicating to several physical components easily. This aligns with the functional requirements listed for our system.

Based on the results and decisions of Major System-Level Trade A, the Fieldroid system makes use of a single board computer that receives constant localization feedback from a single or multiple beacons. Since the system only needs to react to feedback loops and communicate to various actuators, we need to use a CPU platform that is capable of this. The CPU on-board Fieldroid shall consist of a BeagleBone Black, a Linux OS Board, or a 32-Bit ARM board.

Alternatively, there are multiple solutions for this subsystem. Instead of a single board computer, we can choose to integrate a real-time controller. Real-time controllers allow us to make real-time corrections to our system. In particular, we can make the robot extremely responsive to its changes thus significantly increasing its level of accuracy and precision well beyond the capabilities of a human. Although real-time controllers can provide a strong and extremely reliable solution to our problem, the high cost of these devices is an important consideration if pursuing this solution.

6.3. Operating System

For this subsystem, the decisions from Major System-Level Trade A and Subsystem B had to be taken into account. Note, that for our project we chose hardware components first and then proceeded to choose an operating system that supports our hardware. Furthermore, given our chosen operating system, we have multiple options to explore for firmware.

For this subsystem trade, we decided to choose an operating system that is fast, allows for a wide programming freedom, and features good community support for hardware components. Having an OS that efficiently performs its tasks allows us to achieve our overarching objective in a timely manner. Furthermore, a stable and reliable OS adds to the robustness of our system making it more user friendly. Based on these 3 main factors, several distributions in Linux OS can provide us with the tools we need. The distributions in question are Ubuntu 14.04, Xubuntu 14.04, and Arch Linux. These options allow us to program in any programming language and have strong capabilities and features for robotic applications.

Alternatively, we could choose to deploy an operating system that is driven by convenience for the user rather than operational performance. This might also restrict our programming freedom to fewer options.

6.4. Drive System

For overall robot system stability it is desirable to have a robust drive system. It will significantly affect the time required for task completion which is one of the most important non-functional requirements for Fieldroid. Also, it is essential to have an easily maneuverable system to be able to paint intricate designs on a field.

Following the trade study, a three wheeled Fieldroid, is the most appropriate drive system. A three wheeled drive system will provide better stability which is required for the system to be able to hold the weight of the overall paint system, and simultaneously navigate a field of grass.

6.5. Paint System

Selection of an effective paint system is important. Current field painting operations performed by manual labor are accurate but time consuming, so it is important for our system to paint accurately and quickly. Also, it is an important subsystem which determines the overall reliability of Fieldroid.

The critical attributes contributing to a working system include the type of pump used to deploy paint and the type of spray mechanism. From the trade study, it is observed that the second best option is using a Diaphragm pump based mechanism. Aerosol sprays are convenient and fast, but when painting large fields they can accumulate significant costs. For autonomous Fieldroid operation it is required that there is sufficient paint storage on board. Aerosol cans are small and their paint capacity is much less than the typical pump system.

6.6. Control Systems

Fieldroid must utilize effective control systems in order to achieve our stated performance requirements for efficiency and precision. The onboard CPU will integrate our sensing systems (localization, resource monitoring) with our actuation systems (driving, painting) in order form a negative feedback loop and effectively optimize Fieldroid’s performance.

The most critical control loops included on Fieldroid will support autonomous navigation and painting. The drive system will feature PID controls which link localization information directly to motor speed. This feature is critical for smooth and accurate motion. Additionally, the paint system will regulate the amount of paint being dispensed based on information received from the drive system and localization system. This will result in the efficient use of paint and consistent painting performance. All of these control loops will be managed by Fieldroid’s onboard CPU.

6.7. User Interface

Communication with the Fieldroid system must be facilitated by a user interface (UI). This UI must be simple and intuitive so that the user can quickly send commands to the system. An easy to read interface will also allow the user to monitor Fieldroid’s current status and alert the user of any problems such as a low battery, low supply of paint, or a blocked path.

As a result of Subsystem Trade F, we will be creating a mobile application available for download by the user. This type of UI takes advantage of a user’s existing device and completely eliminates expenses such as interactive monitors. Mobile devices are constantly accessible and convenient to monitor if the user is away from the Fieldroid. Having a UI which is physically detached from the Fieldroid keeps the user dirt and paint free.

7. Project Management

Successful completion of The Fieldroid prototype alpha will require a meticulous project management plan. The following represents this pathway.

7.1. Work Plan and Tasks

As seen above in our subsystems, the following units will need to be addressed in our technical tasks. Correspondingly, there are major functions that need to be achieved in these systems that will coincide with our major functional requirements seen above. Below is the alignment between subsystems, major technical achievements, and the breakdown of minor tasks. The subsystems are in order of importance.

	Subsystem	**Major Technical Achievement**	**Minor Task 1**	**Minor Task 2**	**Minor Task 3**
1	Localization	Communicate position to robot	Build sensor structure	Build receiver system	Generate communication
2	Drive System	Move robot according to given command	Build chassis	Assemble motors and wheels	Control motors
3	Paint System	Dispense paint on command	Build paint dispenser	Control paint dispenser	
4	CPU	Talk to all 'smart' components	Build CPU infrastructure	Connect all communication lines	Generate communication
5	Firmware	Integrate software on 'smart' components	Install on system	Send signals to subsystems	Receive signals on subsystems
6	Algorithms	Take input and create planned path output	Build algorithm	Take input	Convert data to usable output
7	User Interface	Interactively take input from user	Build interface	Talk to CPU	

Table 1. Work Plan and Tasks for Fieldroid

Along with the major technical achievements and minor tasks, development work has been done on major milestone creation. Proper time gaps were allowed for ordering of parts, testing, integration, and validation of all systems described. The following is a list of the major milestones that must be completed in order to achieve the above.

	Milestone	Date To Be Completed
1	Complete chassis construction, Communicate with survey gun, Show draft of CAD drawings	Wednesday, Oct 15th
2	Finalize paint system design, Attach motors and wheels to chassis	Wednesday, Oct 22nd
3	Robot moves via commands from CPU, CPU talks to Survey Gun	Monday, Oct 27th
4	Constructed Paint System, Robot moves in square pattern	Monday, Nov 3rd
5	Paint scale field and lines, Show design for case	Monday, Nov 17th
6	Paint full size field and lines	Monday, Nov 24th
7	Robot (with case) paints field, lines, and names	Wednesday, Dec 3rd
21	Robot has two options for fields	Monday, Dec 8th
22	Complete user interface	Friday, Jan 30th
23	Reassess system	Friday, Feb 27th
24	Tune hardware	Friday, Mar 27th
25	Algorithm redevelopment	Friday, Apr 24th

Table 2. Major Milestones

7.2. Schedule

To meet the milestones discussed above, the Gantt chart below has been developed for tracking major milestones. It incorporates time for integration and testing in order to meet the requirements. Below is just an image, but the working document is attached. Spring milestones are mentioned above, but not included in the schedule for brevity. The goals for the first two project reviews are noted below.

7.2.1. Progress Review 1

1. Show off completed chassis structure (nothing attached yet)
2. Demonstrate signal communication between survey gun and CPU
3. Show CAD draft for entire robot

These goals are of minimal demonstrable effort, but are planned by allotting time for ordering of parts, review of design, and testing. No less than two weeks prior to this review, the parts should be ordered and on their way. Design for the chassis should begin immediately and overall design for the robot should be in development. A plan for interfacing between the CPU and the Beacon should be constructed. Upon receiving the CPU, com link, and survey gun, the integration of the three can begin according to the plan that was developed. The chassis can also begin construction. By the 15th of October, the draft design for the robot, the chassis structure, and the communication should be demonstrated. These intermediate testing and planning tasks are outlined in the Gantt chart below.

7.2.2. Progress Review 2

1. Show off motor/wheel/chassis assembly
2. Show final design for paint system

With a week between Progress Review 1 and 2 (PR1 & PR2), little more can be achieved, but hopes are to gain clear momentum moving forward. Wheels and motors should have been ordered with the original parts and therefore can begin attachment with completion of the chassis in PR1. With the drive system design finalized, the next design to finalize is the paint system as it is crucial for development. This design should be finalized and will be presented at PR2.

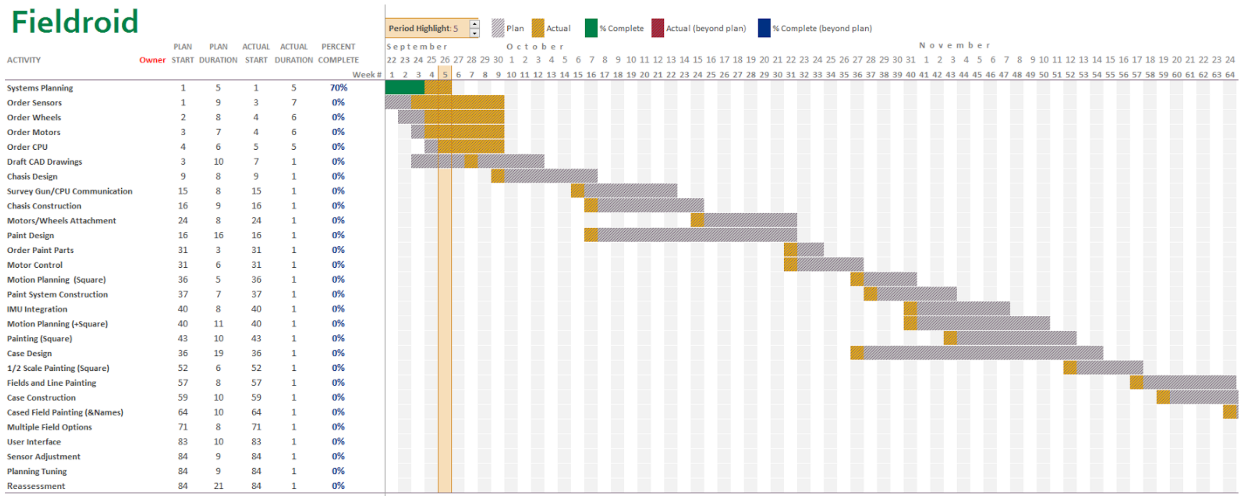

Figure 16. Gantt chart from start of project until November 2014.

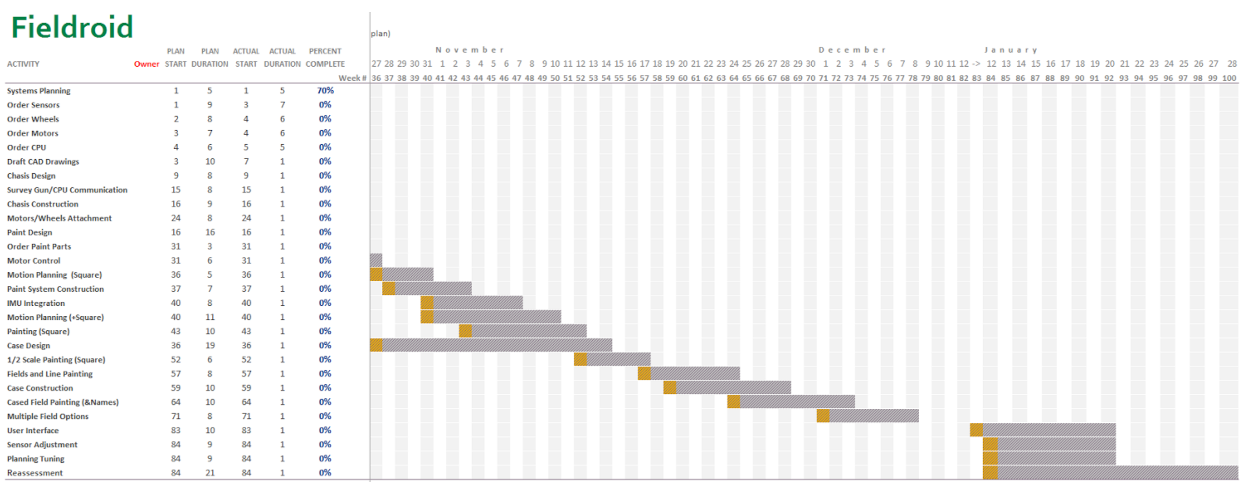

Figure 17. Gantt chart (cont.) from November 2014 until January 2015.

7.3. System Validation

7.3.1. Test Conditions

The robot will operate outside on a flat grass field. The system requires a fully charged survey gun and fully charged mobile robot. The validation experiment shall be conducted within 30ft x 20ft. The system will utilize shaving cream as the marking tool, which can be washed off or will evaporate over time.

7.3.2. Procedure

1. The survey gun will be placed at least 5 ft away from the field area on flat ground.
2. The robot will be placed on the bottom left corner of field and placed facing towards the left side goal posts.
3. The user will turn on both systems and launch the calibration of the robot.
4. The user will input preferences for the field (in this case, a miniature field of 30ftx20ft).
5. The user will launch the robot.
6. The robot will drive to the survey gun when finished.

7.3.3. Performance Metrics

- The robot and survey gun will turn on without error.
- The robot will confirm calibration.
- The robot will take multiple field options.
- The robot will move about the field when launched.
- The robot will paint a field when launched.
- The robot will be judged on scale of 1-10 by 3rd party on the quality of the field.

7.4. Team Responsibilities

The responsibility is also broken down by subsystems. Each member of the team will be in charge of two subsystems and will have an expertise in some auxiliary area. Milestones are generally heavy in specific subsystems and those persons who are responsible will take up the responsibility for those milestones.

Member	Responsibility 1	Responsibility 2are	Auxiliary Responsibility
Matt Clark	Localization	Algorithms	CS Lead
Jaghvi Mehta	CPU	User Interface	Budget Approver
Stephen Smith	Paint System	Firmware	Mech Lead
Ander Solorzano	Drive System	Power Systems	EE Lead

Table 3. Responsibilities of Team Members.

7.5. Parts List and Budget

The layout of the budget is seen below. These are major components, however allocation for hardware and miscellaneous have been included. Additionally, a 30% run over was accounted for and included at the bottom. The average expected cost for parts falls well within the budget, but careful consideration of purchases should be made as maximum prices for items listed run the budget over by 60%.

	Item	Description	Quantity	Minimum Cost	Maximum Cost	Average	Notes
1	**Survey Gun**	Primary localization system	1	$0.00	$2,000.00	$1,000.00	We may be able to borrow one of these
2	**IMU**	On board sensor	1	$0.00	$200.00	$100.00	Dolan may have in inventory
3	**CPU**	Main thinking portion	1	$80.00	$200.00	$140.00	This affects processing power, and sensor capability
4	**Wheels**	High fidelity needed	2 + caster	$50.00	$400.00	$225.00	Assumes differential drive system
5	**Motors**	Precision control is important	2	$100.00	$600.00	$350.00	Medium torque with large need for controllable accuracy
6	**Chassis Parts**	Materials for constructing chassis	misc	$100.00	$500.00	$300.00	Standard interfaceable, possibly 3D printed
7	**Paint Actuator**	Fabricated dispenser	misc	$0.00	$200.00	$100.00	Possibly 3D printed
8	**Paint Sensor**	Controllable actuation	1	$1.00	$10.00	$5.50	Could be as simple as a touch sensor
9	**Communication**	Wireless comm. for survey gun	1	$40.00	$150.00	$95.00	Interfaces with the CPU and allows the survey gun to talk
10	**Motor Controllers**	Interface from CPU to motors	2	$40.00	$180.00	$110.00	Devices with high controllability are key
11	**Hardware**	Fasteners, attachments, etc	misc	$35.00	$200.00	$117.50	Misc hardware parts
12	**Shaving Cream**	Fake paint product	mult	$20.00	$80.00	$50.00	We might be able to buy this in bulk
13	**Battery**	For power	1	$10.00	$80.00	$45.00	Should be decently low power system
14	**Ultrasonic Sensor**	Close range sensing	4	$40.00	$120.00	$80.00	Alternatives could be proposed for proximity sensing
15	**UI Comm**	Probably bluetooth for UI	1	$30.00	$100.00	$65.00	Necessary for communication with mobile device
		Subtotal		$546.00	$5,020.00	$2,783.00	The average is very forgiving
		Budget Forgiveness	30.00%	$163.80	$1,506.00	$834.90	Assume 30% runover from budget
		Final Total		**$709.80**	**$6,526.00**	**$3,617.90**	Maximum is over, but the average is achievable

Table 4. Proposed budget.

7.6. Risk Management

It is best to understand risks up front in order mitigate them in the future. The following explains in detail the major concerns with developing an autonomous field painting robot and gives some approaches for managing those risks.

7.6.1. Accuracy

The largest and most obvious item plaguing The Fieldroid is its ability to obtain precision accuracy when painting field lines. People currently layout templates and string in order to gain perfect lines and shapes for a field. A robot has to localize itself and controllably plan a path that has the same level of accuracy. Typical outdoor localization techniques, like gps, do not have the necessary fidelity in order to achieve these results. The survey gun, a solution employed in the field, will allow for this level of accuracy and is our plan for mitigation.

7.6.2. Cost

Survey guns, as mentioned above, are very expensive. This will eat a large portion of the budget. To be able to construct an autonomous ground vehicle on top of purchasing this equipment will be difficult. The budget laid out above accounts for these expenses. Another document, for purchase tracking, has been created that requires three team members check and approve purchases before going through. Due to each of these members having different responsibilities, there should be some level of analysis put on each purchase. This will hopefully reduce our costs.

7.6.3. Testing

The robot needs to be tested and validated. Dispensing paint on any grass field on or near CMU's campus will create issues. Demonstration of painting process is necessary for achieving the goals of the project, however, using real paint creates an issue. By dispensing shaving cream instead of paint, there should be no problem. Shaving cream washes off immediately with no harm to the environment and if left, it will evaporate. The product used in the world cup by the referees is essentially shaving cream and due to costs concerns, the latter will be the better option.

7.6.4. Team

The team consists of young inexperienced engineers. While some robotics development experience has been acquired by various team members, the overall ability of the team to construct a working robotic prototype is low due to limited past experience. However, with the help of strong mentors and guidance of professors, this project will be feasible.

7.6.5. Time

In most cases, an engineering project of this scale would not be expected to have a working prototype in less than 4 months. This document exists to solve that problem. Careful consideration of the schedule has been made and can be seen above. Also, strong efforts will be made in order to adhere to this timeline.

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