Kuwait University
College of Engineering and Petroleum
Mechanical Engineering Department
ME484/1A – Industrial Safety & Loss Prevention

Automated Farming

Capstone Report

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January 30th, 2022

Abstract

Automated farming was targeted for the roots in has in sustainability and self-sufficient systems, the numbers have shown that self-sufficiency in agriculture is a problem worth solving in Kuwait and the world. Awareness is increasing and it's driving the demand for sustainable solutions which was validated with market research. A collaboration with a company that builds autonomous agricultural robots, Farmbot, forms the base for this project where the feasibility of the product is studied for the region showing promising results of break-even period less than 3 years for the worst case. The weeding mechanism was switched from motors to efficient lasers with no moving components, which eliminated unwanted vibrations and power draws. The laser was evaluated by developing a totally separate weed detection and elimination method in MATLAB using smart vision systems and a 3D printer assembly. Components required for the Farmbot upgrade were designed, and prototypes were built and tested to confirm that the expected outcomes were achieved.

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Introduction

Agriculture, alternatively referred to as farming, is the process of growing and harvesting plants and animals in order to produce food, fiber, and animal feed. Numerous agricultural products are utilized on a daily basis, from clothes to bed sheets. Agriculture can be summrized into five words: farming, food, fabric, flowers, and forestry. The origins of agriculture can be traced all the way back to the Fertile Crescent, a region in the Middle East. This region encompasses the modern states of Syria, Lebanon, Palestine, Jordan, Egypt, Cyprus, Turkey, and Iran, as well as the northern region of Kuwait. Agriculture began in the Neolithic era, approximately 10000 BCE and tools were made of stone.

Figure 1: Ancient tools used in agriculture

Agriculture continued to evolve during which new methods and tools for cultivating crops were developed, including crop rotation, mechanical harvesters, steam-powered tractors, and gasoline-powered tractors. Another agricultural boom occurred in the 20th century, specifically in agriculture chemistry, which includes the application of chemical fertilizer, chemical insecticides, and soil composition. Agricultural development is one of the most effective strategies for eradicating extreme poverty and feeding the growing population. Agriculture is also critical for economic growth, accounting for 4% of global gross domestic product (GDP) in 2018. [2]

Kuwait faces three major challenges in agriculture: first, harsh climate conditions due to the country's dry climate and long, hot summers; second, limited natural water resources; and third, limited agricultural land due to 90 % of land being unsuitable for farming. Kuwait has a low reliance on subsistence agriculture. Additionally, Kuwait faces a high risk of food insecurity as a result of its lack of self-sufficiency and reliance on imported food, as Kuwait's crop production is limited and primarily consists of grain, potato, and vegetables. In order to tackle this problem Kuwait's Vision 2035 includes a goal of achieving food security by 2035 through sustainable agriculture and encouraging the private sector and foreign companies to invest in new agriculture technologies. As a result, Kuwait now has the largest indoor vertical farm in the Middle East, which was built by the german company &ever. [3]

Table 1: Development of consumption & self-sufficiency of main agriculture products from 2015 to 2019 [4]

Quantity in Ton — الكمية بالطن

Kinds		2019	2018	2017	2016	2015	النوع	
Fish	Local Prod.	2215	2433	2876	3886	2892	الانتاج المحلي	الأسماك
	Consumption	31758	30303	30664	27944	33385	المتاح للاستهلاك	
	Per Capita(kgm)	7.1	7.2	7.5	7.1	8.4	معدل نصيب الفرد (كجم)	
	Self Sufficient	7%	8%	9%	14%	9%	الاكتفاء الذاتي	
Shrimps	Local Prod.	666	698	1232	1646	1508	الانتاج المحلي	الروبيان
	Consumption	6439	7276	6469	6169	6307	المتاح للاستهلاك	
	Per Capita(kgm)	1.4	1.7	1.6	1.6	1.6	معدل نصيب الفرد (كجم)	
	Self Sufficient	10%	10%	19%	27%	24%	الاكتفاء الذاتي	
Fresh Veg.	Local Prod.	430227	354496	401113	332955	361096	الانتاج المحلي	الخضر الطازجة
	Consumption	1033773	816943	788561	745481	786994	المتاح للاستهلاك	
	Per Capita(kgm)	232	193	193	190	198	معدل نصيب الفرد (كجم)	
	Self Sufficient	42%	43%	51%	45%	46%	الاكتفاء الذاتي	
Green Fodder	Local Prod.	404545	385736	400601	331404	408145	الانتاج المحلي	أعلاف خضراء
	Consumption	635425	619909	654368	363285	451246	المتاح للاستهلاك	
	Self Sufficient	64%	62%	61%	91%	90%	الاكتفاء الذاتي	

The rapid change in the world and the realization of the scarcity of sustainability has skyrocketed the demand for sustainable, self-sufficient systems that humans can rely on to provide them with the most basic of needs and laying the first block of Maslow's hierarchy of needs which is the physiological needs block (air-water - food). This, combined with the high level of awareness and the appeal of high quality, non-GMO, and organic produce to most and if not all consumers. The team was confronted with this urge to develop a product that could satisfy a small portion of the above idea while utilizing their engineering skills. In this project, the team will thoroughly discuss the process from the day the seed was planted until the crops of hard work were harvested.

Mission Statement

The first step in developing any project especially when it is focused and the attempt of solving a real-life problem that can touch the lives of a great deal of people is to have a well-defined well written mission statement and use it to guide the efforts of the team towards the solution. The team went through the process of writing its mission statement in the initial phases and supported it with other information to help better shed the light on what is required and narrow their focus on the exact problem to solve for exactly the targeted user.

Title

Automated Farming

Product Description

Robotic farming machine allowing farmers to automate simple, repetitive tasks such as water plants, eliminating weeds, and planting seeds by using a simple interface, so they can focus more on the quality of their produce and their customer's experience

Benefit Proposition

- Easy to deploy one stop solution.
- Simple to interact with and manipulate.
- Affordable.
- Upgradeable, customizable, and open source.

Primary Market

Small-scale farmers and at home farmers.

Secondary Market

Hobbyists, enthusiasts, and research laboratories

Assumptions and Constraints

- Availability of materials (in Kuwait)
- Limited time and budget
- No lab/workshop access equipped with new technology
- Exposure to harsh weather/environment.
- Electrically powered components always require power (Batteries or hooked in)

Market Research

Before making any presuppositions, the team have decided to conduct thorough market research using the methods available to them. The team had the opportunity to interview people with some "skin in the game". The questions were quoted from the textbook of the course "Product Design and Development by Ulrich and Eppinger" to help minimize bias when writing the question. This exercise has provided the team with a substantial amount of information to use as the keystone for the development of the project and to assess the market needs. The raw data gathered from the customers is present below in the form of a question and answer.

When would you use this product?

Desire healthy/fresh/organic self-grown crops at home

Conducting research in labs or a personal experiment

Educational tool to satisfy most STEM objectives

Interesting project to work on and manage (enthusiasts)

Why would you use this product?

To automate farming/growing tasks such as

Water plants

Planting seeds

Eliminate weeds

Monitor the health of plants

Control the environment (greenhouse)

Supplement plant (health management through vitamins and pH)

Harvest crops

Typical session of using this product?

Phase 1: (Plan growing needs - purchase seeds - ask the device to plant)

Phase 2: (Device should plant seeds - the device should grow plants)

Phase 3: Device must harvest crops

Phase 4: Clean and prep growing area for new cycle

What do you like about this product?

Community-based

Automate some tasks

Easy to use

Efficient and reliable (time-saving)

No assembly requirement

What do you dislike about this product?

Not enough small-scale options in the market

Most available solutions offer a single automation

Complexity of repairs & troubleshooting

Expensive to acquire

Small-scale has a very limited growing area

Limited crops variety in available solutions

What issues do you consider when purchasing the product?

Price to acquire and fix

Ease of fixing and troubleshooting

Range of crops (types)

What is it automating (what tasks)

Ease of use and setup

Growing space/area

Indoor and outdoor capability

Is there a community built around the product?

Reliability

What improvements would you make to existing products?

Automate multi-tasks

Upgradable

Custom-sized growing area

Easy to repair

The answers to the previous questions provided the team with the customer and market needs. They gave them an idea about the desired product which must contain the crucial needs. Most of the existing products are expensive to acquire, complex to use & repair, small scale, limited type of crops, and not more than one automated task. This showed that there is a shortage in the market of products that can do more than one automated tasks such as planting the seeds, watering the plants, monitoring the plants health, detecting the weeds, etc. and it can be solved by having a multitasking automated device. The complexity of use and repair can be solved by having a simple interface, useful technical manual, and a community base. The product suppose to fit in a customizable growing area that contain multiple types of crops. The farming device or machine can be built using reasonably reliable materials to have a less expensive product. Achieving the previous needs help with having a healthy and fresh self growing-crops, educational purposes, conducting researches in labs, and working in interesing projects.

Product Specifications

Customer Requirements and Importance

To make use of the customer, the customer needs previously gathered in the initial market research stage must first be interpreted into semi-technical terms where the team can use to base their design and functionality. After the interpretation of the needs, it is also required to assign an importance rating for each of the interpreted customers' needs to help the team decide what needs they answer in their first iteration or so-called their minimum viable product. The interpreted needs with their respective importance rating (1 lowest & 5 is highest) are represented in the following table.

Table 2: Interpreted customer needs and their importance ratings

No.	Interpreted Customer Need	Imp.
1.	No permanent fasteners	5
2.	Use standard parts that are easy to find and are av. for DIYer and enthusiasts	5
3.	Detect when plants need to be watered	5
4.	Detect when weeds emerge	5
5.	Measure relative humidity	3
6.	Measure pH level of soil	2
7.	Detect when crops are ready for harvest	1
8.	Quality materials	5
9.	Can be controlled by the regular farmer/person	5
10.	Commonly used components	4
11.	Re-assemble	5
12.	Open source	3
13.	Water plants	5
14.	Measure temp	3
15.	Monitor health of plant	5
16.	Harvest crops	1

17.	Tasks have a small no. of steps to be completed	4
18.	Kill Weeds	5
19.	Mobile application	4
20.	Humidity regulation	3
21.	A supplementary system with delivery	2
22.	Controllable light system (simulate sun)	3
23.	Temp control system (with vent.)	3

From the previous table, the top 10 needs based on their importance can be summarized in the following list:

- No permanent fasteners with easy to find spare parts
- Detect when plants need to be watered and water them
- Detect the emergence of weeds and eliminate them
- Quality materials
- Can be controlled by the regular farmer/person
- Re-assemble-able
- Monitor health of plants

This list gives an indication of what the targeted customer is looking for which offers insight into what features the system must have to be considered a minimum viable product, nevertheless, other needs should also be taken into account as this rating is subjective and when the time comes for the customer to pay its a completely different scenario, thus; the team must take into account not just the needs they think they need at the current time and consider how to build a product that can help pivot their life to a better place. This level of depth is not required by the team, but it would be nice to consider, making the other needs open for debate whether to be included or not which will be due to cost-benefit analysis as this project has a strict deadline.

List of Metrics

The customer needs must also be interpreted to technical terms for them to be measurable. Identifying the metrics for each need and assigning a unit to it will not just help in the understanding of the needs but will also pave the path for the upcoming steps where the team must benchmark their proposed solution against other currently existing alternatives in the market. The metrics and units are available in the following table.

Table 3:Metrics and needs

No.	Interpreted Customer Needs No	Metric	Imp.	Units
1	1,2,10,11,12	Generic screws, fasteners, parts (widely av.)	5	*List*
2	3,4,7,14,15,19	Smart vision system	5	*Binary*
3	2,10	Number of places the items are accessible	4	*List and Count*
4	18	Min. avg. radius of weed	3	*mm*
5	18	Max. avg. radius of weed	3	*mm*
6	18	Accuracy of targeting	4	*mm*
7	5	Accuracy of measurement (RH)	3	*% Error*
8	5	Resolution of measurement (RH)	3	*%*
9	5	Range of measurement (RH)	3	*%*
10	6	Range of measurement (PH)	4	*PH (unitless)*
11	6	Accuracy of measurement (PH)	4	*PH (unitless)*
12	6	Resolution of measurement (PH)	4	*PH (unitless)*
13	8	Life	5	*Years*
14	13	Accuracy & precision of watering	5	*%*
15	13	Min. radius of watering (plant)	1	*mm*
16	13	Max. radius of watering (plant)	4	*mm*
17	13	Nozzle exit pressure	4	*kPa*
18	13	Resolution of amount of water released	4	*mL/s*
19	14	Resolution of measurement	3	*C*
20	14	Range of measurement	3	*C*
21	14	Accuracy and precision of measurement	3	*%*
22	17	Avg. no. of steps for each task	3	*no. of steps*
23	3	Accuracy and precision of detection	5	*%*
24	4	Accuracy and precision of detection	5	*%*
25	7	Accuracy and precision of detection	5	*%*
26	9	No. of steps to set up	4	*No. of steps*
27	9	Ease of setup	4	*Custom rating*

28	9	Ease of use	4	*Custom rating*
29	9	Ease of troubleshooting	4	*Custom rating*
30	16	Types of crops that can be harvested	2	List
31	16	Crops storage area	1	m^3
32	21	No. of supplement type that can be stored	3	*Count*
33	21	Amount of supplement that can be stored	2	*L*
34	21	Exit pressure of supplement delivery system	2	*kPa*
35	20	Resolution of control (level of humidity)	3	*%*
36	20	Time to change 1% of rel. humidity per m3	3	S/m^3
37	22	power rating of system	3	*Watt*
38	22	% of the area covered	3	*%*
39	22	Wavelength range	5	*nm*
40	23	Resolution of control (level of temp.)	3	*C*
41	23	Time to change temp. 1C (heating)	2	*min.*
42	23	Time to change temp. 1C (cooling)	2	*min.*
43	19	Can be controlled by mobile/computer	4	*Binary*

The first column of the previous table shows the number of the metric, the following column represents the number of the needs related to that specific metric which can be used to cross-reference with the former needs table. The third column shows the metric itself followed by its importance in the next column, and finally, the unit for each metric can be found in the last column.

Needs-Metrics Matrix

Using the previously mentioned information, the interpreted needs and the metrics assigned to them the team was able to build a needs-metrics matrix which is a base for the house of quality which is to be built in the upcoming stages of the project. The needs-metrics matrix is presented in the following figure.

No.	Need	1 Generic Screws,Fastners,Parts (Widely Av.)	2 Smart Vision System	3 Number of places the items are accessible	4 Min Avg. Radius of weed	5 Max Avg. Radius of weed	6 Accuracy of targeting	7 Accuracy of measurement (RH)	8 Resolution of measurement (RH)	9 Range of measurement (RH)	10 Range of measurement (PH)	11 Accuracy of measurement (PH)	12 Resolution of measurement (PH)	13 Life	14 Accuracy & Precision of watering	15 Min Radius of watering (plant)	16 Max Radius of watering (plant)	17 Nozzle exit pressure	18 Resolution of amount of water released	19 Resolution of measurement	20 Range of measurement	21 Accuracy and Precision of measurement	22 Avg no. of steps for each task
1	No permanent fasteners	✖																					
2	Easy to find spare parts	✖		✖																			
3	Detect when plants need to be watered		✖																				
4	Detect when weeds emerge		✖																				
5	Measure relative humidity							✖	✖	✖													
6	Measure pH level of soil										✖	✖	✖										
7	Detect when crops are ready for harvest		✖																				
8	Quality materials													✖									
9	Can be controlled by the regular farmer/person																						
10	Commonly used components	✖		✖																			
11	Re-assemblable	✖																					
12	Open source	✖																					
13	Water plants														✖	✖	✖	✖	✖				
14	Measure temp	✖																		✖	✖	✖	
15	Monitor health of plant	✖																					
16	Harvest Crops																						
17	Tasks have small no. of steps to be completed																						✖
18	Kill weeds				✖	✖	✖																
19	Mobile application																						
20	Humidity regulation																						
21	Supplement system with delivery																						
22	Controllable light system (Simulate sun)																						
23	Temp control system (with vent.)																						

No.	Need	23 Accuracy and Precision of detection	24 Accuracy and Precision of detection	25 Accuracy and Precision of detection	26 No. of steps to setup	27 Ease of setup	28 Ease of use	29 Ease of troubleshooting	30 Types of crops that can be harvested	31 Crops storage area	32 No. of supplement type that can be stored	33 Amount of supplement that can be stored	34 Exit pressire of supplement deliv. system	35 Resolution of control (level of humidity)	36 Time to change 1% of rel. humidity per m3	37 power rating of system	38 % of Area Covered	39 WaveLength Range	40 Resolution of control (level of Temp)	41 Time to change temp 1C (Heating)	42 Time to change temp 1C (cooling)	43 Can be controlled by mobile/computer
1	No permanent fasteners																					
2	Easy to find spare parts																					
3	Detect when plants need to be watered	✖																				
4	Detect when weeds emerge		✖																			
5	Measure relative humidity																					
6	Measure pH level of soil																					
7	Detect when crops are ready for harvest			✖																		
8	Quality materials																					
9	Can be controlled by the regular farmer/person				✖	✖	✖	✖														
10	Commonly used components																					
11	Re-assemblable																					
12	Open source																					
13	Water plants																					
14	Measure temp																					
15	Monitor health of plant																					
16	Harvest Crops								✖	✖												
17	Tasks have small no. of steps to be completed																					
18	Kill weeds																					
19	Mobile application																					✖
20	Humidity regulation													✖	✖							
21	Supplement system with delivery										✖	✖	✖									
22	Controllable light system (Simulate sun)															✖	✖	✖				
23	Temp control system (with vent.)																		✖	✖	✖	

Figure 2: Needs-Metrics Matrix

Target Specifications

The product specifications are objective, precise, and measurements of the product performance and by meeting the specifications, the product meets customer requirements as defined in the Textbook. In order to obtain the specifications, the customer needs were organized into a hierarchy and each need was assigned with an importance and a metric as it was shown in the presented information above.

The current target specifications are based on the components available in the market and/or the interpreted needs based on the understanding of the team members. The target specifications discussed below are not final and are subject to change after further market research is done. The change will be made with the objective of positioning the developed product in the area that allows for targeting the desired customer and keeping the costs as low as possible. The assumed target specifications are shown in table xx below with the justification (if any) for each one of them.

Table 4: Target specifications with justifications

No.	Units	Target Value	Further Justification
1	List	-	to be specified later
2	Binary	Yes	-
3	List and Count	-	to be specified later
4	mm	10 *mm*	Reducing the size will increase the complexity of the weed detection system, hence smaller diameter is not needed since the system will not be able to detect a weed before that
5	mm	50 *mm*	the device shouldn't allow for weeds to reach that size so the elimination criteria is smaller than that.
6	mm	5 *mm*	Because of the above-mentioned justifications
7	% Error	3%	Within industry standard for affordable and available components and no further accuracy is needed for the targeted customer
8	%	3 to 5%	No further accuracy is needed for the application as a small deviation wouldn't have a huge effect especially for the use case of the product
9	%	10% to 90%	Most plants are grown within this range. 10% cacti and 90% for pineapples (tropical)
10	PH (unitless)	0 to 14 (Standard)	This is an industry standard and it covers the entire range including the needed range
11	PH (unitless)	0.1	It covers the needs of the application

12	PH (unitless)	0.1	This is the res. for most available meters, smaller res. are available but are not needed since the range of PH for most plants is between 5 to 7.5 (some may require higher or lower)
13	*years*	5 to 10 *years*	May differ later
14	*%*	75*%*	since all that is required to to water the area that the plant is in and the water will get soaked up and the plant can get it through its roots
15	*mm*	-	doesn't matter after further analysis
16	*mm*	1 *m*	to make sure the area of any plant is covered
17	*kPa*	65 to 200 *kPa*	to allow for the water to reach the desired location and not harm the plants when it is released-on top of it and this range is available domestically and, in most buildings, thus it might eliminate the need of a pump
18	*mL/s*	10 *mL/s*	this is to be controlled to not over/under water the plants - can't be decided now since it is related to the nozzle exit size
19	*C*	1 *C*	no further res. is required since all that is needed is to be within the range of the desired temperature and deviation by the amount of the desired value for the target wouldn't have a substantial effect for the use case of the device
20	*C*	0 to 60 *C*	Most plants (for the use of the device to be built can only be grown in that range)
21	*%*	1 to 3*%*	equipment is widely available and all that is needed is be in range of a required temperature
22	no. of steps	-	must be compared with other devices on the market (will be decided in the benchmarking process)
23	*%*	90*%*	this value needs to be high since it is somewhat harmful for the plant to not be watered when it is needed and for that to be repeated multiple times
24	*%*	90*%*	weeds will feed on the resources that are available for the main plants so they must be eliminated as soon as the emerge hence a high accuracy is required
25	*%*	70*%*	leaving a crop for a while before harvesting it would/shouldn't have a huge effect (even getting it before it is 100% ripe)
26	No. of steps	-	must be compared with other devices on the market (will be decided in the benchmarking process)
27	Custom rating	-	must be compared with other devices on the market (will be decided in the benchmarking process)
28	Custom rating	-	must be compared with other devices on the market (will be decided in the benchmarking process)
29	Custom rating	-	must be compared with other devices on the market (will be decided in the benchmarking process)
30	List	-	-
31	m^3	-	To be specified later
32	*Count*	4 to 6	since multiple supplements are usually needed - maybe the device can have an expansion kit
33	*L*	2 to 3 *L*	To allow for the storage of multiple types of supplements (different compartments adding up to 2 to 3L with 500ml for each)

34	*kPa*	65 to 200 *kPa*	Similar to water exit pressure
35	%	2% to 5%	all is required is to be within the range of the desired RH values
36	S/m^3	10 *min*	since the range needed shouldn't vary by too much and the existence for this system is just to maintain the required value (10 min) should be enough. it should also be able to completely change the number but can take longer times to setup if it requires to go from 10% to 80% for example
37	*Watt*	50 to 150 *Watt*	within the range of a small home appliance - excluding greenhouse env. control - in standby it should be as close as possible to 0
38	%	100%	Must cover the entire growing area to achieve the required effect of imitating the sun
39	*nm*	400-700 *nm*	This is the range of wavelength that replicate the sun
40	*C*	1 to 3 *C*	All that is needed is to be within the vicinity of the required growing temperature
41	min	15	Faster change is not required for the application
42	min	15	Faster change is not required for the application
43	Binary	Yes	Not needed

The first column in the previous table shows the number of the metric which can be used to find the metric for the previous metric table. The second and third columns show the unit and desired range/value for each metric, with the last column justifying the range/value. The table was presented in this format to not repeat the same information multiple times.

Project Plan

After the selection of the theme and the general idea of the project, the team attempted to employ a mix of the project planning techniques discussed in class by the instructor and other methods leading to the use of simple identification of milestones and tasks for each milestone. Then the team will use a Gantt chart to monitor the progress and make sure they are on track throughout the entire project. The team can also refer to the Gantt chart and adjust it based on any changes that occur.

The project was split into milestones as shown in the following tables:

Table 5:Project milestones

No.	Milestone	Start	End	Days
1	Team formation and theme selection	27-Oct-2021	8-Nov-2021	11
2	Market research and customer needs	13-Nov-2021	20-Nov-2021	7
3	Product specification and phase 1 report	21-Nov-2021	2-Dec-2021	11
4	Concept generation	24-Nov-2021	5-Dec-2021	11
5	Concept selection	6-Dec-2021	11-Dec-2021	5
6	Problem Identification & possible solutions	9-Dec-2021	18-Dec-2012	9
7	Design and Assembly	29-Dec-2021	6-Jan-2022	8
8	Fabrication (Coding prototype)	31-Dec-2021	27-Jan-2021	28
9	Final report and prototype delivery	22-Jan-2022	30-Jan-2021	8

Each milestone has multiple subtasks as mentioned has multiple tasks starting from the team formation and theme selection which start on 27-Oct-2021 and ending at the final report and prototype delivery which end on 30-Jan-2021. The detailed tasks list for all the milestones, and their dependencies on each other is listed and coded in the following tables.

Milestone 1: Team Formation and Theme Selection

Table 6: Team formation & theme selection millstone

Code	Deliverables Milestones	Dep.	Start	End	Days
A	Team formation	-	27-Oct-2021	27-Oct-2021	1
B	Select theme	A	28-Oct-2021	30-Oct-2021	3
C	Team evaluation	A	28-Oct-2021	28-Oct-2021	1
D	General Idea selection	B	30-Oct-2021	31-Oct-2021	2
E	Doctor idea approval	D	1-Nov-2021	2-Nov-2021	2
F	Letter of intent	D	3-Nov-2021	9-Nov-2021	7
G	Mission statement	D	3-Nov-2021	9-Nov-2021	7

Milestone 2: Market Research and Customer Needs

Table 7: Market research and customer needs milestone

Code	Deliverables Milestones	Dep.	Start	End	Days
H	Initial market research	F,G	13-Nov-2021	14-Nov-2021	2
I	Identify customer needs	H	15-Nov-2021	16-Nov-2021	2
J	Translate customer needs into needs hierarchy	I	17-Nov-2021	17-Nov-2021	1
K	Assign importance to needs	J	18-Nov-2021	19-Nov-2021	2
L	Assign metrics to customer needs	K	20-Nov-2021	20-Nov-2021	1

Milestone 3: Product Specifications and Phase I Completion

Table 8: Product specifications and phase I completion

Code	Deliverables Milestones	Dep.	Start	End	Days
M	Product target specifications	L	21-Nov-2021	23-Nov-2021	3
N	Build house of quality	L	21-Nov-2021	21-Nov-2021	1
O	Write phase 1 report	M,N	24-Nov-2021	1-Dec-2021	8
P	Create phase 1 presentation	M,N	24-Nov-2021	30-Nov-2021	7
Q	Phase 1 report (hand in)	O	2-Dec-2021	2-Dec-2021	1
R	Phase 1 presentation	P	1-Dec-2021	1-Dec-2021	1

Milestone 4: Concept Generation

Table 9: Concept generation milestone

Code	Deliverables Milestones	Dep.	Start	End	Days
S	Concept generation	M,N	24-Nov-2021	26-Nov-2021	3
T	Functional decomposition	M,N	24-Nov-2021	26-Nov-2021	3
U	Concept selection	S,T	27-Nov-2021	28-Nov-2021	2
V	Benchmark concepts/specifications	U	29-Nov-2021	2-Dec-2021	4
W	Narrow down concepts	V	3-Dec-2021	3-Dec-2021	1
X	Cost analysis for developed concepts	W	4-Dec-2021	5-Dec-2021	2

Milestone 5: Concept Selection

Table 10: Concept selection milestone

Code	Deliverables Milestones	Dep.	Start	End	Day
Y	Select final concept	X	6-Dec-2021	6-Dec-2021	1
Z	Establish final product specifications	Y	7-Dec-2021	7-Dec-2021	1
AA	Develop product architecture	Z	8-Dec-2021	9-Dec-2021	2
AB	Detailed cost analysis for selected concept	AA	10-Dec-2021	11-Dec-2021	2

Milestone 6: Problem identification and Possible Solutions

Table 11: Problem identification and possible solutions milestone

Code	Deliverables Milestones	Dep.	Start	End	Day
AC	Identify possible problems in the final concept	AB	11-Dec-2021	15-Dec-2021	5
AD	Proposed solution for problem	AC	15-Dec-2021	19-Dec-2021	5
AE	Phase 2 report	AD	19-Dec-2021	28-Dec-2021	10
AF	Phase 2 presentation	AE	28-Dec-2021	29-Dec-2021	2

Milestone 7: Design and Assembly

Table 12: Design and assembly milestone

Code	Deliverables Milestones	Dep	Start	End	Day
AG	Testing and validation of solution	AD	29-Dec-2021	31-Dec-2021	3
AJ	Prototype plan and approach	AG	31-Dec-2021	1-Jan-2022	2
AK	Purchase all required material for proof of concept and validation	AJ	1-Jan-2022	5-Jan-2022	5
AL	Prototype initial software and hardware testing and design	AK	5-Jan-2022	6-Jan-2022	2

Milestone 8: Fabrication (Coding Prototype)

Table 13: Fabrication milestone

Code	Deliverables Milestones	Dep.	Start	End	Day
AH	Required CAD models for solution	AG	31-Dec-2021	1-Jan-2022	2
AI	Fabricate final design for proposed solution	AH	1-Jan-2022	3-Jan-2022	3
AM	prototype fabrication and testing	AL	6-Jan-2022	20-Jan-2022	15
AN	Prototype troubleshooting and re-building (if needed)	AM	20-Jan-2022	21-Jan-2022	2
AO	prototype calibration and enhancement	AN	21-Jan-2022	22-Jan-2022	2

Milestone 9: Final Report and Prototype Delivery

Table 14: Final report and prototype delivery

Code	Deliverables Milestones	Dep.	Start	End	Days
AP	Write and deliver final report	AO	22-Jan-2022	27-Jan-2022	6
AQ	Write and deliver final presentation	AO	22-Jan-2022	27-Jan-2022	6
AR	Abstract	AP	27-Jan-2022	27-Jan-2022	1
AS	Poster	AP	27-Jan-2022	27-Jan-2022	1
AT	Build and deliver project website	AP	20-Jan-2022	29-Jan-2022	10
AU	Deliver Prototype	AO	27-Jan-2022	27-Jan-2022	1

Gantt chart

For each member to keep up with the tasks and deliver the project on time a Gantt chart was used to visualize the tasks to be used by the team members which is to be found on the following figure. Each milestone has a different color and a horizontal bar indicating the progress. A copy of the Gantt chart is available in the upcoming pages.

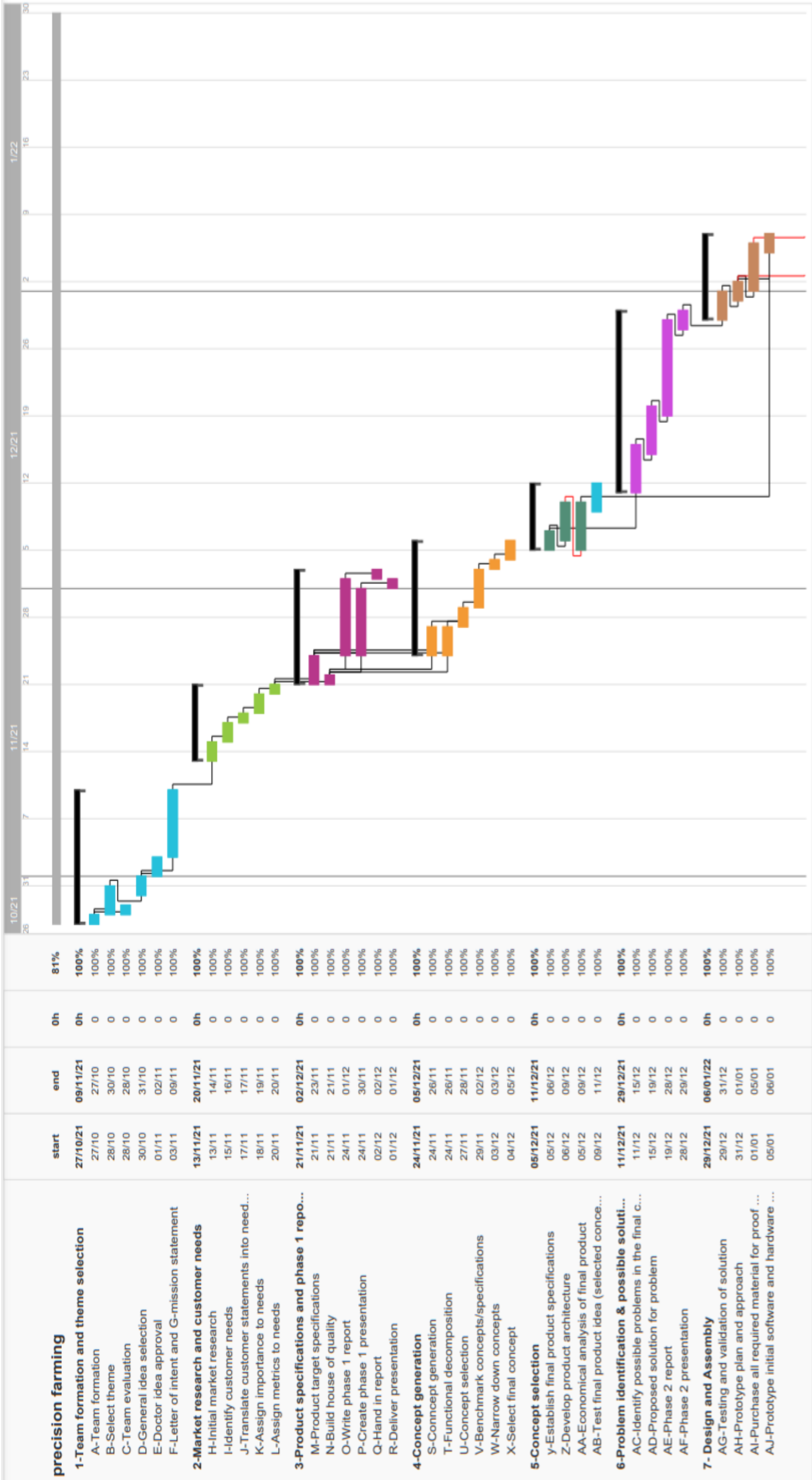


Figure 3: Gantt chart page 1

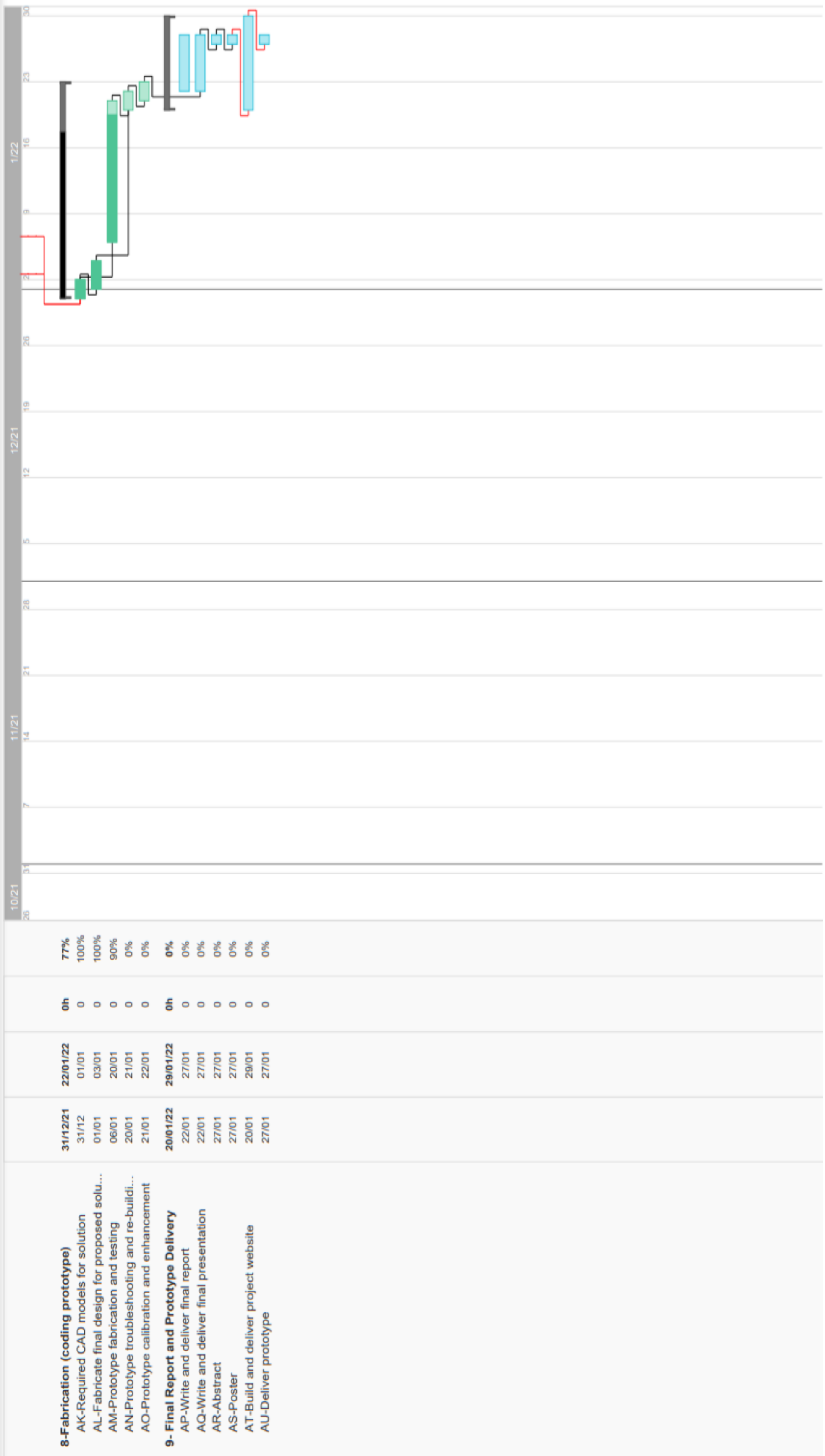


Figure 4: Gantt chart page 2

Concept Generation

Ideas

The team conducted extensive research on existing solutions in the market for both large- and small-scale applications when developing the concept for this project. After spending sufficient time independently researching solutions, the team decided to hold a meeting for a couple of brainstorming sessions during which they employed a variety of brainstorming strategies and concluded the series of brainstorming sessions with a set of concept sketches generated using the C-sketch method, as illustrated below.

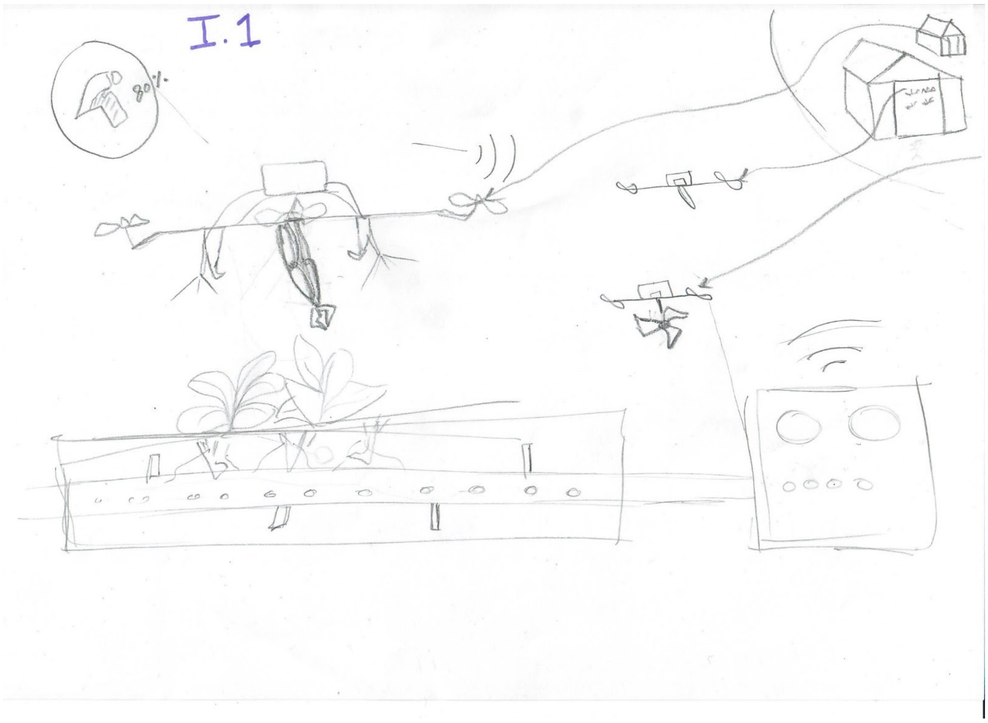


Figure 5: First generated concept (I1)

The concept presented in the figure above suggests the use of drones, each with specific functionality, and all drones are dispatched from a base. The drones are self-controlled and are connected with a detection system that is equipped with multiple sensors buried underground and a smart vision system. The main advantage of this system is the flexibility of the growing area as it is not bounded by a frame and the requirements are the same for a wide range of growing areas. The main problem with the system is the complexity of the autonomous drone system and the high possibility of failure combined with the difficulty of troubleshooting.

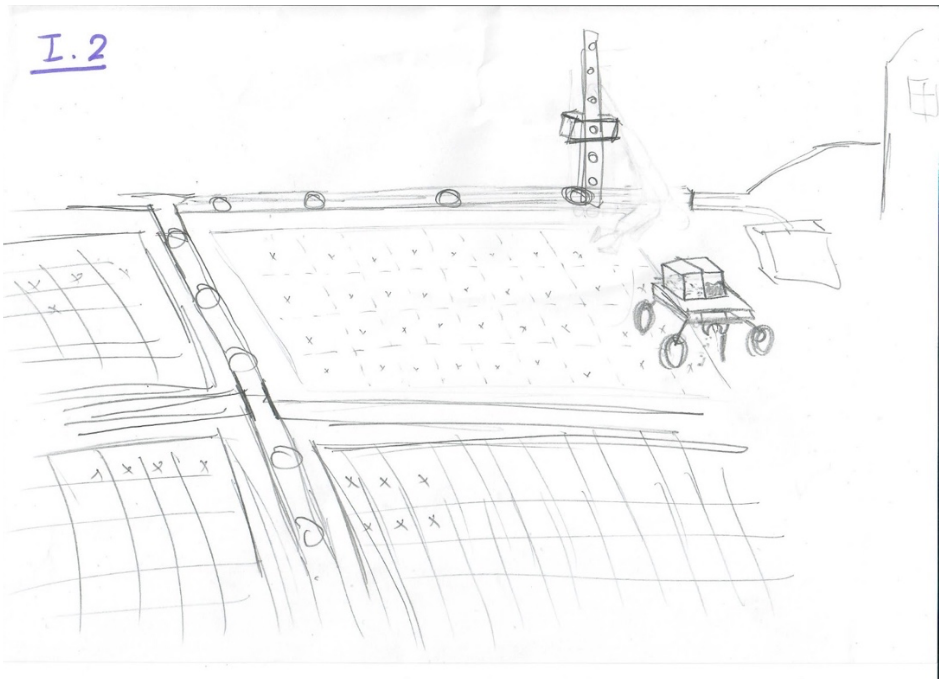


Figure 6: Second generated concept (I2)

The second generated concept proposes a rail system that goes around the growing area, and the rail system itself is the method of delivery for supplies. Mounting holes in fixed distances are present on the rails and an arm that moves on the rails and connects to the ports/holes is used to deliver the supplies from the storage area to the desired location. Supplies transported in the rail system can range from supplements to water and seeds. An advantage of this system is the simple components to be used in it and their availability in the market, with the main disadvantage being the limited growing area and the high number of parts.

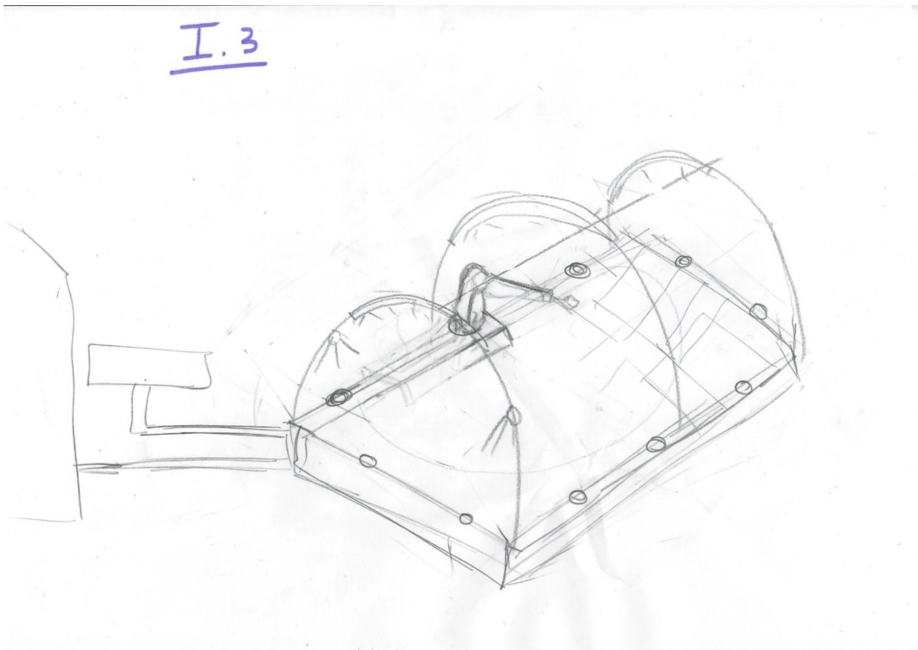


Figure 7: Third generated concept (I3)

The third developed concept suggests the use of a greenhouse as the mainframe with a railing system embedded inside of it similar to the one discussed in the previously proposed solution (I2). other than the rail system the greenhouse is equipped with climate control components which is a desired feature in the region due to the extreme weather conditions. The added benefit for this concept above what was earlier mentioned is the wide range of plants available for growing because of the greenhouse, which also introduces the limitation of the growing area and the required maintenance of the arm and rail system.

Figure 8: Fourth generated concept (I4)

The last generated concept proposes the use of a camera in combination with sensors buried in the ground as the input to the system with a system of pipes underground to deliver supplies and water to the plants. The camera and sensors will monitor the health of plants and growing stages. This system should be easily upgradable due to the simplicity of components used, the main disadvantage is the high pumpkin power required for the delivery of supplies and the difficulty associated with repairing and changing faulty sensors.

The concepts generated were discussed briefly to show the process used in the concept generation phase, all concepts have more depth than what is shown and mentioned, only the relevant information was mentioned. And the final selected concept is discussed thoroughly in the following stages of the report

The final selected concept

After numerous discussion sessions, the team has decided on a combination of Ideas 2 and 3, where it will be a frame system with a simple arm that moves alongside it and will be located inside a temperature-controlled greenhouse.

The system will meet the following specifications and include the following features:

- A greenhouse with lights and a camera attached to the ceiling
- The greenhouse with a fan to control airflow and temperature
- The greenhouse with a humidifier to control humidity
- The greenhouse with a rail system on the outside edge
- The module with an arm that is vertical when not in use
- A module carrying the arm that has a predetermined location for it to rest and connect to the valve/connection
- The tracks also serve as the delivery system for water and supplements
- The connection/valve on the track is how the water and supplements get from the tracks to the arm
- The arm is considered a rail that has a module connected to it with the necessary tools (Soil PH - soil temp - soil humidity - Solid health)
- A camera mounted on the green house's ceiling will monitor the emergence of weeds and plant growth, as well as determine when crops are ready for harvest.
- Automatically triggered lights on the ceiling will simulate sunlight and provide necessary exposure.

Functional Decomposition

Watering

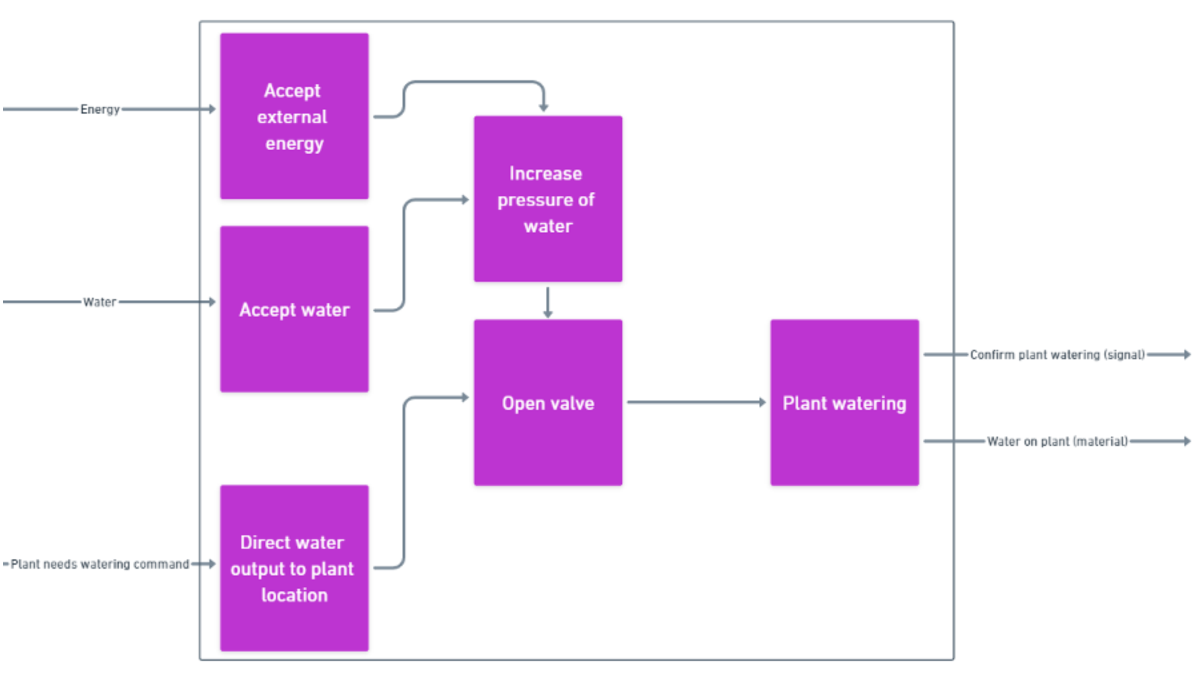


Figure 9: Functional decomposition for watering

This diagram illustrates the function decomposition for automatic plant watering. Three system inputs are required: energy in the form of electrical power, water in the form of a fluid, and a command informing the system that it is time to water the plants. The system has two outputs: water to be released on the plants and a signal confirming the plant watering process. When the energy input is accepted as external energy and used to increase the water pressure, the water input is accepted by the system, and the command indicating the plant's needs is accepted, the watering process is initiated.

The system will accept the water input and use the energy input to increase the pressure of the water, which will then wait at the end of a valve for the watering input command to release the water flow and accomplish the objective of watering the plants, triggering the output.

Weeding

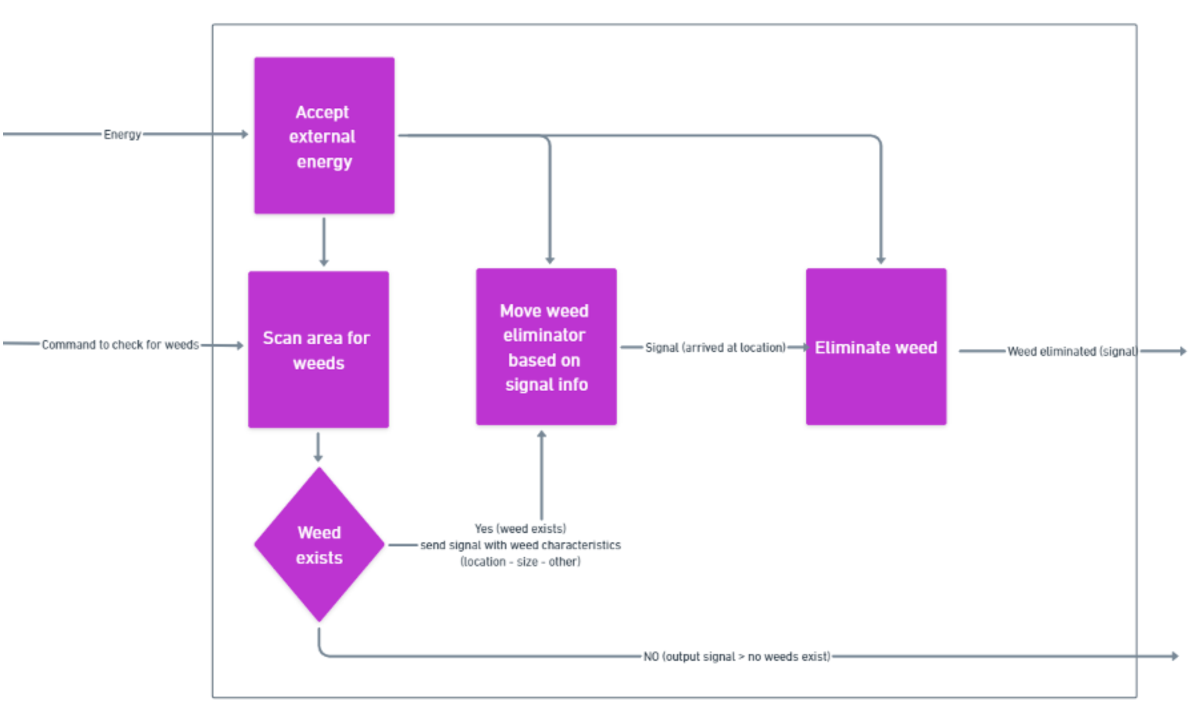


Figure 10: Function decomposition for weeding

The figure above illustrates the functional decomposition required for weeding. After receiving the command to check for weeds, the system uses electrical energy to scan the area and, if a weed is detected, the system moves the weeder in accordance with the weed's location and size. After that, the weeder will begin eradicating the weed and will signal when it is complete. In contrast, if the area is scanned and no weeds are detected, the system will transmit a signal indicating that no weeds were detected.

The weeding functional decomposition helped with choosing the mechanisms and techniques of the subsystems as follow:

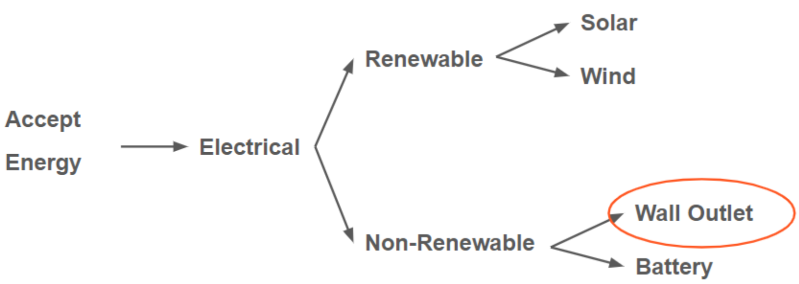


Figure 11: Classification tree for accepting energy

The figure above shows the classification tree for accepting the external energy. Answering the following questions were useful to choose the techniques:

- What kind of energy need to be saved?
- Is it a renewable power source or it doesn't matter?
- What kind of power source?

Results in choosing the wall outlet which is a non-renewable power source for electrical energy.

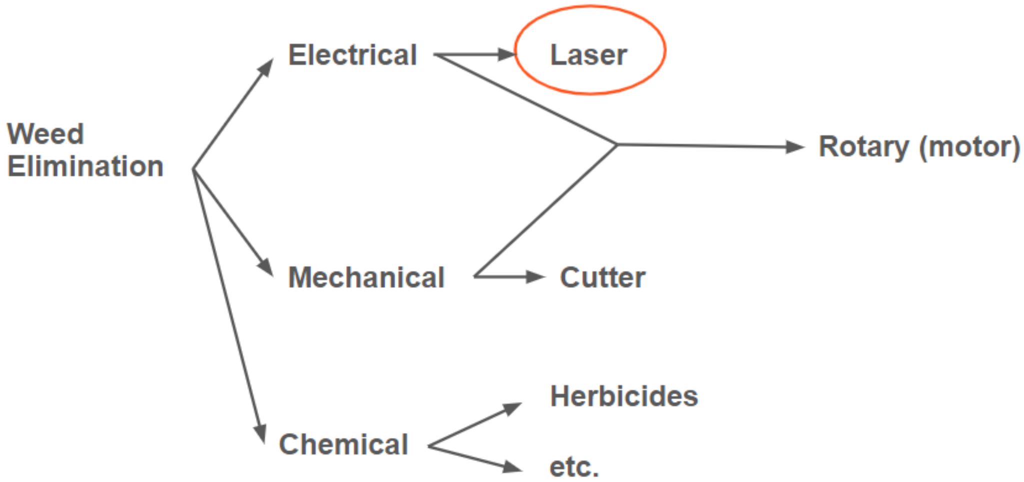


Figure 12: Classification tree for weed elimination

The figure above shows the classification tree for weed elimination. Answering the following questions was useful to choose the techniques:

- What are the techniques that can be used? Is it a combination of more than one?
- What tools can be used for each technique?

Result in choosing a laser which is an electrical tool capable of burning the weeds.

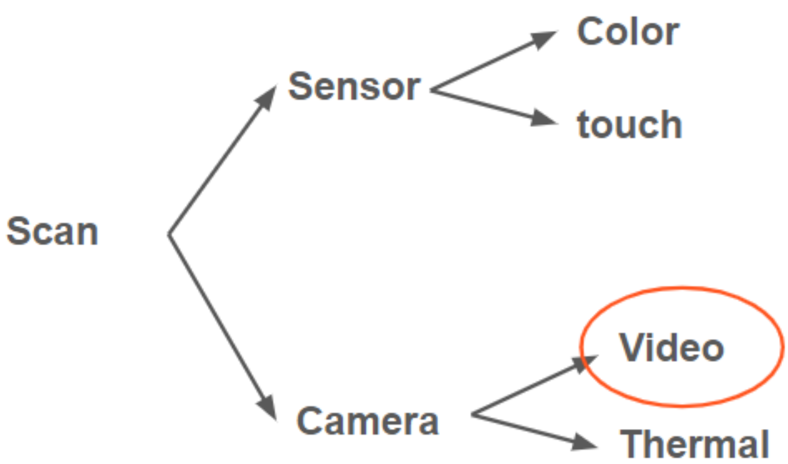


Figure 13: Classification tree for area scanning techniques

The figure above shows the classification tree for the area scanning techniques Answering the following questions were useful to choose the techniques:

- What kind of scanner needs to be used?
- What kind of scanning tool?
- How does the scanning tool work?

Result in choosing a regular video camera to scan the planting area and looks for weeds.

Seed Planting

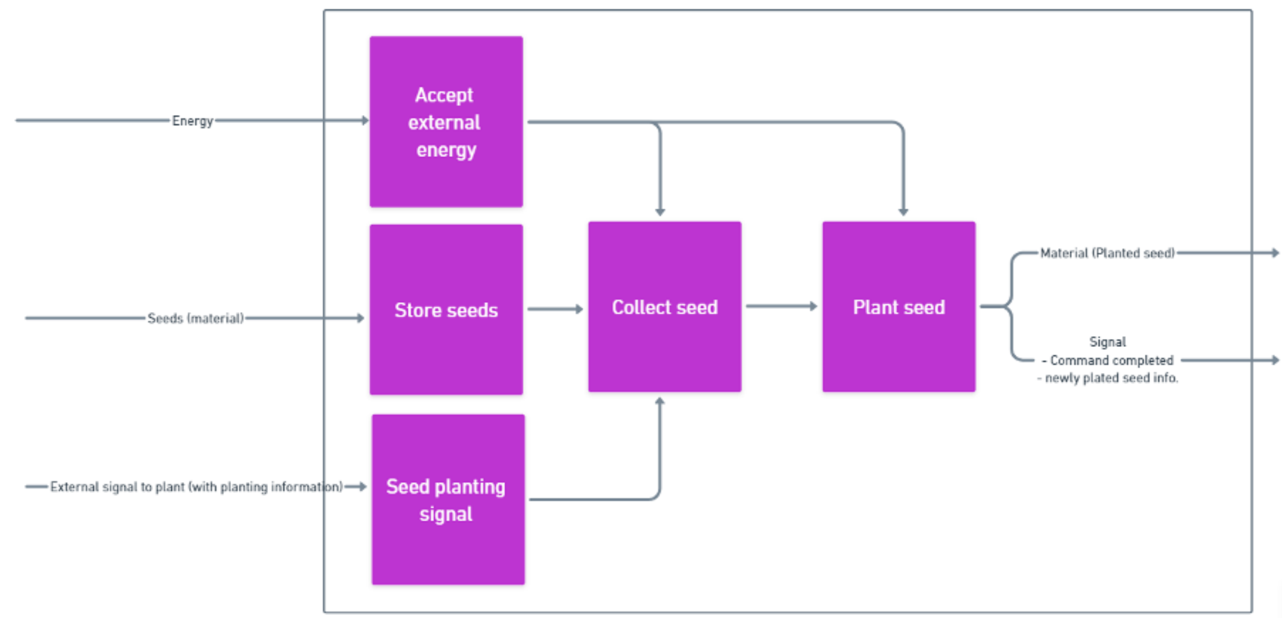


Figure 14: Functional decomposition for seed planting

This figure shows the functional decomposition for seed planting. The system has three inputs: energy in the form of electrical power to supply the system with the necessary power to perform the tasks, The seeds are used as the planting material, and a command is used to inform the system about the plants. The system has two outputs: the seed as the material pushed beneath the soil at the proper depth and a signal informing the system of the planting's completion and information. When external energy is accepted and used to power the seed collection and planting mechanisms, seeds are stored and planted, and the planting command is accepted to initiate the planting process, the inputs and outputs interact.

Supplement System

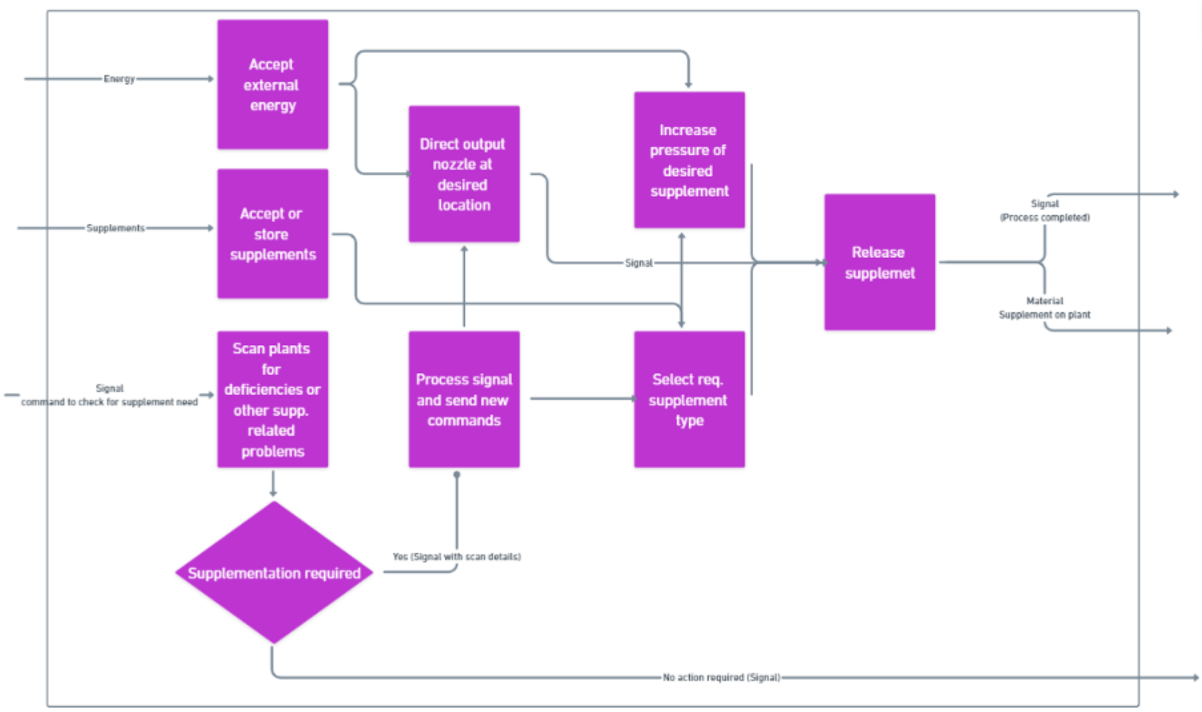


Figure 15: Functional decomposition for the supplement system

This figure shows the functional breakdown of the supplement system. The system will begin by scanning for deficiencies in the plants and storing the necessary supplements. The system will then send a signal indicating the location and type of supplement required if a deficiency is detected in a plant. Following that, it will direct the nozzle to the desired location and increase the supplement's pressure using electrical energy. This process results in the release of the supplement onto the plant, along with a signal indicating its presence. If no deficiency is detected, the system will send a signal indicating that the plant did not require additional nutrients.

Climate Control

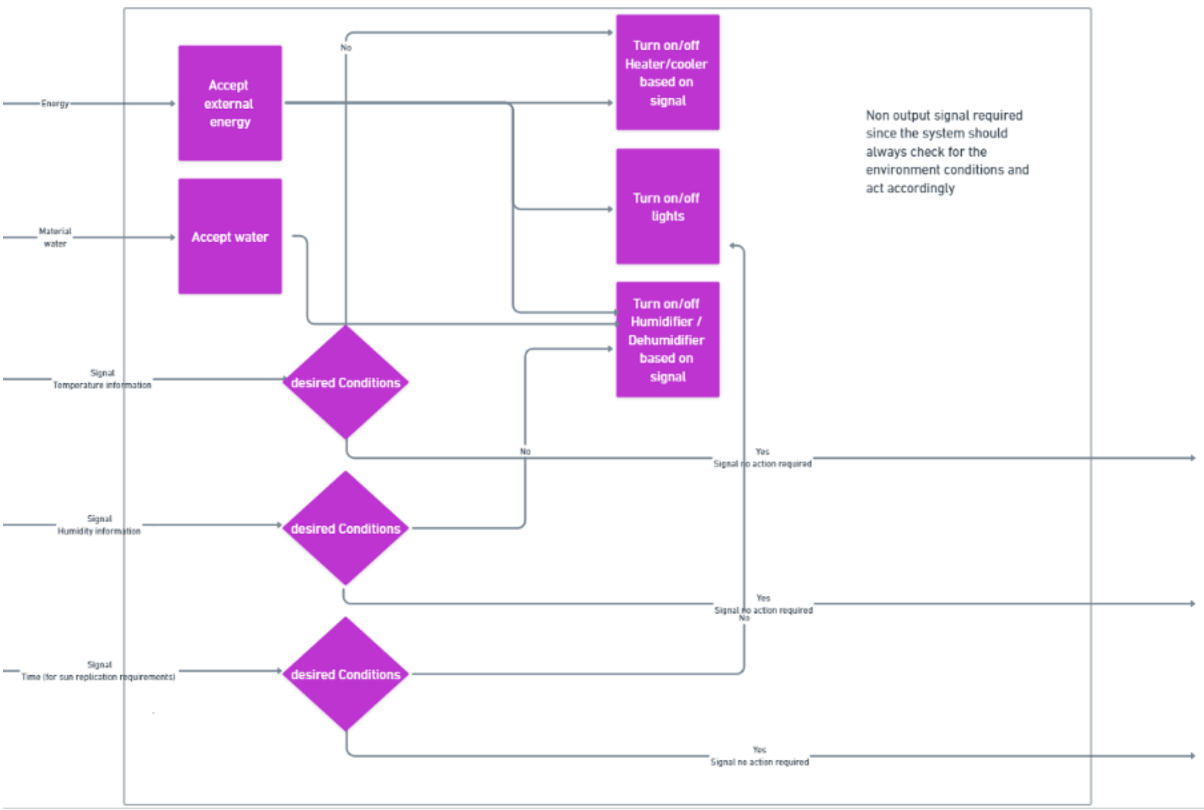


Figure 16: Functional decomposition for climate control

This is figure illustrates the functional decomposition for the climate control system. The system has five inputs: energy in the form of electrical power, water as the fluid, and three signals that inform the system about the temperature, humidity, and time. The system produces no outputs because it is constantly monitoring the climate conditions. The system is designed to accept ally electrical energy, and distribute it to the conditioning devices. Accept the water and use it to humidify or dehumidify the surrounding environment. The system will determine whether the current climate conditions are desirable or not and will turn on/off the conditioning devices accordingly.

Harvesting

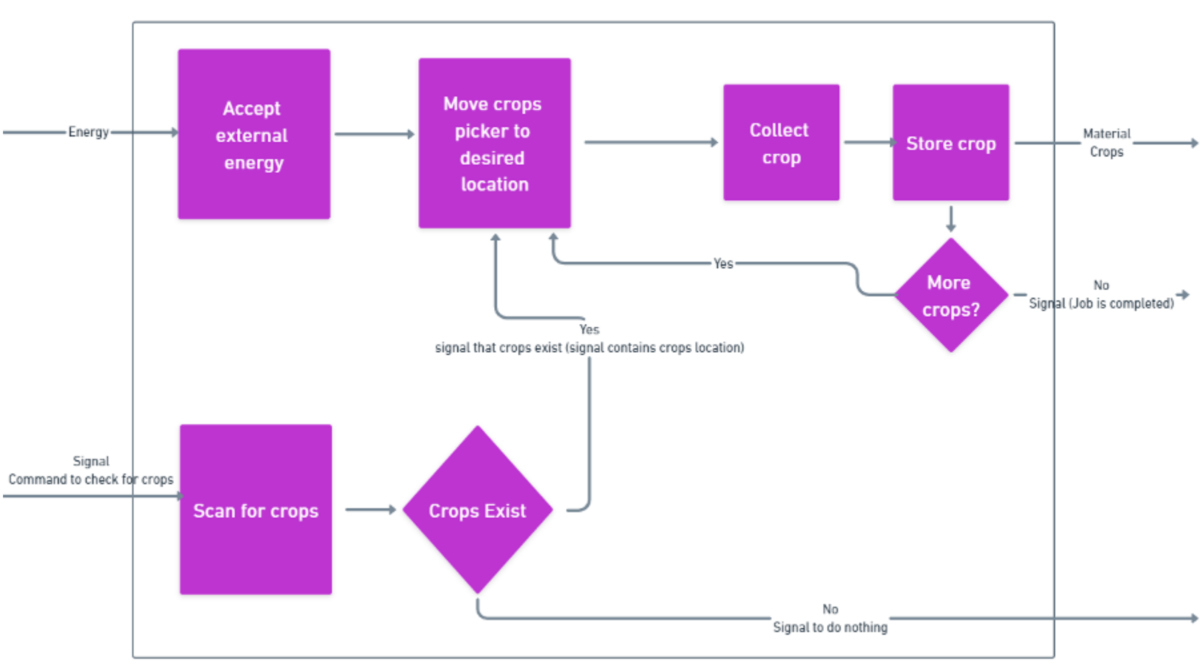


Figure 17: Functional decomposition for harvesting

This is the harvesting system's functional decomposition. The system will begin scanning the area immediately for crops that require harvesting. If crops are detected, the system transmits a signal to the picker indicating their location, which the picker then moves to using electrical energy. The picker will then collect the crops and determine if additional crops need to be harvested or stored. If, on the other hand, the system detects that the crops are still growing, it will send a signal indicating that no further action is required.

Concept Selection

In this section of the report the team will demonstrate the various methods used to select the final concept, and the different studies/analyses conducted. First, the report will show benchmarking of multiple concepts to validate the targeted specifications and their availability in the market, where the team has selected a total of 6 concepts that are mentioned below in detail to compare with one another. The team has made the decision to include both large-scale and small-scale options due to the lack of small-scale solutions in the market.

Concept benchmarking and other concepts

The products chosen for comparison are mentioned below with a description for each one of them.

Concept 1 Tertill

Tertill is a solar-powered weeding robot that looks for weeds every day. It has a solar panel placed on the top and provides it with all the power needed to detect the weeds within an area of (200 [ft^2], 18.6 [m^2]). There are two techniques to prevent the weeds from growing in the planting area. The first technique uses a weed whacker that cuts the weed depending on the plant's height and it will cut all the plants below half-inch height. The second technique is preventing the weeds from growing during their vulnerable stages by moving the soils repeatedly around them using its wheels. The device uses a touch panel with a good sensitivity level to detect the actual plants and to prevent running into them. The body of the device is made of polycarbonate which can stand through hot and cold climate conditions. There are some limitations to using the device correctly. The device might mistake a short plant for weed and to prevent that, each newly planted seed must be surrounded by a physical barrier longer than half-inch. The plants must be spaced a foot apart from each other for the device to move between them. The weed wacker should be replaced and it lasts for one or two months. The soil level should be balanced to have better performance and prevent the wheels from getting stuck. The device uses a lithium battery that can be charged and keeps the device working through the night. The devices cost 350$.

Figure 18: Concept 1 (Tertill)

Concept 2 Dino

Dino is an automated weeding machine for high scale farming. It uses deep learning to detect the plants, uses a real-time kinematic GPS, sensors, and cameras to navigate and scan the surroundings. It can count the plants and can-do crops mapping. It uses electricity to do the tasks and drive the four motors which are connected to the wheels. The machine covers about 40468.6 [m^2] per day. The price is expected to start from 50,000$ to 100,000$.

Figure 19: Concept 2 (Dino)

Concept 3 Farmbot

Farmbot Genesis is an open-source farming gantry system that can do multiple tasks such as watering, planting, health monitoring, weed detection, and weed elimination. It can do tasks in three dimensions which are the X, Y, and Z-axis. It needs to be connected to electricity around the clock to do its job all the time. The Genesis XL has dimensions of 3 [m] of gantry width and 6 [m] track length which results in 18 [m^2] of planting area. It can grow plants within the maximum height which is 0.5 [m]. Farmbot cost 4,995$ for the Genesis XL latest version.

Figure 20: Concept 3 (Farmbot)

Concept 4 AVO

AVO is a fully automated robot that is used to eradicate weeds. It is powered by solar panels and equipped with a lidar system that detects obstacles and people. AVO includes embedded software for treating a variety of crops. Additionally, it includes a mobile application that enables remote control. It consumes 95% fewer weedkillers than conventional methods. AVO is 750 kg in weight and uses an ultra-targeted spraying method with an accuracy of 8 x 3 cm to reach each plant. It can cover up to ten hectares per day.

Figure 21: Concept 4 (AVO)

Concept 5 MARS

MARS is a seed-planting mobile agriculture robot. It uses satellite navigation and cloud-based data management to track the location and planting time of each seed. Additionally, it employs an algorithm to determine the optimal path and time required to complete the task. MARS can operate in swarms of six to twelve units that cover an area of one hectare per hour. MARS electric motors have a rating of 400 W and consume 70% less energy than tractors. It is simple to assemble, compact in size, lightweight, and easy to maintain.

Figure 22: Concept 5 (MARS)

Concept 6 Argas T-16

The Argas T-16 is an automated agriculture drone used to water large areas of plants. It is equipped with a 16-liter tank, four delivery pumps, and eight sprinklers. The drone can cover ten hectares per hour. It is equipped with a radar system that utilizes digital beamforming technology to operate the drone at any time of day or night. Additionally, this technology scans the area for obstacles. The drone's control range is 3 kilometers. Under normal operating conditions, the Argas T-16 is dustproof, waterproof, and corrosion-resistant.

Figure 23: Concept 6 (Argas T-16)

Comparison between concepts

To compare the aforementioned concepts and products that are available the team has drawn up a concept selection matrix. The concept selection matrix is the resulting matrix from comparing multiple concepts with one another to help select the final design, in this process the team used available products in the market and benchmarked them with the list of customer needs generated in phase 1. Below the matrix is present, and the key for each needs to help in reading and understanding the table. In each column, a [+] represent a need being met with … better than the target specification, a [0] shows that either the product doesn't have the required feature or it can be upgraded to allow for the required feature, a [-] value indicated that the feature doesn't exist and in no way the product can allow for making it available.

Key for needs in the following table.

[1] No permanent fasteners.

[2] Use standard parts that are easy to find and are av. for DIYers and enthusiasts.

[3] Detect when plants need to be watered.

[4] Detect when weeds emerge.

[5] Measure relative humidity/soil moisture

[6] Measure pH level of the soil.

[7] Detect when crops are ready for harvest.

[8] Quality materials.

[9] Can be controlled by the regular farmer/person.

[10] Commonly used components.

[11] Re-assemblable.

[12] Open-source.

[13] Water plants.

[14] Measure temperature.

[15] Monitor the health of plants.

[16] Harvest crops.

[17] Tasks have a small number of steps to be completed.

[18] Kill Weeds.

[19] Mobile application.

[20] Humidity regulation.

[21] Supplement System with delivery.

[22] Controllable light system (Simulate sun).

[23] Temp control system (with vent.).

[24] Plant seeds.

Table 15: Concept selection matrix

Key	Imp	Tertill	Dino	Farmbot	AVO	MARS	Argas T16
1	5	[+]	[-]	[+]	[-]	[+]	[+]
2	5	[0]	[-]	[+]	[-]	[0]	[+]
3	5	[-]	[-]	[+]	[-]	[-]	[+]
4	5	[+]	[+]	[+]	[+]	[-]	[-]
5	3	[-]	[-]	[+]	[-]	[-]	[-]
6	2	[-]	[-]	[-]	[-]	[-]	[-]
7	1	[-]	[-]	[0]	[-]	[-]	[-]
8	5	[0]	[+]	[+]	[+]	[0]	[+]
9	5	[+]	[+]	[+]	[+]	[+]	[+]
10	4	[-]	[-]	[+]	[-]	[-]	[-]
11	5	[+]	[0]	[0]	[0]	[+]	[0]
12	3	[-]	[-]	[+]	[-]	[-]	[-]
13	5	[-]	[-]	[+]	[-]	[-]	[+]
14	3	[-]	[0]	[+]	[0]	[-]	[+]
15	5	[0]	[0]	[+]	[0]	[0]	[+]
16	1	[-]	[-]	[-]	[-]	[-]	[-]
17	4	[0]	[0]	[0]	[0]	[0]	[0]
18	5	[+]	[+]	[+]	[+]	[-]	[-]
19	4	[+]	[-]	[+]	[+]	[+]	[+]
20	3	[-]	[-]	[-]	[-]	[-]	[-]
21	2	[-]	[0]	[0]	[0]	[-]	[0]
22	3	[-]	[-]	[0]	[-]	[-]	[-]
23	3	[-]	[-]	[0]	[-]	[-]	[-]
24	5	[-]	[0]	[+]	[0]	[+]	[-]
Sum +		6	4	15	5	5	9
Sum -		-14	-14	-3	-13	-15	-12
Sum 0		4	6	6	6	4	3
Net Score		-8	-10	12	-8	-10	-3
Rank		3	5	1	3	5	2

The table above shows the results for the selection matrix, as it is seen that most of the products have a net score of (-) and this is due to the reason that the customer needs were generated with the targeted customer being small scale and home farmers, and as it was mentioned in the phase 1 report that the majority of the available products in the market serves the large scale farming industry with no regards to the small sale consumer, and since the target is the small scale farmer, purchasing multiple devices to automate multiple tasks is not feasible. Making the decision to go with Farmbot as the starting point for development in this project is the obvious decision due to it meeting the required criteria and covering a wide range of the desired customer needs.

Selection of Final Concept

After Reviewing multiple concepts and extensive research conducted for the previously mentioned products that are available in the market. The team has selected the Farmbot product as the starting point for their development. This decision was made for various reasons with the primary factor - contributing to this decision-making process - being the fact that in the benchmarking table shown previously the Farmbot concept covers most of the required target specifications discussed in the phase 1 report. Other important reasons have also played a great role in making the decision and they are listed below.

Course and budget limitations

Unfortunately, the nature of this Capstone Design Course offers limited resources and a short timeline for the delivery of a proven and prototyped concept which in a way forces the team to settle with a simple or minor concept/problem to develop or fix. Thus, after looking at the various concepts discussed in the previous section from both budget and timeline perspectives the best decision was to select an already available concept in the market and direct the efforts of the team and their available resources to solve a problem with the existing concept or enhance its performance. For the limitations, the team has decided to select the Farmbot option shown previously.

Required experience and manufacturing capability

Fully developing a concept from the ground up to require a great deal of previous experience which the team has none. Also, the lack of workshops in Kuwait and on-campus in combination with the limited raw material available especially for prototyping poses a barrier in the face of development and manufacturing.

Other reasons

After contacting the manufacturer of Farmbot, the team was able to get crucial information about one of the mechanisms available in the product, which was the undesired weed wacking mechanism on the device (this will be discussed extensively later on), this mechanism introduced undesired vibrations to the system and had a fairly large minimum radius.

The team was also able to coordinate with the manufacturer of Farmbot to figure out a procedure to use their developed design and weeding mechanism to be added to the open-source Farmbot project, meaning that the development done in this course will be used in a real-life project that other people can use for no cost, this fact contributed greatly in the selection of Farmbot.

After further discussion with the people working on the Farmbot project it was decided that the team needs to do is develop a new weed eliminating mechanism thus it eliminated the cost of acquiring the full automated farming device, and now the team only needs to use minimal parts from the actual Farmbot device to make sure their developed concept is compliant with Farmbot and work on the integration from the newly developed concept side of things (will be discussed extensively).

The Selected Concept – Farmbot

Product Architecture

Farmbot offers a wide variety of options to select from when purchasing a farmbot device there are multiple decisions to consider, in the beginning the customer should deicide on the level of automation desired in the device as farmbot offers two main version which are the Farmbot Express and the Farmbot Genesis. The Farmbot Express offers a lower level of automation, it doesnt have x axis tracks as it it runs over the raised bed meaning the customer must make sure the surface would allow for such motion and it has less computing power, for the Genesis version of the Farmbot, it offers a higher level of automation where it is more a set it and forget it for most of the time type of device, and it has greater computing power. The farmbot Express is more suitable for the customer who is willing to have daily interaction with their Farmbot. The Genesis is more suitable for scale operations as the time required to upkeep the device is lower, but on the other hand it will require more knowledge in electronics and simple mechanics as it has more components thus more points of failure. After selecting the version of farmbot that is desired, then comes the other decision of deciding the growing are for each device. Both the Genesis and the Express have regular size version with a growing dimension of (1.5m x 3m) 4.5m2 and (1.2m x 3m) 3.6m2 respectively. For the XL version the Express offers a maximum growing are of (2.4m x 6m) 14.4m2 and the Genesis Xl has a growing area of (3m x 6m) 18m2. All farmbot devices can be modified for personal projects and different use cases, it can also be inside a greenhouse with a controller for environmental variables (seperate and not part of Farmbot products).

Details of the Farmbot product

For demonstration purposes and to meet the required customer needs the team has decided to analyze the advanced version of Farmbot, which is the newly released Genesis V1.6. (https://genesis.farm.bot/v1.6/assembly/intro)

Farmbot Genesis is the most sophisticated Farmbot model which comes with the most useful features and it is flexible since most of the parts can be replaced with new parts that can be useful to accomplish new tasks and functionalities. It can grow plants, protect them, and take care of them with the highest level of precision. The tools and the functionality of the device can be modified to run experiments which helps improve the agricultural industry. Genesis has two versions depending on the size of the device. One of the versions is called Genesis which has a gantry width of 1.5 [m] and track length of 3[m]. The other version is called Genesis XL which is larger, its gantry width is 3 [m], and its track length is 6 [m]. Both of the versions have a maximum plant height of 0.5 [m] and they are shown in the figure below.

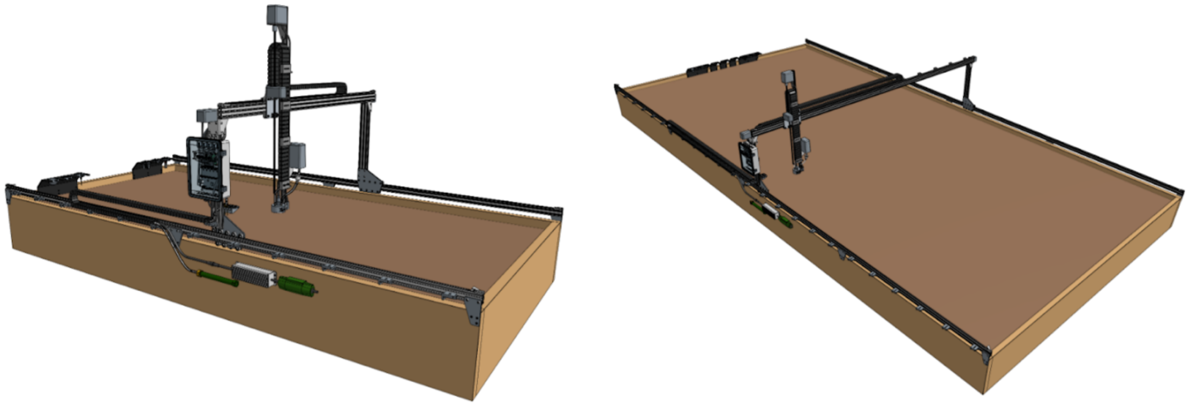


Figure 24: Assembled Farmbot Genesis V1.6

There are two ways to mount the device on the planting field. The first way is to mount it on a bed. There are two types of beds which are a fixed raised bed and mobile raised bed as shown in the figure below. Genesis requires a bed size of an outer width of 1.48 [m] and the recommended outer bed length is 3 [m]. Genesis XL requires a bed size of an outer width of 2.98 [m] and the recommended outer bed length is 6 [m]. The second way is to mount on wood posts and it is called pier block supports.

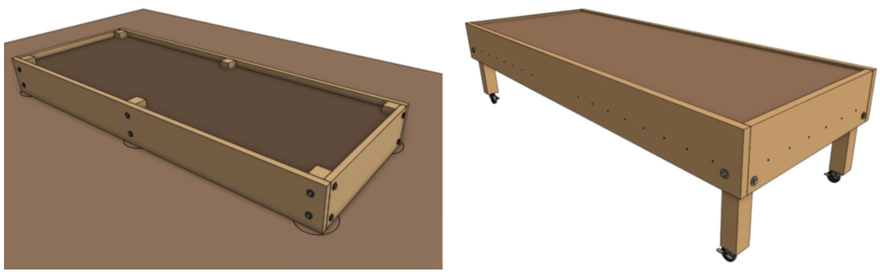


Figure 25: Farmbot mounting options

FarmBot Genesis V 1.6 uses two tracks to enable the gantry to move precisely along the x-axis. They are designed to be attached to a raised bed or other similar structure. Each track is made up of 1.5m-long aluminum extrusions that are connected end-to-end to create a 3m-long track for the Genesis model. By removing or adding a section of the aluminum extrusion, the tracks can be shortened or lengthened. According to the Farmbot website, assembling the tracks should take between two and twelve hours, depending on the size of the bed used. Plates are used to secure the tracks to the bed. Plates are classified into two types: track end plates and track joining plates. The track end plate is used to secure the start and end of the tracks to the bed, whereas the track joining plate is used to connect and secure the extrusions to the bed.

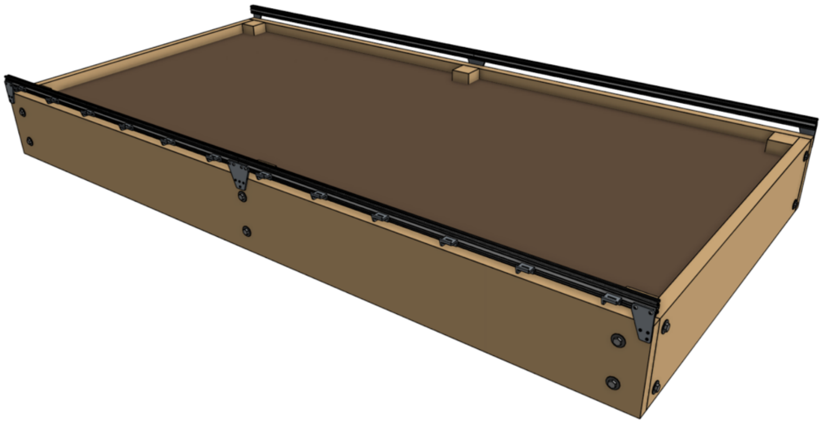


Figure 26: Farmbot 3D model assembly of tracks and plates

The figure shows the 3d model of the the whole assembly of the track and plates attached to the bed.

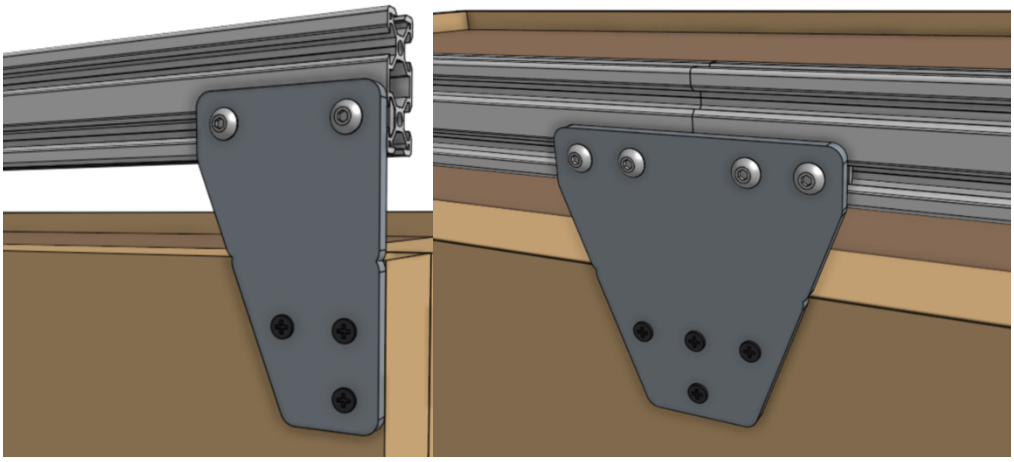


Figure 27: End and joining plates

The gantry acts as the y-axis for Farmbot and made of V-slot aluminum extrusion. The gantry is attached to the tracks by gantry wheel plates. Two motors are attached to each side of the gantry to allow it to move in the x-axis, the gantry is designed in this style where it is elevated above the bed level to minimise interference with any growing plants. The estimated time required to assemble the gantry is two hours.

Figure 28: Gantry and Z axis assembly

This figure shows Farmbot's z-axis, which is used to plant seeds, water plants, eliminate weeds, and monitor soil moisture using a universal tool mount. It is able to slide on the gantry using a cross-slide which shown in the figure below.

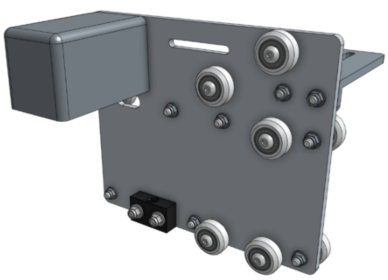


Figure 29: Farmbot cross slider

After assembling all of the parts mentioned above the completed model of the Farmbot Genesis V1.6 will look like the 3D mockup shown in the figure below.

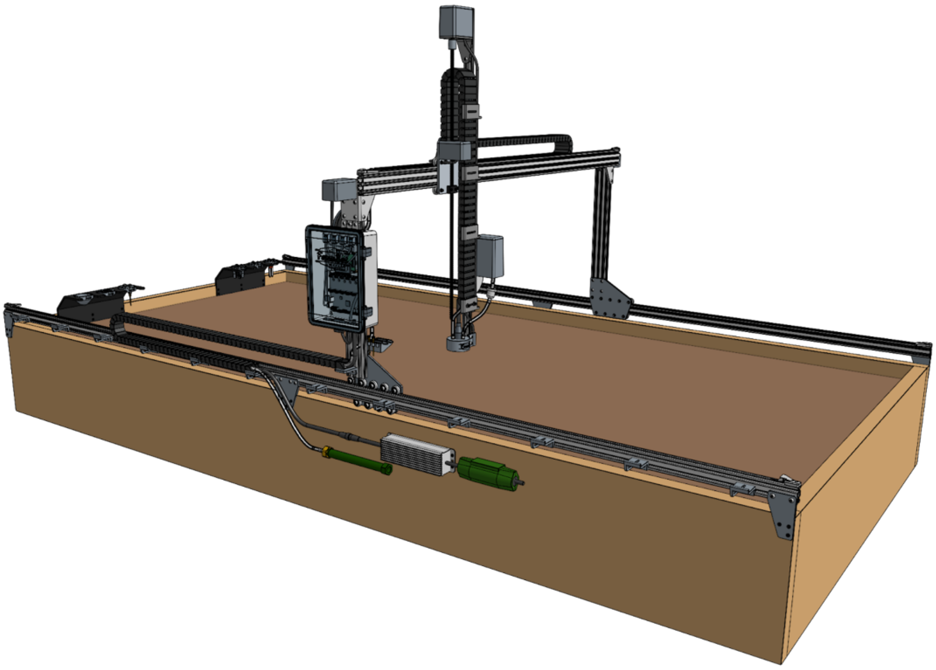


Figure 30: Assembled Farmbot Genesis V1.6

The figure above shows a picture of the 3D model of the completed device including all the parts. After connecting and assembling all the parts together, the final product should be a fully functioning device that can plant the seeds, water the plants, detect the weeds, eliminate the weeds, read the soil properties, and monitor the planting area along with the plants' health using a camera. The device uses a 3D printed mount called the universal tool mount which can be attached and connected to a tool using magnets. The universal mount shown in the figure below.

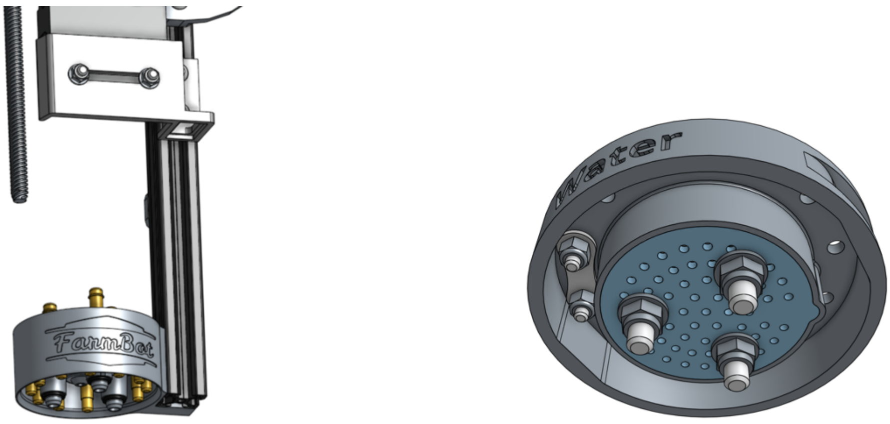


Figure 31: Watering UTM and nozzle

In order to water the plants the device will connect the universal tool mount with the watering tool which is the watering nozzle and it is shown in the figure below. The device has a pressure regulator to control the water output. Since it is an open source product the watering tool can be redesigned using its 3D model to change the water output.

Figure 32: Farmbot watering plant inside greenhouse

The figure above shows the water nozzle attached to the universal tool mount during the plants watering process. As shown in the figure the water stream has been defused using the water nozzle to prevent the plants from getting damaged from the concentrated water stream.

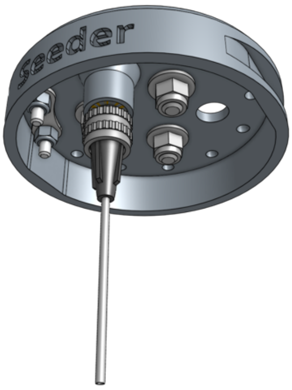


Figure 33: Farmbot seed injector

The figure above shows the seed planting tool which is called the seeder or the seed injector. The tool includes a needle that can be changed by the user depending on the seed's size. The concept is to use a vacuum pump to suction and hold the seed and inject it into the ground at the selected location. The device will go back and forth picking up the seeds from a cup or an external source and to the selected locations.

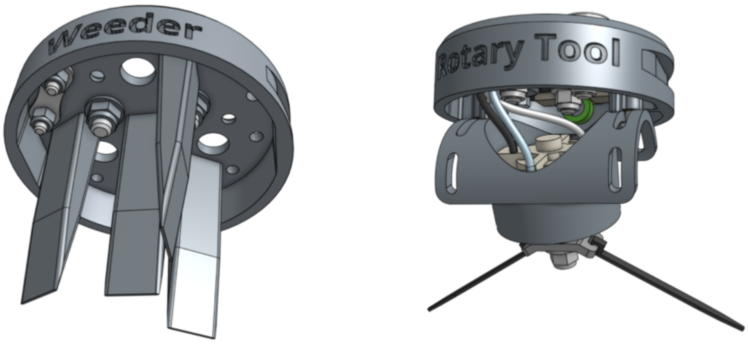


Figure 34: Farmbot weeders

The two tools shown above are the tools that have been used to kill the weeds in their vulnerable stages. One of the wedding tools is called the weeder which kills the weed by smashing and pushing them into the ground which prevent the weeds from growing. The other tool is called the rotary tool which has a DC motor and two blades to cut the weeds besides its other functions such as soil surface milling and an additional function which is 5 [mm] drilling which requires a drilling chuck.

Figure 35: Soil sensors

The figure above shows the soil sensor tool which helps getting an accurate reading for the soil properties. It has a moisture sensor that can measure the soil moisture which gives indications and information about the amount of water in the soil. The right side of the figure shows the soil sensor during the soil moisture measuring process.

Figure 36: Farmbot in action

The figure above shows an actual existing product. It shows the variety of crops that can be grown using the device (such as: spinach,beets, etc.) . The used device in the figure is the Genesis XL version 1.6 which is the latest version.

Farmbot is controlled by a custom microcontroller known as farmdunio. This microcontroller communicates via G-code with a Raspbery Pi. The stepper motors, universal tool mount, and other peripherals are controlled by Farmdunio. Additionally, it provides power to all electronic components. The Raspbery Pi, on the other hand, is in charge of tracking plants, taking photos, and controlling the push buttons. The electronic components are contained in a container referred to as the electronics box that is attached to the gantry. The figures below show the different components of the electronic box.

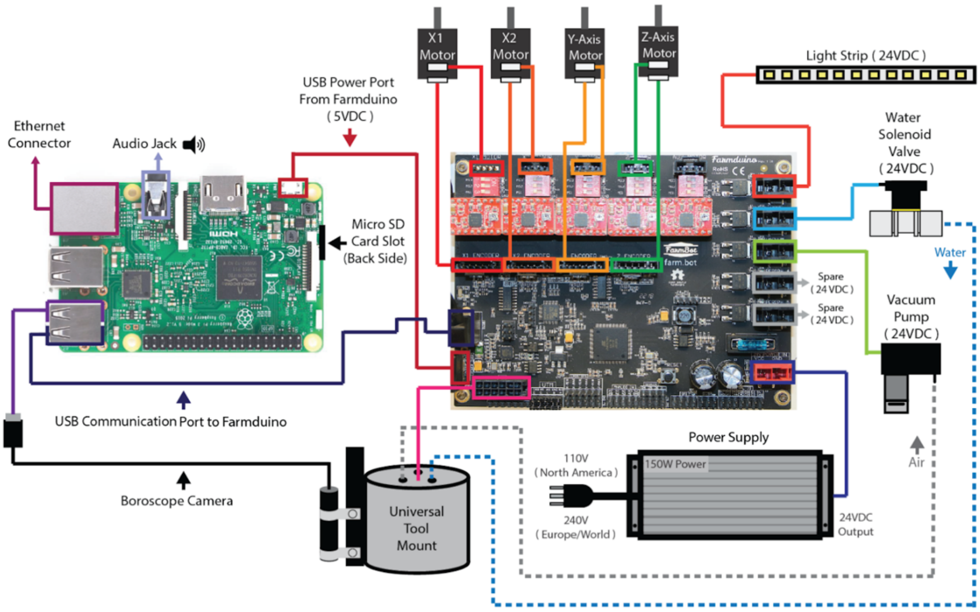


Figure 37: Farmbot circuit diagram

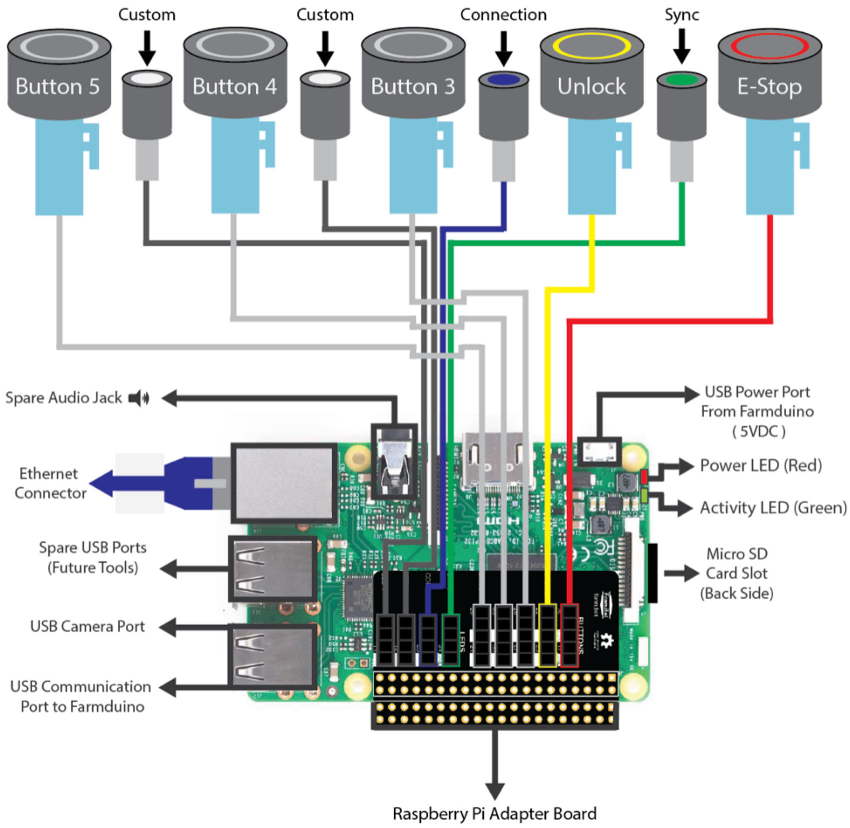


Figure 38: Farmbot Raspberry Pi connections

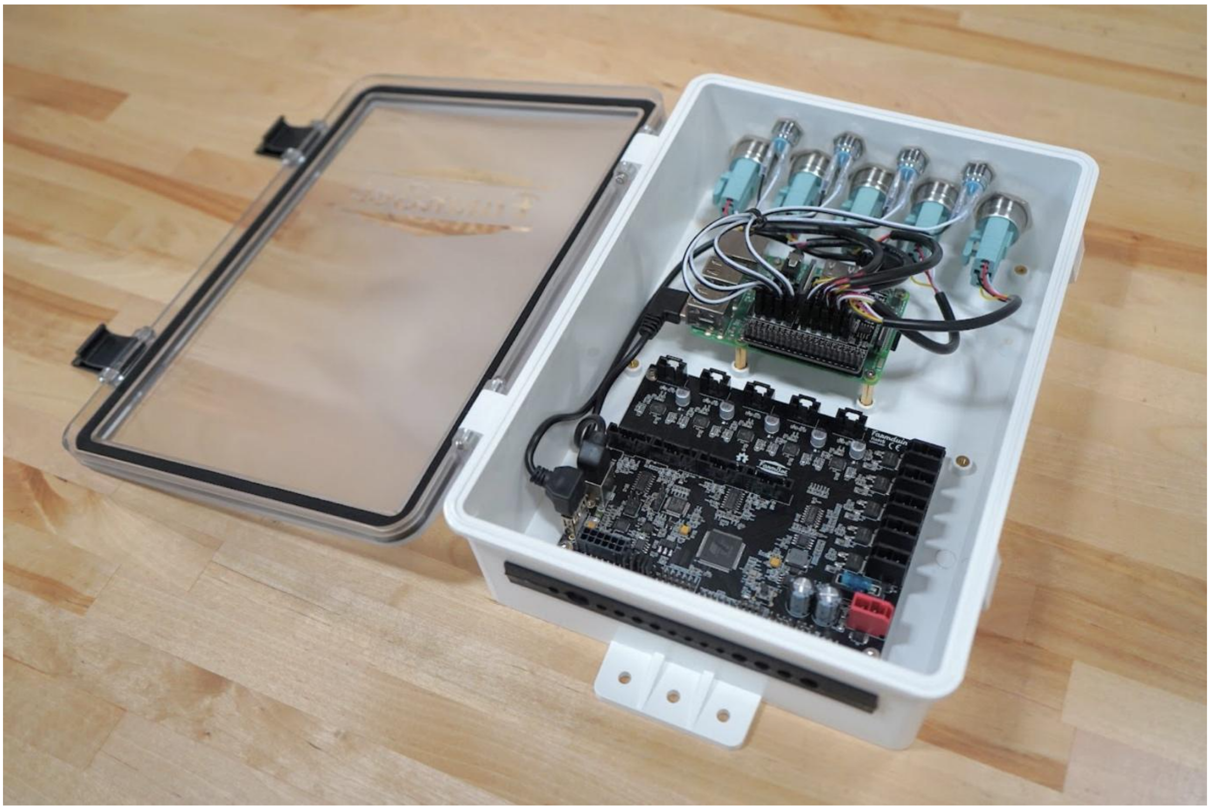


Figure 39: Fully assembled Farmbot electronic box

Bill of material

This tables below show the required quantity and the price of each component. It includes the extruisons, plates, brackets, plastic parts, fasteners, hardware, drive train, electronics, wiring, and tubing.

Extrusion:

Table 16: Extrusion bill of material

Item	$/Unit	Qty	Total
Track Extrusion	$30.00	4	$120.00
Gantry Column	$15.00	2	$30.00
Gantry Main Beam	$35.00	1	$35.00
Z-Axis Extrusion	$20.00	1	$20.00

Plated and Brackets:

Table 17: Plates and brackets bill of material

item	$/Unit	Qty	Total
Track End Plate	$12.00	4	$48.00
Track Joining Plate	$15.00	2	$30.00
Gantry Wheel Plate	$25.00	2	$50.00
Gantry Corner Bracket	$30.00	2	$60.00
Cross-Slide Plate	$25.00	1	$25.00
Z-Axis Motor Mount	$20.00	1	$20.00
3-Slot Toolbay	$40.00	2	$80.00
50mm Cable Carrier Mount	$8.00	1	$8.00
80mm Cable Carrier Mount	$10.00	1	$10.00
Belt Clip	$3.00	6	$18.00
Z-Axis Hardstop	$3.00	2	$6.00
Seed Trough Holder Mount	$5.00	1	$5.00

Plastic Parts:

Table 18: Plastic parts bill of material

Item	$/Unit	Qty	Total
40mm Horizontal Cable Carrier Support	$3.00	12	$36.00
60mm Horizontal Cable Carrier Support	$3.00	6	$18.00
60mm Vertical Cable Carrier Support	$3.00	4	$12.00
60mm Cable Carrier Spacer Block	$3.00	1	$3.00
75mm Horizontal Motor Housing	$10.00	3	$30.00
80mm Vertical Motor Housing	$12.00	1	$12.00
Camera Mount Half	$3.00	2	$6.00
Seeder	$7.00	1	$7.00
Seed Bin	$7.00	1	$7.00
Seed Tray	$7.00	2	$14.00
Seed Trough	$3.00	2	$6.00
Seed Trough Holder	$8.00	1	$8.00
Soil Sensor	$7.00	1	$7.00
Solenoid Valve Mount	$6.00	1	$6.00
Universal Tool Mount	$30.00	1	$30.00
Vacuum Pump Housing	$15.00	1	$15.00
Vacuum Pump Mount	$6.00	1	$6.00
Watering Nozzle Top	$7.00	1	$7.00
Watering Nozzle Bottom	$5.00	1	$5.00
Weeder	$7.00	1	$7.00
Weeder Blades	$2.00	12	$24.00

Fasteners and Hardware:

Table 19: Fasteners and hardware bill of material

Item	$/Unit	Qty	Total
M2.5 x 4mm Screws	$0.15	8	$1.20
M2.5 x 16mm M/F Standoffs *	$0.50	4	$2.00
M3 x 6mm Screws	$0.10	10	$1.00

M3 x 12mm Screws	$0.15	40	$6.00
M3 x 35mm Screws	$0.20	4	$0.80
M3 Locknuts	$0.10	20	$2.00
M5 x 10mm Screws	$0.15	150	$22.50
M5 x 16mm Screws	$0.20	40	$8.00
M5 x 30mm Screws	$0.30	45	$13.50
M5 Flange Locknuts	$0.10	70	$7.00
M5 x 6mm Spacers	$0.20	30	$6.00
M5 x 6mm Eccentric Spacers	$2.00	15	$30.00
M5 Tee Nuts	$0.40	20	$8.00
20mm Nut Bar	$1.50	6	$9.00
40mm Nut Bar	$1.75	28	$49.00
60mm Nut Bar	$2.00	20	$40.00
100mm Nut Bar *	$2.50	2	$5.00
25mm Wood Screws	$0.05	35	$1.75
Dowel Pins *	$2.00	6	$12.00
15 x 5 x 5mm Ring Magnets	$3.00	21	$63.00
Zip Ties *	$0.05 to $0.10	85	$5.25
Assembly Tools	$1.00 to $5.00	8	$32.00

Drivetrain:

Table 20: Drivetrain bill of material

Item	$/Unit	Qty	Total
V-Wheel	$6.00	30	$180.00
X-Axis GT2 Timing Belt	$40.00 to $180.00	2	$80.00
Y-Axis GT2 Timing Belt	$20.00 to $30.00	1	$20.00
Belt Sleeve	$0.50	6	$3.00
20 Tooth GT2 Pulley	$6.00	3	$18.00
5mm to 8mm Shaft Coupling	$6.00	1	$6.00
Leadscrew	$35.00	1	$35.00
Leadscrew Block	$7.00	1	$7.00

Electronics and Wiring:

Table 21: Electronics bill of material

Item	$/Unit	Qty	Total
Electronics Box	$95.00	1	$95.00
Power Supply	$60.00	1	$60.00
Power Supply Cable	$20.00 to $70.00	1	$20.00
Raspberry Pi 3	$40.00	1	$40.00
MicroSD Card	$15.00	1	$15.00
Pi Adapter Board	$10.00	1	$10.00
Push Button	$7.00	5	$35.00
LED Indicator	$5.00	4	$20.00
Farmduino	$120.00	1	$120.00
Raspberry Pi Power Cable	$5.00	1	$5.00
Farmduino Data Cable	$5.00	1	$5.00
Jumper Wire	$0.25	12	$3.00
NEMA 17 Stepper Motor with Rotary Encoder	$60.00	4	$240.00
Motor Cables	$15.00 to $32.00	4	$80.00
Encoder Cables	$20.00 to $37.00	4	$100.00
X-Axis Cable Carrier	$40.00 to $200.00	1	$40.00
Y-Axis Cable Carrier	$50.00 to $80.00	1	$50.00
Z-Axis Cable Carrier	$30.00	1	$30.00
Universal Tool Mount Cable	$40.00 to $50.00	1	$40.00
Soil Sensor PCB	$6.00	1	$6.00
Solenoid Valve	$8.00	1	$8.00
Solenoid Valve Cable	$10.00	1	$10.00
Vacuum Pump	$15.00	1	$15.00
Vacuum Pump Cable	$15.00 to $20.00	1	$15.00
Peripheral Lead	$3.00	2	$6.00
Camera	$30.00	1	$30.00
Camera Cable	$15.00 to $20.00	1	$15.00
Camera Calibration Card	$1.00	1	$1.00

Jumper Link	$0.25	4	$1.00
LED Strip	$25.00 to $50.00	1	$25.00
UTM PCB	$35.00	1	$35.00
Power Cord Protector	$7.00	1	$7.00

Tubing:

Table 22: Tubing bill of material

item	$/Unit	Qty	Total
Water Tube	$5.00 to $35.00	3	$23.00
Vacuum Tube	$1.00	2	$2.00
Barbs	$6.00	3	$18.00
Inline Air Filter	$10.00	1	$10.00
90-Degree Barb	$2.00	1	$2.00
NPT to Barb Adapter	$5.00	3	$15.00
Garden Hose to Barb Adapter	$7.00	1	$7.00
Pressure Regulator	$8.00	1	$8.00
Rubber Gasket	$1.00	4	$4.00
O-rings	$0.50	3	$1.50
Luer Lock Adapter	$5.00	1	$5.00
Luer Lock Needles	$3.00	9	$27.00
Teflon Tape	$5.00	1	$5.00

Economical and feasibility study

This section of the report will discuss the economics of purchasing a Farmbot, the ROI period is calculated for multiple scenarios for multiple versions of the Farmbot device. In the beginning the assumptions made for the ROI calculation are discussed. The first table shows the cost to acquire a Farmbot and have it shipped to Kuwait.

Table 23: Cost to acquire different version of Farmbot

Device	Device (USD)	Shipping (USD)	Setup (USD)	Total (USD)	Total (KWD)
Farmbot Express	1495	200	73	1768	535.704
Farmbot Genesis	3250	200	163	3613	1094.739
Farmbot Express XL	2000	400	100	2500	757.5
Farmbot Genesis XL	5000	400	250	5650	1711.95

The table above shows the complete cost to acquire a Farmbot and set it up all the way from placing an order online to having it ready to grow in Kuwait. The first column shows the cost to acquire the different versions of the device in USD, the second column shows the estimated shipping cost to Kuwait (as per the quote sent to the team by Farmbot), the setup cost is the estimated cost of the time spent assembling the Farmbot kit as they arrive partially assembled. The last column shows the cost to acquire each device in KWD (the local currency). The upcoming tables shows the cost for the utilities associated with operating a Farmbot and other costs used in the ROI calculations.

Table 24: Utilities cost in Kuwait

Electricity cost	0.01	KWD/kWh
water cost	2	KWD/thousand Gallon
Fuel cost	0.105	KWD/Liter
The average fuel consumption for cars	9.3	Liter/ 100 km

The time to complete the general tasks revolving around owning a Farmbot device are presented in the table below, with the cost for each task being calculated in the local currency KWD.

Table 25: Cost to maintain Farmbot

item	consumption/month	Per consumption cost	Total
Maintain Farmbot	2	7	14
harvest crops (Regular)	2.5	7	17.5
Harvest (XL)	5	7	35
Assemble regular	18	7	126
Assemble XL	25	7	175

The yield for the regular sized Farmbot Express and Genesis is set to a fixed value of 180cups per month and for the XL versions it is set to 432 cups. (These values were obtained from the Farmbot website in the ROI Section). The following calculation were made to estimate the average cost of each cup of vegetables in Kuwait and then calculate the cost for the entire amount of cups that can be produced by the respective farmbot device to be used in the final ROI calculation.

Table 26: Cost of 180 cups of vegetables in Kuwait

item	Rocca	Potato	Broccoli
1 gram cost (Fils)	8	0.58	1.96
grams in 1 cup	5	159	91
1 cup	40	92.22	178.36
monthly cups	180	180	180
cost(Fils)/month	7200	16599.6	32104.8
Avg/month (KWD)	18634.8		
Avg/cup (KWD)	103.52		
Avg/Year (KWD)	223.62		

Table 27: Cost of 432 cups of vegetable in Kuwait.

item	Rocca	Potato	Broccoli
1 gram cost (Fils)	8	0.58	1.96
grams in 1 cup	5	159	91
1 cup	40	92.22	178.36

monthly cups	432	432	432
cost(Fils)/month	17280	39839.04	77051.52
Avg/month (KWD)	44723.53		
Avg/cup (KWD)	248.46		
Avg/Year (KWD)	536.83		

Finally the general cost for visiting the store and the other associated costs of running a farmbot are calculated (using the previously made assumptions). The first table is for running a regular sized Farmbot device and the second table shows the values for running an XL Farmbot device.

Table 28: Costs associated with running a regular size Farmbot

item	Consumption/month	Per Consumption (KWD)	Freq (year)	Total
Visiting Store (time)	3	7	12	252
Visiting store (fuel liter)	0.279	0.105	12	0.35
electrical	8.6 (kWh)	0.01	12	1.1
water	150 (G)	0.002	12	3.6
seeds	3	1.75	12	63

Table 29: Costs associated with running an XL size Farmbot

item	Consumption/month	Per Consumption (KWD)	Freq (year)	Total
Visiting Store (time)	3	7	12	252
Visiting store (fuel liter)	0.279	0.105	12	0.35
electrical	34.4	0.01	12	4.13
water	600	0.002	12	14.4
seeds	12	1.75	12	252

Using all the data calculated above the team was able to generate the following studies to be found the upcoming pages

- 1 Farmbot Express vs store bought.
- 1 Farmbot Genesis vs store bought
- 1 Farmbot Express XL vs store bought
- 1 Farmbot Genesis XL vs store bought
- Scaling up using Farmbot Express XL (2-3-4-5) devices

● Scaling up using Farmbot Genesis XL (2-3-4-5) devices

*Detailed tables can be found in the appendix.

After generating the tables in the appendix the following graphs were plotted to better help understand the results. For the first two figures show the results for the small scale options of owning 1 device and the expenses over time associated with each of the options available to the consumer.

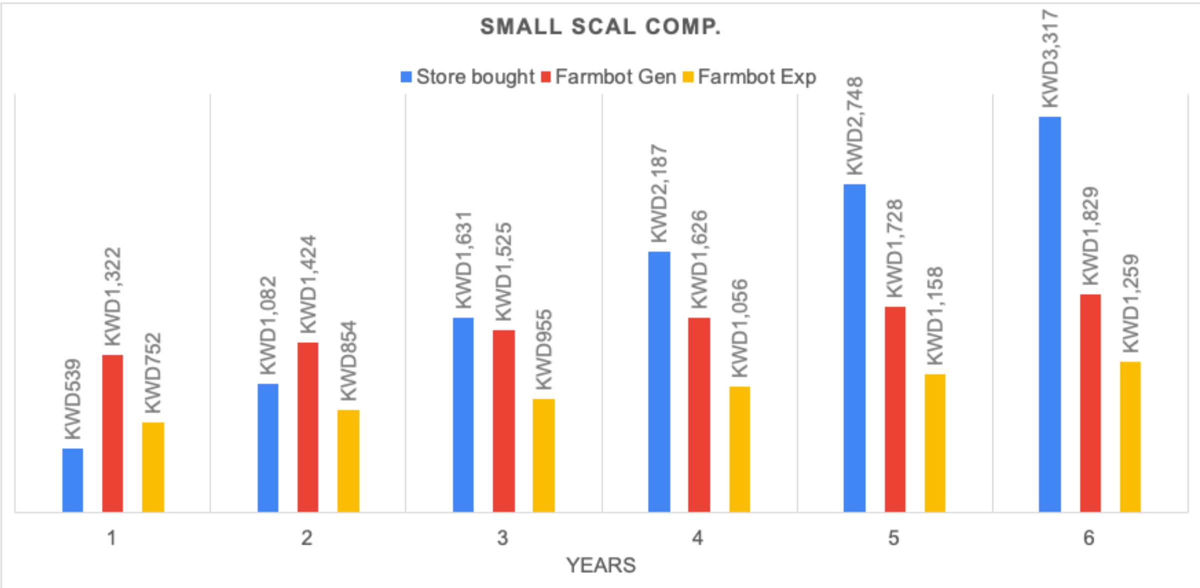


Figure 40: Expenses for small scale Farmbot

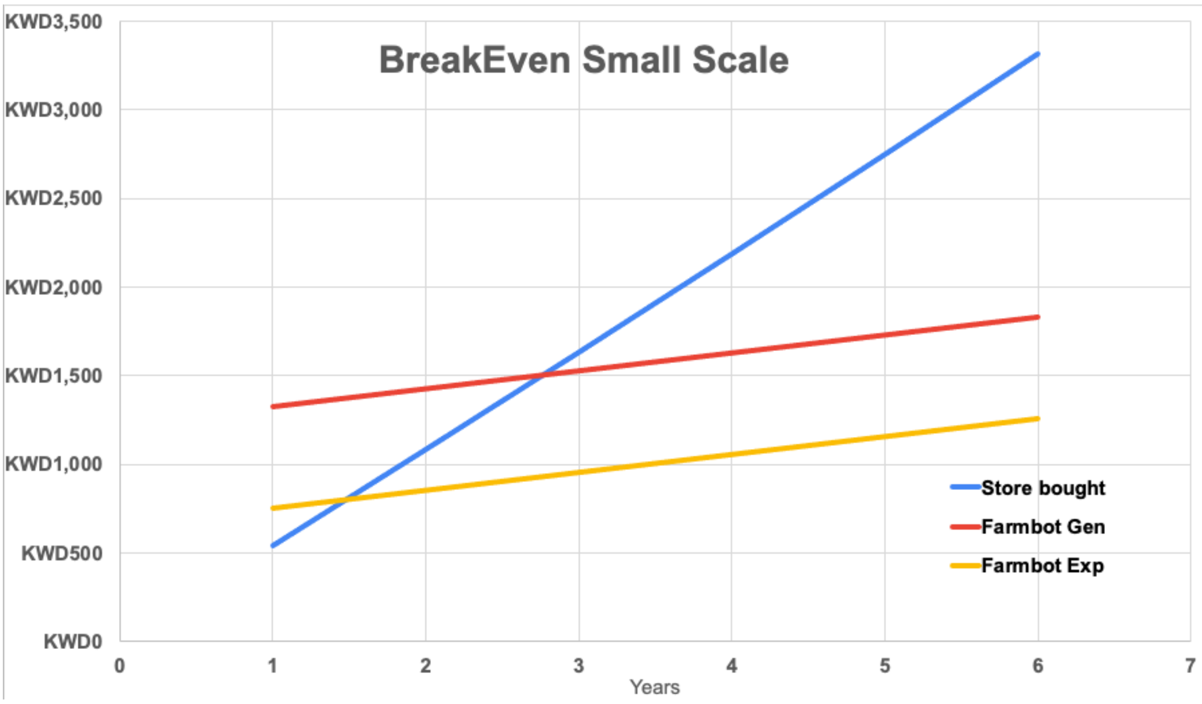


Figure 41: Breakeven for Farmbot versions vs store bought vegetables

In the previously presented figures the numbers associated with operating and owning a Farmbot are plotted to help better understand the data. The first plot in the form aof a bar chat shows the cumulative expenses over the years, whereas the second plot show the break even points for all options available and as it can be noticed that the Farmbot Express will break even after approximately 6 months to a year whereas the Farmbot Genies breaks even before the 3 year mark and the costs associated with the buying the vegetables from stores keeps on increasing with a higher rate than either options of the Farmbot.

For the following graphs the same concept above is used but for a bigger sized growing area were made as the Farmbot family offers an XL version for both the Farmbot Express and the Farmbot Genies, and their respective calculations can be found in the following figures.

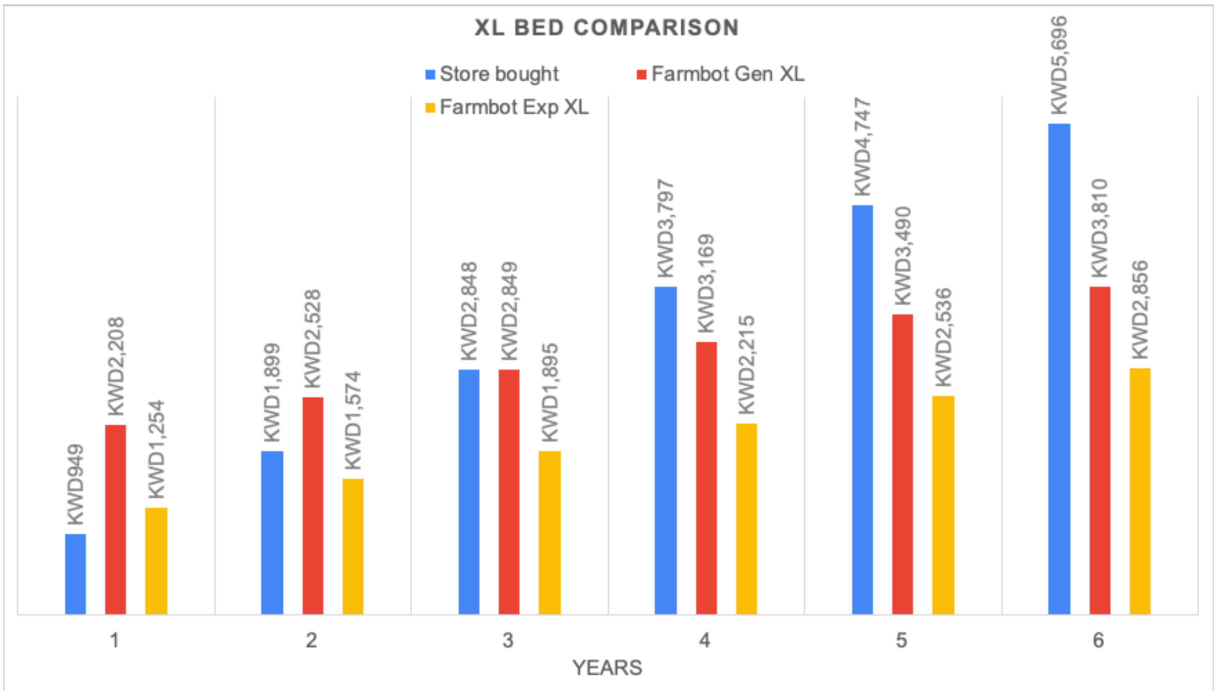


Figure 42: Expenses for deafferent XL versions of Farmbot

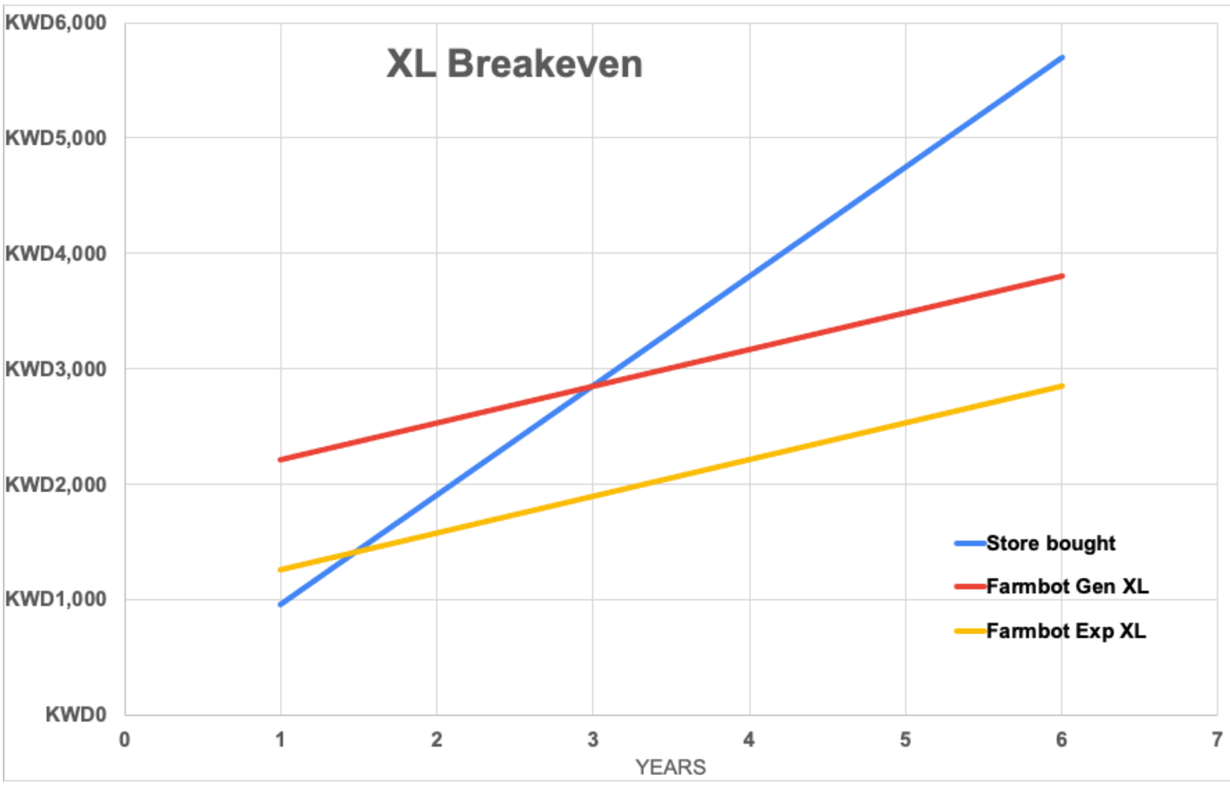


Figure 43: Breakeven for different XL versions of Farmbot

Similar to the figures above for the single regular size Farmbot the numbers for the XL versions of the Farmbot were studied and plotted as shown in figures 35 and 36. Both version the regular and the XL share about the same breakeven point, but as it will be discovered in the next part of the ROI study when upscaling with multiple devices more interesting results show up.
For the following and last section of the ROI calculations the comparison of owning multiple Farmbot devices were compared and the cumulative profit for each scenario was plotted against time as it can be found the two following figures.

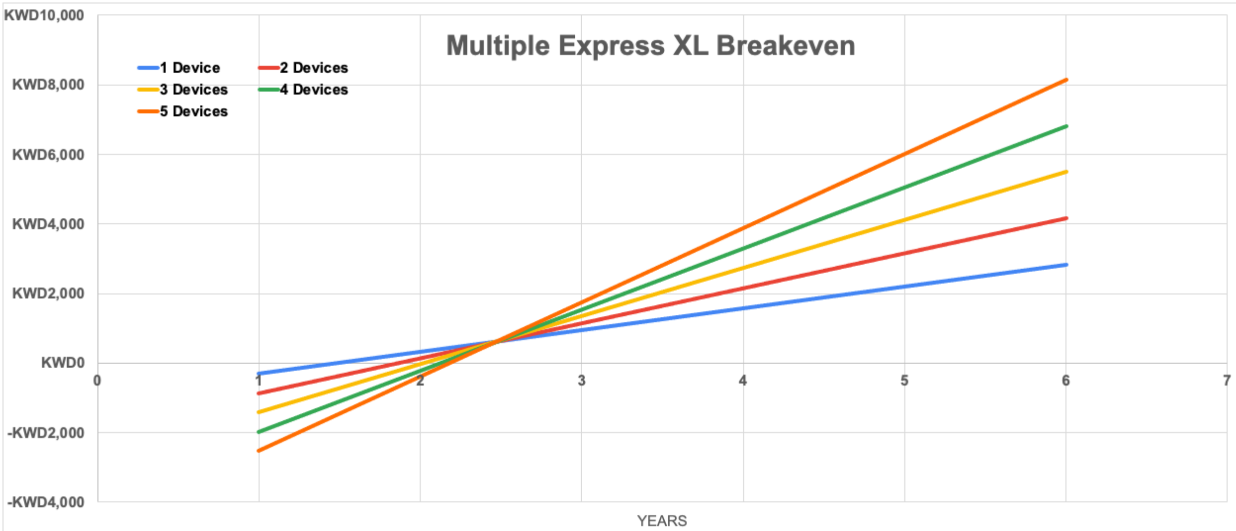


Figure 44: Multi Farmbot Express XL breakeven calculations

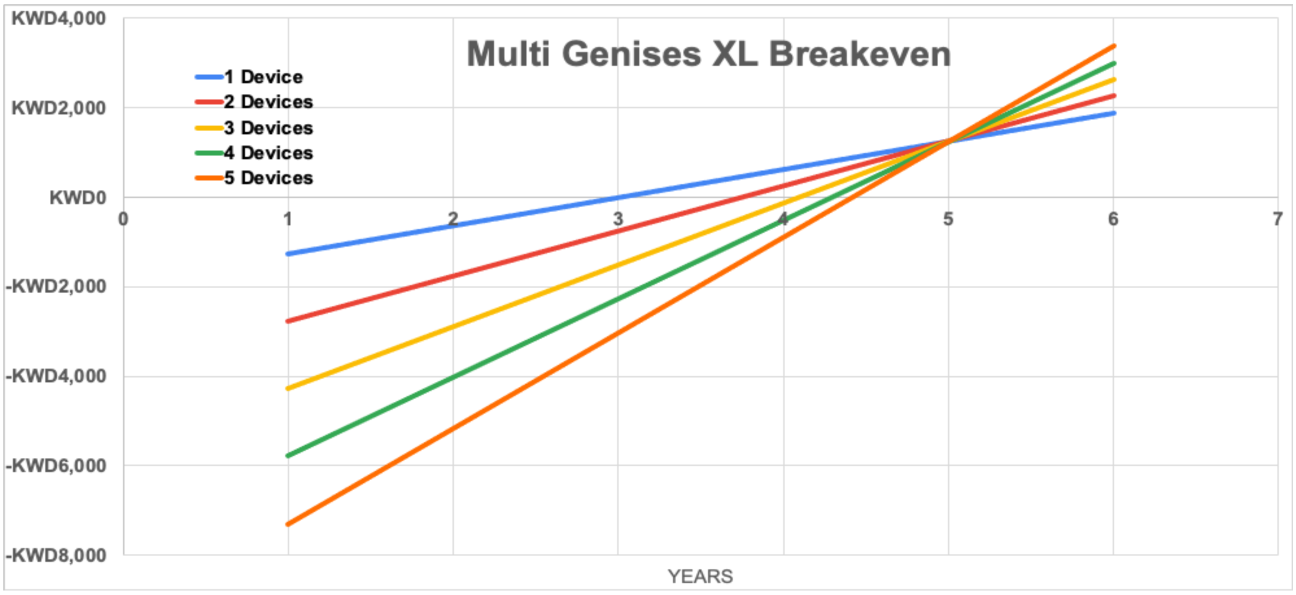


Figure 45: Multi Farmbot Genesis XL breakeven calculations

For the figures above the 0 line represents the breakeven point for each device since each line in both plots represent the cumulative profit in comparison to simply buying the vegetables from stores (using previously made assumptions). As it can be noticed from figure 37 which shows the calculations for owning multiple Farmbot Express XL devices the breakeven point for all options ranging from owning 1 to 5 devices the breakeven point is met before the second quarter of the second year and this option shows promising results especially for restaurant owners who are looking for having exotic herbs and vegetables as parts of their menus. Another observation made from the plot is that at the point where all the lines share the same point is that at that specific point have more devices beats the numbers of having any less so the number of devices owned can be derived only by the produce needs of the owner. For the second figure the same numbers were plotted but for the Farmbot Genies XL version and it is obvious that the device will cost more but yet it might have different use cases as this option offers a wider range of automations and different capabilities that might also be suited for the regular user or possibly to be used in labs which will have a different way for calculating the ROI since it’s a completely different game.

In conclusion Farmbot present itself as a feasible solution for multiple types of consumers especially that it is already a feasible solution when only considering produce that is available in the market and that is reasonably priced. Farmbot can be considered an even more feasible option when the consumer is trying to scratch more than one itch, it is an extremely appealing product to restaurants especially ones that would like to infuse their dishes with exotic vegetables and fruits that are not easy to find or extremely seasonal (will require extra investment for green house). Farmbot is also considered an amazing STEM project for to build as a family projecy or it can be used for even more complex applications in labs and other facilities for experimental purposes.

Farmbot Weeder

As previously stated, the device employs a rotary tool equipped with a 24 [v] DC motor to kill weeds, which may result in undesirable vibration throughout the system. After repeated use, the rotary blades may become damaged, resulting in blade imbalance. Unbalanced blades will generate a series of vibrations that will travel from the motor to the gantry. Vibrations will affect both the tool and the universal mount, dislocating them and potentially affecting their alignment and accuracy. The figure below shows the parts which might be affected by the vibrations.

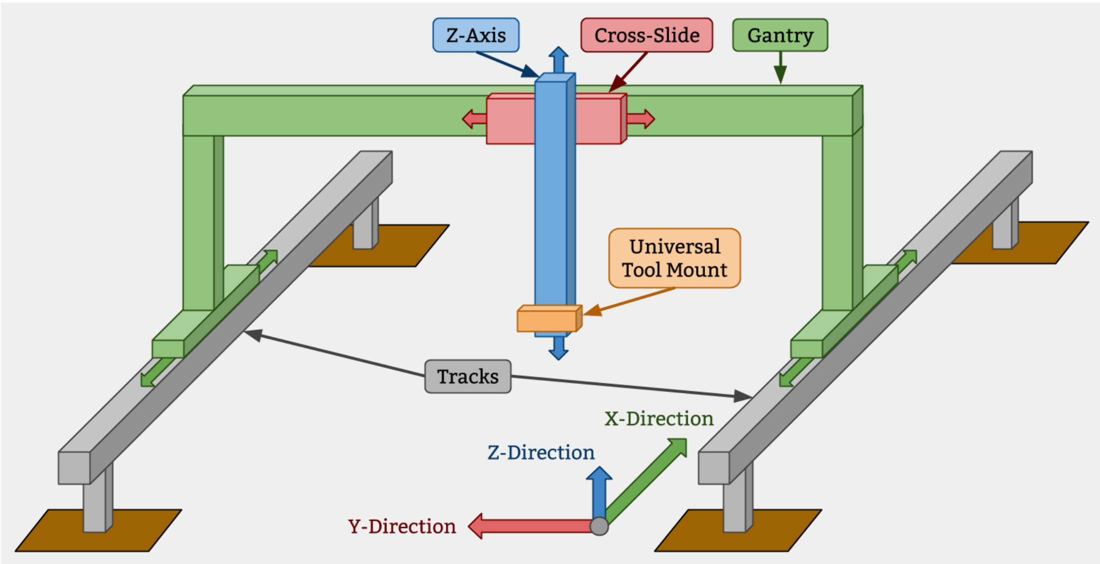


Figure 46: Farmbot Simplified Model

The cross-slide might be affected by the vibrations by loosening up the belt shown in the figure below and leading to an unstable movement along the gantry.

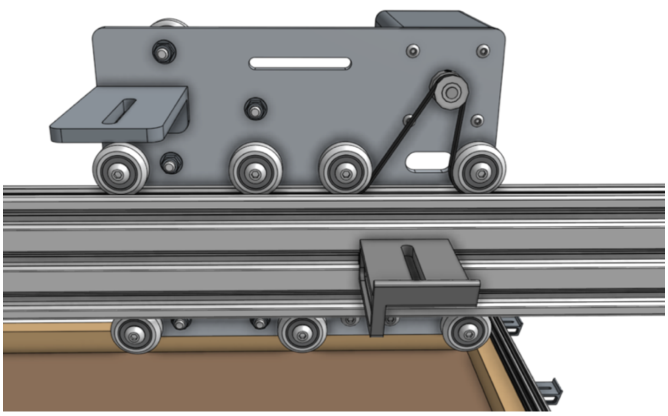


Figure 47: Farmbot cross-slide

Besides the vibration problem, there are additional issues such as the weeder's power consumption and weeder limitation. Due to the length of the blades, the weeder can only target large weeds and cannot eliminate small weeds. Additionally, because it is imprecise, it may cause damage to nearby plants. After stating all of these issues, it's evident that the primary improvement to Farmbot would be to implement a different method of weeding. An email was sent to the Farmbot company to discuss feasible product improvements (can be found in the Appendix)

Initial solution research

Since the Farmbot already has a UTM (universal tool mount) system then and the weed wacker is not fixed to the actual device then it can easily be swapped with a powerful laser module that has a UTM end on to it that can easily be operated by the same current software on the Farmbot with minor code adjustments. The following figures will show the initial design components and the general idea around the laser module to be added to the system which will be extensively discussed in the final Phase 3 version of the report.

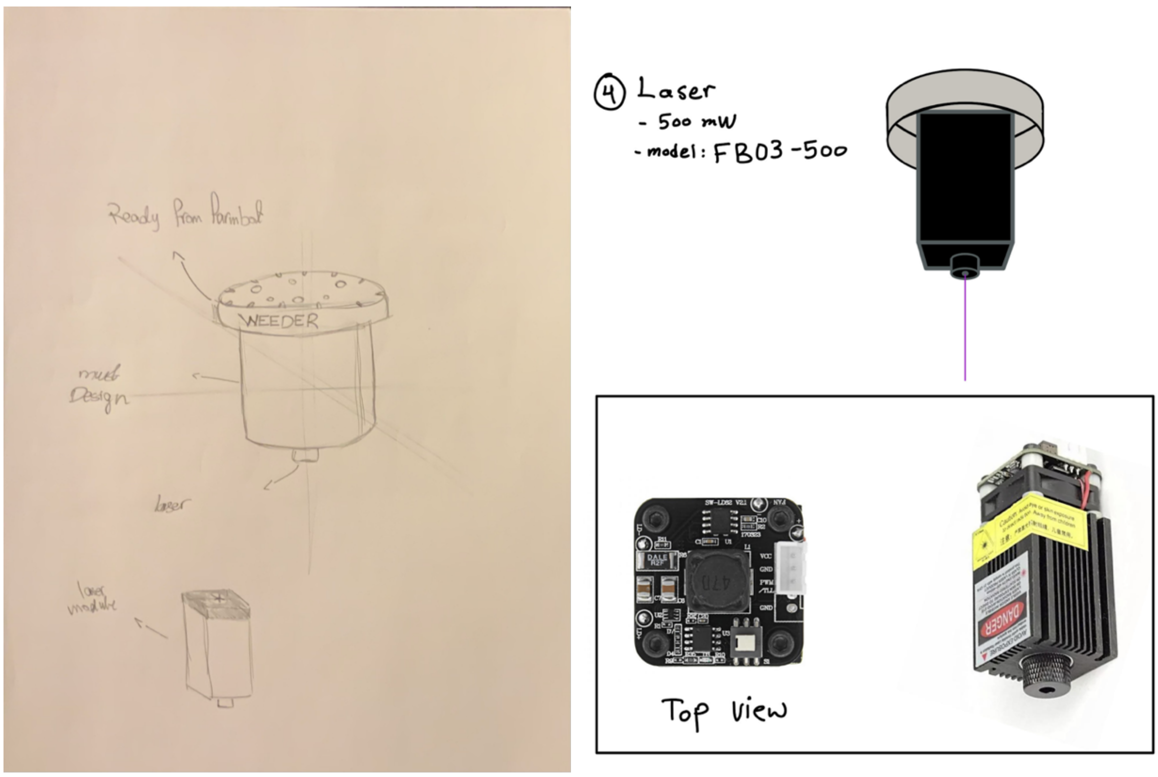


Figure 48: Laser module sketch

Detailed Solution for Problem

Due to the previously mentioned reasons and the inability to acquire and set up a fully functional Farmbot device the team has decided to split the validation of the problem-solution into multiple segments and by doing so the team will also better satisfy the engineering analysis objective of this capstone project with hands-on experience in mimicking the behavior of a Farmbot by developing its own autonomous weed like detection software to identify objects and burn them with laser as if they were weeds. The team has also made sure that the laser module used is capable of burning weed in the second section of this validation process, and finally, the components to integrate the laser module with Farmbot were designed using CAD software and fabricated and tested for fit using a 3D printer.

Proof of concept (prototype details)

To validate the proposed solution with the limited budget constraint, it was decided to use a 3D printer to replication a Farmbot. The 3D printer was modified to have a webcam attached to it to be used as the weed scanning tool, and the laser to be used in the finalized Farmbot was also attached to the 3D printer to be a part of the prototype.

Figure 49: Ender3Pro (3D Printer Used)

The figure above shows the exact model used in the fabrication of the prototype and the choice of a 3D printer was obvious as it has a 3 axis gantry system which is exactly what Farmbot uses but this has a much smaller form factor and is widely available and more affordable. The reasons behind why this exact model was chosen are due to its low price and the fact that it has an open-source microcontroller and software that allowed the team to fully control the 3D printer through a serial connection with a USB cable. Since this is not a growing area and having weeds will cause a mess the weed was replaced with a red circle and a red whiteboard magnet such as the one presented in the figure below was used

Figure 50: Whiteboard magnets

Assembly

As mentioned previously the 3D printer had a camera and a laser module attached to it. A custom-designed mounting bracket was designed specifically for this application and then it was printed using the 3D printer.

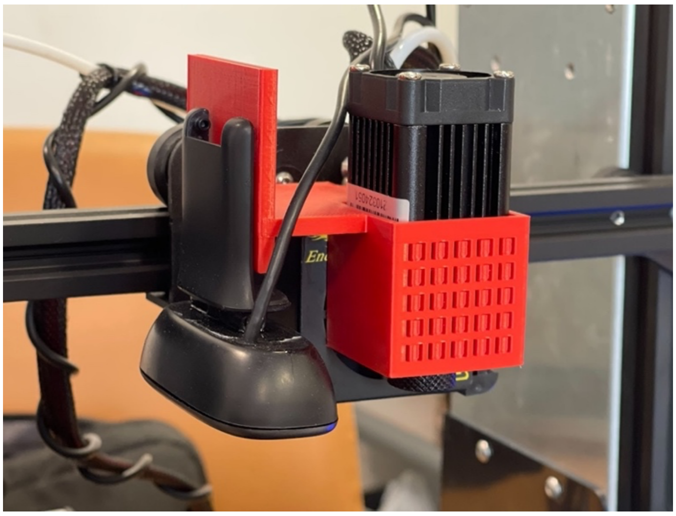


Figure 51: Custom designed mount

The custom-designed mount is shown in the figure above. The mount allowed for a seamless mounting arrangement that did not impair nor interfere with the 3D printing functionality.

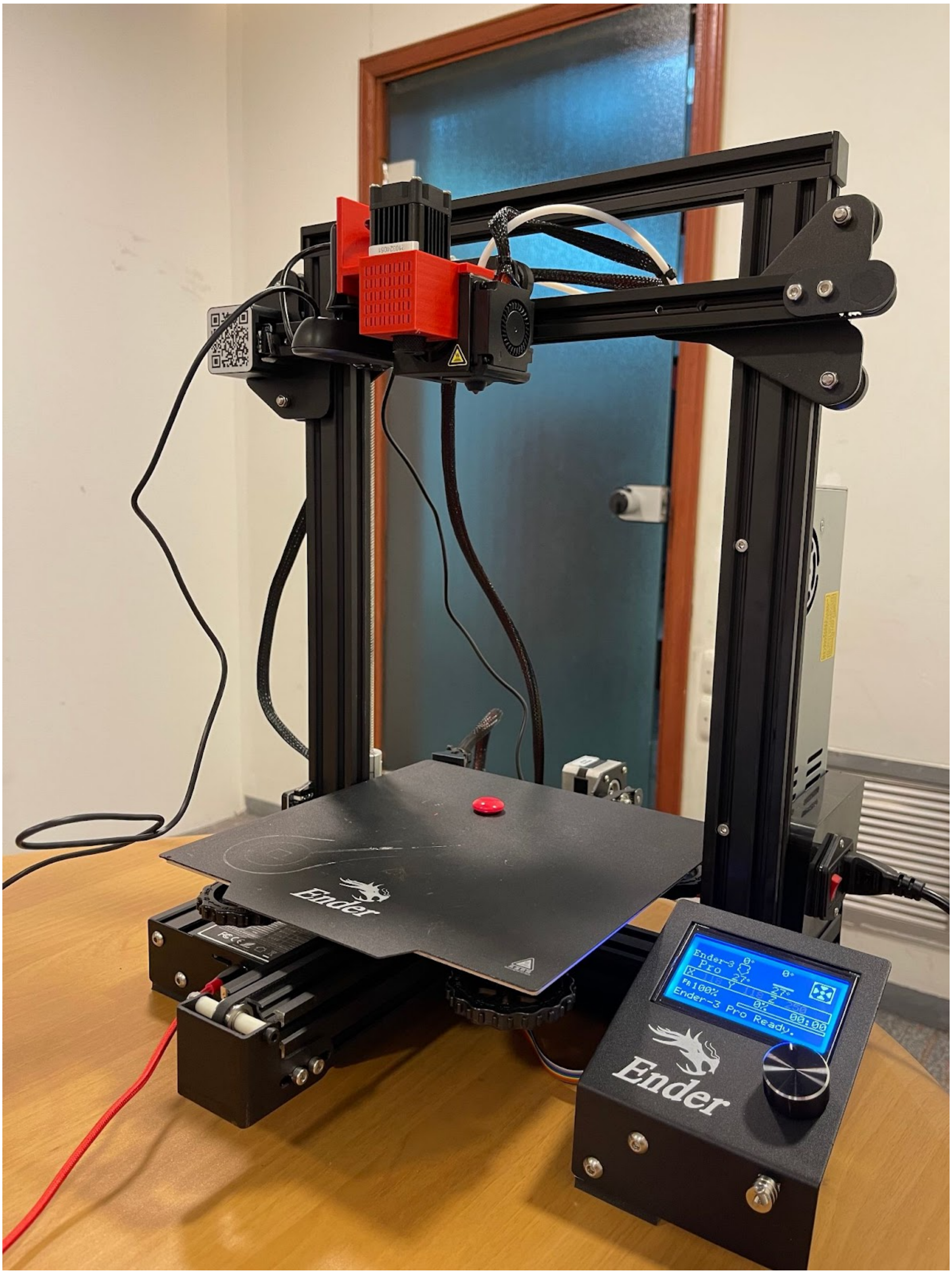


Figure 52: Full Assembly of prototype

The figure above shows the completed assembly of the prototype used for the purpose of the validation process.

Computer program

To control the assembly a computer program was developed to drive the mechanisms a satisfy the required physical objective, which is to the red magnet representing a weed and pinpoint its exact location and then triggers the laser and moves the laser around the red magnet to make sure that if it was a weed that it is most likely to be burnt. For the purpose of this project, MATLAB was since it was the programming tool with which the team members are familiar using.

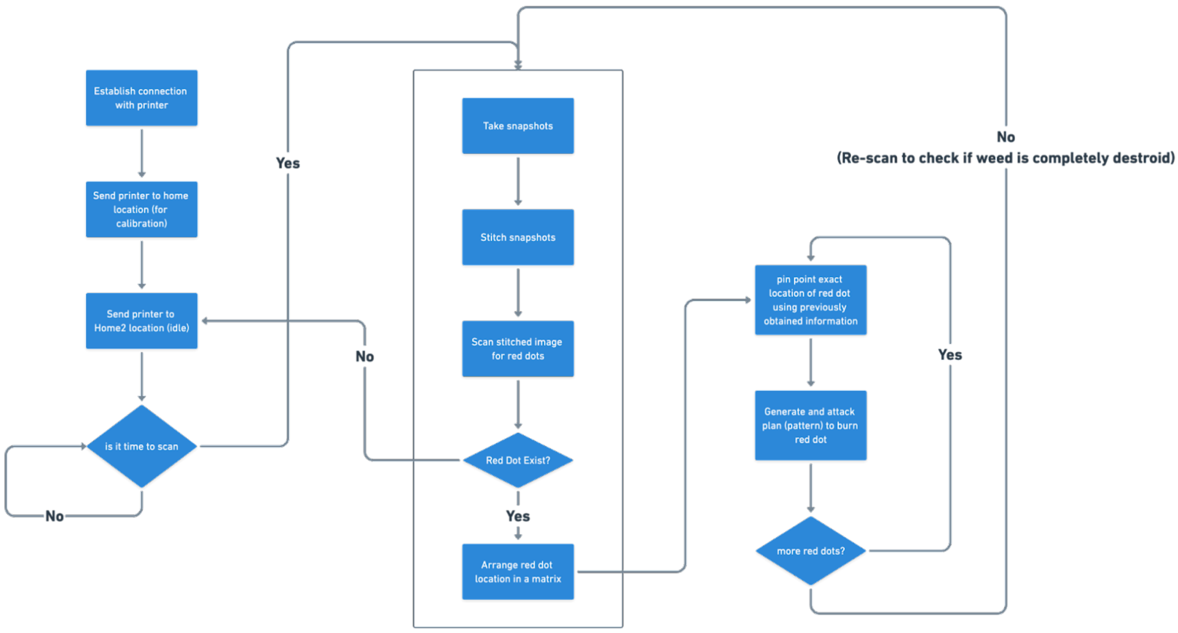


Figure 53: Computer program flow

The logic for the computer program used to control the system is presented in the diagram in the figure above. When the device is first turned on it will calibrate its location and then go to the idle home location waiting for a command to search for weeds. The search for weeds command can be triggered either by a specific event such as time i.e. 7:00 am every Sunday or manually. After the scan command is triggered the computer software will drive the motors to move the camera to multiple locations to take a snapshot of the bed which in this case represents the growing area, then the previously taken images are stitched together to make the full image of the bed as shown below

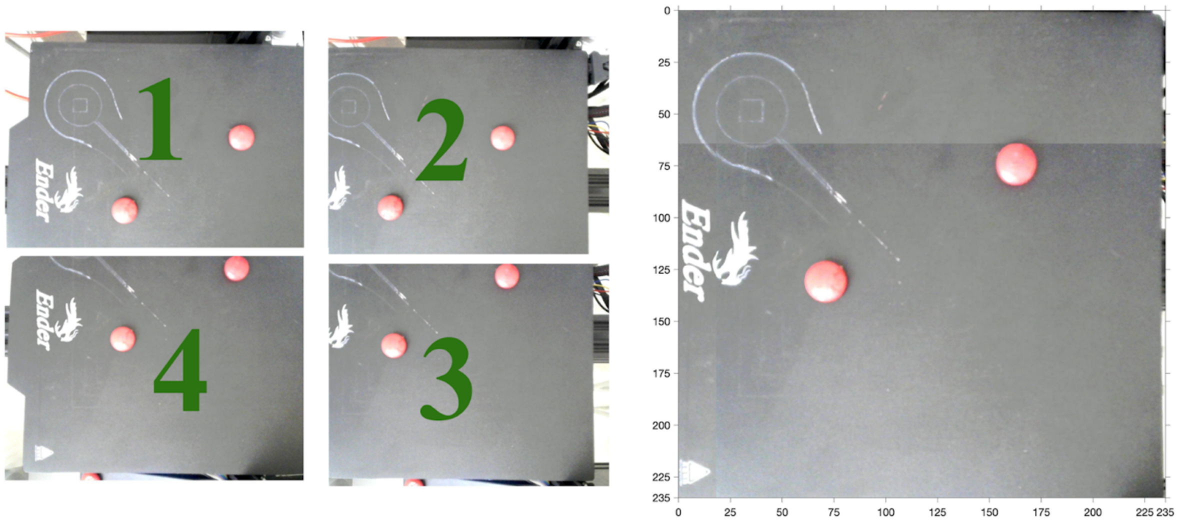


Figure 54: Image stitching using computer program demo

The figure above shows the images taken at a different location and then the stitched version. After stitching the images, the final stitched image is then referenced to real-life coordinates of the bed. After having a way to convert pixel location to mm location on the bed of the 3D printer, the image is analyzed and a mask is applied where anything that is red in the image is then turned into white with everything else being black as shown in the figure below.

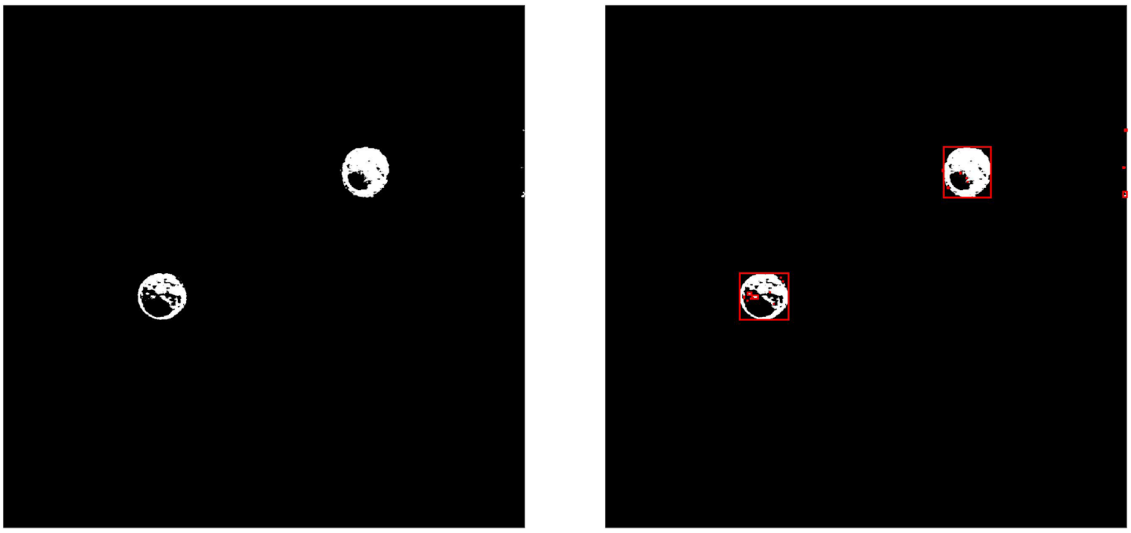


Figure 55: Red dot detection method

In the figure above it shows the masked red regions with boxes around them. The reason for the boxes is to be able to get the XY pixel location for the red magnets and to eliminate the noise in the image by only considering the boxes that meet certain criteria (in this case the area of the box) and reject all other boxes. The information of all confirmed boxes is then stored in a matrix format. After location each red magnet the 3D printer is then instructed to take the camera to the location of the first red dot in the matrix of red dots (order is not important in this case), the reason the camera is first taken to the red magnet before the laser is to pinpoint the exact location of the red magnet with a certain accuracy which reduces any errors from the previous location estimation process in a dramatic manner.

The figure above shows the location of the red magnet before the enhancement and after and as it can be concluded that a great deal of correction has taken place. After doing so the distance from the head of the laser and the camera lens is known (in this case it is 48mm in the X and 23 mm in the Y). The printer will bring the lens of the laser to the center of the red magnet and then trigger the laser.

In the figure the pattern of which the laser will burn the weed is shown, the reason this pattern (The Archimedean Spiral) was chosen was that the magnet was circular and it was fairly simple to manipulate without causing any damage to the bed of the 3D printer, another pattern is used when a weed is to be eliminated)

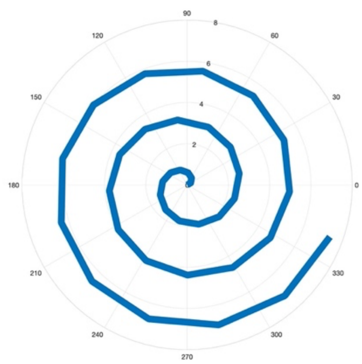


Figure 56: Attack pattern

Pseudo-code

After describing what happens in each operation of the code the pseudo-code is presented for each function below (Taking into consideration)

Initiation

```
Establish connection to 3D printer
Open communication line to 3D printer
Connect to & open webcam
Command printer to go home (Calibrate)
Command printer to go to home2 (MAX Z MID (X,Y))
```

Scanning the area

```
Send Camera to Corner 1
wait for printer to move Camera
Take Snapshot1

Send Camera to Corner 2
wait for printer to move Camera
Take Snapshot2

Send Camera to Corner 3
wait for printer to move Camera
Take Snapshot3

Send Camera to Corner 4
wait for printer to move Camera
Take Snapshot4

Create empty canvas of predetermined size (array)
Fille empty canvas
Top left corner with Snapshot1
Top right corner with Snapshot2
Bottom right corner with Snapshot3
Bottom left corner with Snapshot4

Convert stitch image array to image type
Crop stitched image to exclude undesired region
Reference cropped image to real bed dimensions
```

Detecting red dots

```
Create a mask for all anything red in the image
assign a box around all white regions in masked image

for number of boxes
    if box area > known area in pixels of red magnet - 15%
```

```
        store box coordinates
    end
end

for number of selected boxes
    create array with of   X and Y location after referencing + Static error
end
```

Honing in on red dots

```
Send printer to X and Y location of red dot (previously corrected)
Take printer to specified height
Take a snapshot.X
Locate circle (Xc,Yc,R)

while desired accuracy < current accuracy
    move printer by 0.1(Xd-Xc)
    get new circle location (X,Y,R)
    if x is at center (with desired accuracy (factor))
        break
    end
end

Repeat above for Y

Store final XYlocation of red magnet
```

Eliminating the red dot (burn it with laser)

```
Send printer to XY location of magnet
Generate archimedean from center of circle to edge
Turn on Laser
Move printer following spiral path
Turn off Laser
```

Testing and Results

In the figure below the red magnets used are shown before and after the burning process using the laser

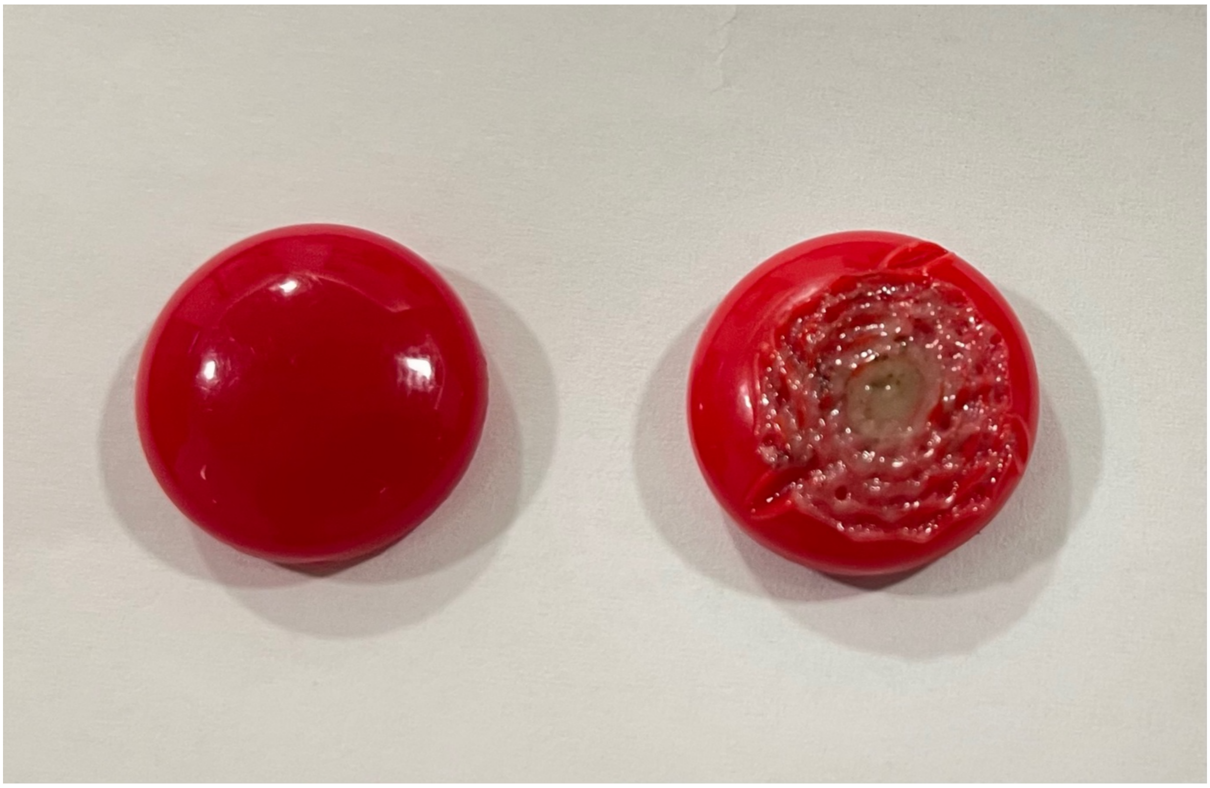


Figure 57: Red dot before and after burning

As it can be seen that the laser was capable of melting the plastic cover of the white board magnet indicating that it will be powerful enough to burn organic leafs which will also be demonstrated in the following section of the report. The pattern used for attack (Archamedian spiral) can also be seen in the second burnt magnet on the right hand side.

Proof of concept - Weed Elimination

In this section the results for burning an actual weed are shown. In the first figure below a small plant demonstrating a weed (in size) is used in a small, a perfectly healthy small plant.

Figure 58: Healthy weed before burning

The plant in the figure above will go throught the burning process and the results are shown below in the next figure.

Figure 59: Dead weed after being burnt with laser

Redesigned components for Farmbot

As mentioned before Farmbot devices use a universal tool mount that can be attached to a different type of tools to do a certain task. A laser housing was designed using COMSOL to be used in the weed elimination process. To have a better understanding of the designed parts look at the figure below which shows the part from four different dimensions. The final design should be able to be attached to the Farmbot weeder tool using a couple of screws.

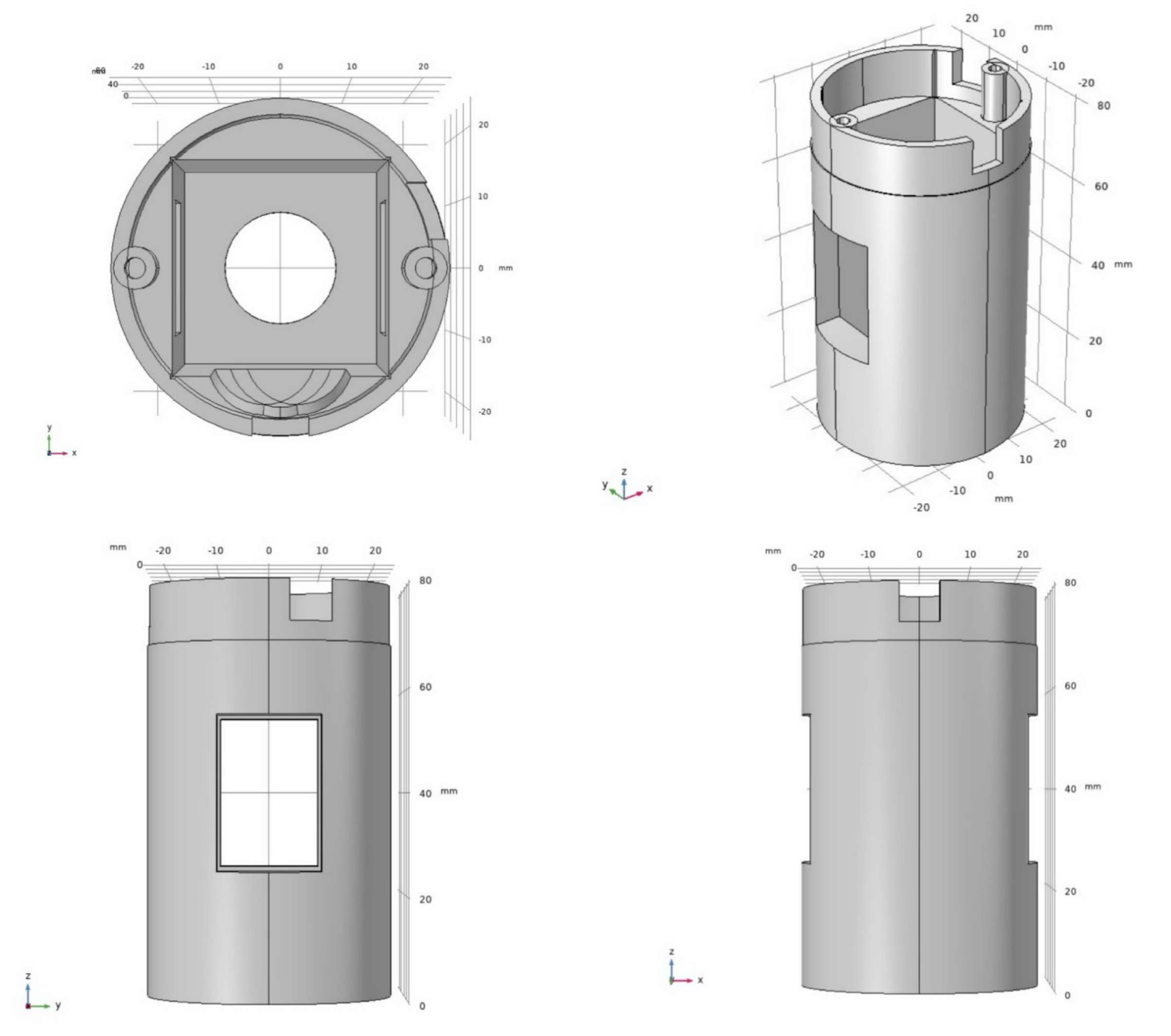


Figure 60: 3D model of laser housing for Farmbot

After designing the final model of the laser housing was manufactured by a 3D printer using a filament made of thermoplastic polymer (PLA) which is made of renewable resources (recycled material). The laser was able to fit inside the housing with a very small clearance of value 1 [mm] at each side. The minimum wall thickness equals to 2.25 [mm] which can be seen on the top walls of the cylinder. The final 3D printed laser housing is shown in the figure below.

The figure below shows the Farmbot weeder tool which can be attached to their universal tool mount using magnets as mentioned before. It can be manufactured using a 3D printer and it is shown in the figures below.

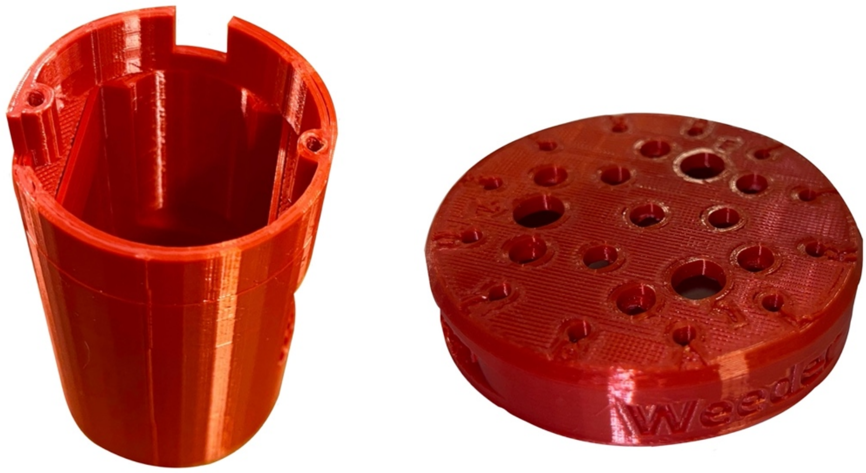


Figure 61: Laser housing and cover

The laser housing can relate to the weeder tool using a couple of screws as shown in the figures below.

After connecting the laser housing with the weeder tool, it will be ready to attach it with the universal tool mount which is equipped with most of Farmbot devices. The three big holes on the top of the weeder tool are for attaching the magnets with it using screws. The other small holes on the around the weeder top are for the wiring.

To achieve the target, which is eliminating the weed, The laser should have enough power to burn the weed. The used laser made by Creality, and it has a blue violet beam. The laser has enough power of 500 mA, and it can burn a weed and it is shown in the figure below.

Figure 62: Assembled laser housing

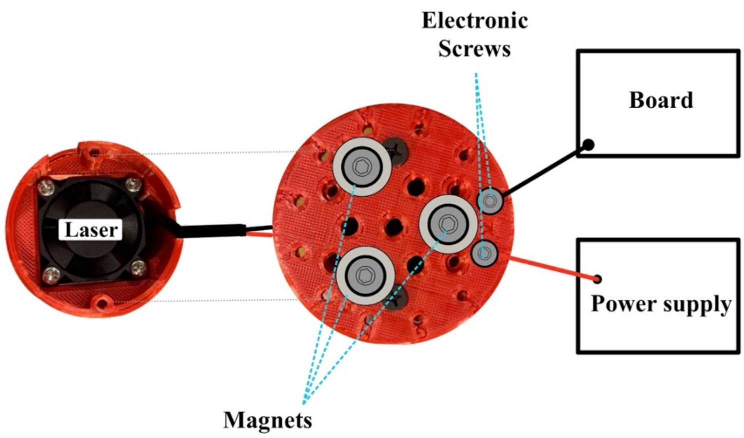


Figure 63: Wiring schematic for weeder housing

The figure above shows the laser wiring and all the needed fasteners from a Top view. The Laser has two wires which can be used to connect the laser with Farmbot devices.The Wires use the small holes of the weeder tool and they can be connected with universal tool mount using the electronic screws to supply the laser with required power and using the magnets to attach and carry the whole tool.

The final design should be ready to work after connecting it with a Farmbot devise using the universal tool mount, The red wire will be connected to a Farmbot power supply, and the black wire will be connected with a Farmbot board. The same method will be used to detect the weeds as the other weed killing tools which Farmbot already designed. The figure below shows the expected final design attached to the Farmbot gantry system through the universal tool mount.

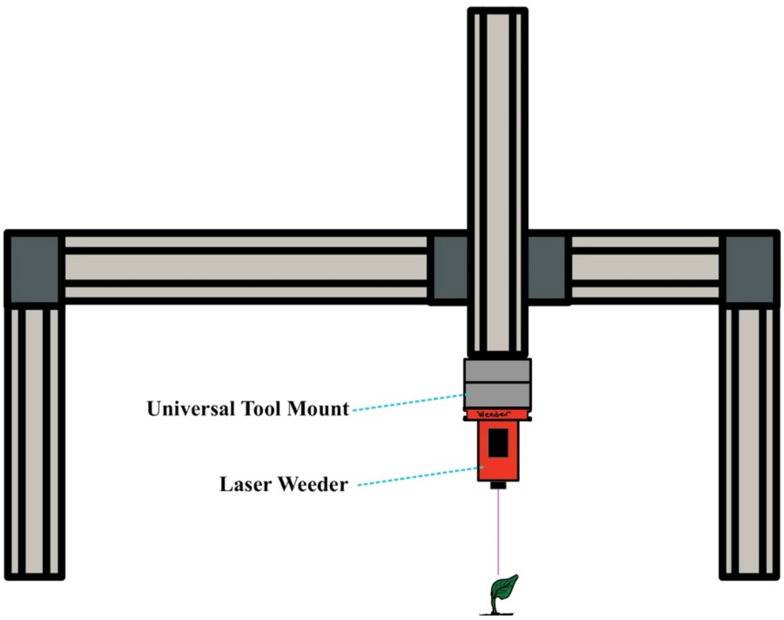


Figure 64: Farmbot gantry with laser (Expected behavior)

Bill of materials of items used

The table below lists the equipment and tools used for this project, both the proof of concept and design and fabrication of the laser housing for Farmbot

Table 30: Bill of material (proof of concept)

Item	$/Unit	Qty	Total
Creality Laser Engraver	37.99	1	37.99$
Creality Ender 3 Pro 3D Printer	219	1	219$
1KG Ender PLA Filament	23.29	1	23.29$
Logitech C310 HD WEBCAM	34.99	1	34.99$
Misc. costs	100	1	100$

Concluding remarks

- Kuwait has a major issue in self-sufficient systems especially in the agriculture field, the percentage of self-sufficient agriculture has been dropping since 2015 (latest statistics available for 2019), which is a problem worth solving.
- A market for self-sufficient and sustainable systems exists in the region and the customer awareness is increasing.
- Open-source projects are gaining more traction and are of high appeal to customers, especially when products can be upgradable and customizable.
- Using visual tools for project planning can dramatically increase the efficiency of information communicated throughout the team, an example used is Gantt charts.
- Functional decomposition is a powerful technique that can be used to influence the decision-making process when upgrading a specific functionality in a device with multiple sub-systems.
- Automation is taking over the agriculture industry as some devices can simply replace tens if not hundreds of employees and do the job more efficiently.
- Solutions for automation in the agriculture industry have been limited to large scale farms with very expensive equipment making the barrier of entry huge for the world of automation.
- Farmbot (the selected concept) is one of the first eco-systems that offer a multi-level automation and is targeted for actual farming and not just maintaining a single plant.
- Farmbot can be used in a plethora of scenarios ranging from greenhouses to labs and simply outdoor in the sun, with the capability of customizing each device to serve specific goals for specific conditions and different objectives.
- The economic analysis showed that Farmbot is a feasible device to be used in Kuwait with a breakeven period of less than 3 years in the worst-case scenario.
- Economic analysis concluded that Farmbot is a feasible solution for households and showed promising results for restaurants with the dream to use exotic produce all year long.
- Contacting the manufacturer of a product is a necessary step to validate a problem thought to exist in a device before attempting to solve it – it can also lead to a collaboration with the manufacturer.

- Using multiple levels for proof of concept is an efficient technique before fully investing in a solution that does not deliver on results.
- Teamwork is a crucial aspect in the development of any project/product since all members have different backgrounds and skills that can influence the success of the project differently.

References

Ulrich, K. T., & Eppinger, S. D. (2016). *Product Design and Fevelopment Sixth Edition.* New York: McGraw-Hill Education.

Farmbot. (n.d.). Retrieved from Farmbot: https://farm.bot/pages/roi

Appendix

ROI detailed tables

In order to allow for the following tables to be read the keys must be used

Code	time
A	Farmbot Acquiring + (Shipping to kuwait) + 5% extra cost for setup
B	Farmbot setup time
C	Vegetables
D	Organic markup (30%)
E	Seeds
F	Water
G	Electricity
H	Transportation to and from store in vehicle
I	Time to purchase veggies (transport and in-store)
J	Time to harvest veggies each day
K	Time to maintenance FarmBot
L	Total
M	Total Cumulative
N	Profit

And at the top of each column the F represents the cost for the Farmbot and the S represent the cost for the store bought options.

Express												
Year	1		2		3		4		5		6	
item	F	S	F	S	F	S	F	S	F	S	F	S
A	525	0	0	0	0	0	0	0	0	0	0	0
B	126	0	0	0	0	0	0	0	0	0	0	0
C	0	220	0	224	0	228	0	233	0	238	0	243
D	0	66	0	67.2	0	68.4	0	69.9	0	71.4	0	72.9
E	65	0	65	0	65	0	65	0	65	0	65	0
F	1.25	0	1.25	0	1.25	0	1.25	0	1.25	0	1.25	0
G	3.6	0	3.6	0	3.6	0	3.6	0	3.6	0	3.6	0
H	0	252	0	252	0	252	0	252	0	252	0	252
I	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5
J	17.5	0	17.5	0	17.5	0	17.5	0	17.5	0	17.5	0
K	14	0	14	0	14	0	14	0	14	0	14	0
L	752.35	538.5	101.35	543.7	101.35	548.9	101.35	555.4	101.35	561.9	101.35	568.4
M	752.35	538.5	853.7	1082.2	955.05	1631.1	1056.4	2186.5	1157.75	2748.4	1259.1	3316.8
N	-213.85	213.85	228.5	-228.5	676.05	-676.05	1130.1	-1130.1	1590.65	-1590.65	2057.7	-2057.7

Genisis												
Year	1		2		3		4		5		6	
item	F	S	F	S	F	S	F	S	F	S	F	S
A	1095	0	0	0	0	0	0	0	0	0	0	0
B	126	0	0	0	0	0	0	0	0	0	0	0
C	0	220	0	224	0	228	0	233	0	238	0	243
D	0	66	0	67.2	0	68.4	0	69.9	0	71.4	0	72.9
E	65	0	65	0	65	0	65	0	65	0	65	0
F	1.25	0	1.25	0	1.25	0	1.25	0	1.25	0	1.25	0
G	3.6	0	3.6	0	3.6	0	3.6	0	3.6	0	3.6	0
H	0	252	0	252	0	252	0	252	0	252	0	252
I	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5
J	17.5	0	17.5	0	17.5	0	17.5	0	17.5	0	17.5	0
K	14	0	14	0	14	0	14	0	14	0	14	0
L	1322.35	538.5	101.35	543.7	101.35	548.9	101.35	555.4	101.35	561.9	101.35	568.4
M	1322.35	538.5	1423.7	1082.2	1525.05	1631.1	1626.4	2186.5	1727.75	2748.4	1829.1	3316.8
N	-783.85	783.85	-341.5	341.5	106.05	-106.05	560.1	-560.1	1020.65	-1020.65	1487.7	-1487.7

Express XL												
Year	**1**		**2**		**3**		**4**		**5**		**6**	
item	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**
A	758	0	0	0	0	0	0	0	0	0	0	0
B	175	0	0	0	0	0	0	0	0	0	0	0
C	0	536	0	536	0	536	0	536	0	536	0	536
D	0	160.8	0	160.8	0	160.8	0	160.8	0	160.8	0	160.8
E	252	0	252	0	252	0	252	0	252	0	252	0
F	14.5	0	14.5	0	14.5	0	14.5	0	14.5	0	14.5	0
G	5	0	5	0	5	0	5	0	5	0	5	0
H	0	252	0	252	0	252	0	252	0	252	0	252
I	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5
J	35	0	35	0	35	0	35	0	35	0	35	0
K	14	0	14	0	14	0	14	0	14	0	14	0
L	1253.5	949.3	320.5	949.3	320.5	949.3	320.5	949.3	320.5	949.3	320.5	949.3
M	1253.5	949.3	1574	1898.6	1894.5	2847.9	2215	3797.2	2535.5	4746.5	2856	5695.8
N	-304.2	304.2	324.6	-324.6	953.4	-953.4	1582.2	-1582.2	2211	-2211	2839.8	-2839.8

Genesis XL												
Year	**1**		**2**		**3**		**4**		**5**		**6**	
item	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**
A	1712	0	0	0	0	0	0	0	0	0	0	0
B	175	0	0	0	0	0	0	0	0	0	0	0
C	0	536	0	536	0	536	0	536	0	536	0	536
D	0	160.8	0	160.8	0	160.8	0	160.8	0	160.8	0	160.8
E	252	0	252	0	252	0	252	0	252	0	252	0
F	14.5	0	14.5	0	14.5	0	14.5	0	14.5	0	14.5	0
G	5	0	5	0	5	0	5	0	5	0	5	0
H	0	252	0	252	0	252	0	252	0	252	0	252
I	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5
J	35	0	35	0	35	0	35	0	35	0	35	0
K	14	0	14	0	14	0	14	0	14	0	14	0
L	2207.5	949.3	320.5	949.3	320.5	949.3	320.5	949.3	320.5	949.3	320.5	949.3
M	2207.5	949.3	2528	1898.6	2848.5	2847.9	3169	3797.2	3489.5	4746.5	3810	5695.8
N	-1258.2	1258.2	-629.4	629.4	-0.6	0.6	628.2	-628.2	1257	-1257	1885.8	-1885.8

Express (Scaling up to 5 devices)									
Devices		**2**		**3**		**4**		**5**	
year	**Value**	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**
1	total	2507	1646.1	3760.5	2342.9	5014	3039.7	6267.5	3736.5
	total cumulative	2507	1646.1	3760.5	2342.9	5014	3039.7	6267.5	3736.5
	profit	-860.9	860.9	-1417.6	1417.6	-1974.3	1974.3	-2531	2531
2	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	3148	3292.2	4722	4685.8	6296	6079.4	7870	7473
	profit	144.2	-144.2	-36.2	36.2	-216.6	216.6	-397	397
3	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	3789	4938.3	5683.5	7028.7	7578	9119.1	9472.5	11209.5
	profit	1149.3	-1149.3	1345.2	-1345.2	1541.1	-1541.1	1737	-1737
4	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	4430	6584.4	6645	9371.6	8860	12158.8	11075	14946
	profit	2154.4	-2154.4	2726.6	-2726.6	3298.8	-3298.8	3871	-3871
5	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	5071	8230.5	7606.5	11714.5	10142	15198.5	12677.5	18682.5
	profit	3159.5	-3159.5	4108	-4108	5056.5	-5056.5	6005	-6005
6	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	5712	9876.6	8568	14057.4	11424	18238.2	14280	22419
	profit	4164.6	-4164.6	5489.4	-5489.4	6814.2	-6814.2	8139	-8139

Express (Scaling up to 5 devices)									
Devices		**2**		**3**		**4**		**5**	
year	**Value**	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**
1	total	4415	1646.1	6622.5	2342.9	8830	3039.7	11037.5	3736.5
	total cumulative	4415	1646.1	6622.5	2342.9	8830	3039.7	11037.5	3736.5
	profit	-2768.9	2768.9	-4279.6	4279.6	-5790.3	5790.3	-7301	7301
2	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	5056	3292.2	7584	4685.8	10112	6079.4	12640	7473
	profit	-1763.8	1763.8	-2898.2	2898.2	-4032.6	4032.6	-5167	5167
3	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	5697	4938.3	8545.5	7028.7	11394	9119.1	14242.5	11209.5
	profit	-758.7	758.7	-1516.8	1516.8	-2274.9	2274.9	-3033	3033
4	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	6338	6584.4	9507	9371.6	12676	12158.8	15845	14946
	profit	246.4	-246.4	-135.4	135.4	-517.2	517.2	-899	899
5	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	6979	8230.5	10468.5	11714.5	13958	15198.5	17447.5	18682.5
	profit	1251.5	-1251.5	1246	-1246	1240.5	-1240.5	1235	-1235
6	total	641	1646.1	961.5	2342.9	1282	3039.7	1602.5	3736.5
	total cumulative	7620	9876.6	11430	14057.4	15240	18238.2	19050	22419
	profit	2256.6	-2256.6	2627.4	-2627.4	2998.2	-2998.2	3369	-3369

Farmbot E-mail

FarmBot Project

From: **Marc from FarmBot** | marc.roland@farmbot-59bca9df5d36.intercom-mail.com Saturday, 6 Nov 2021, 7:53 PM

To: **y.almatrouk1@gmail.com**

Yousef,

Thanks for taking my call today.

FarmBot is an open source precision agriculture CNC farming project consisting of a cartesian coordinate robot farming machine, software and documentation including OpenFarm a farming plant data repository. The project aims to "Create an open and accessible technology aiding everyone to grow food and to grow food for everyone." FarmBot is an open source project allowing hardware, software and documentation modifications and additions from users.

This is one of our YouTube videos showing one of our latest models (FarmBot Genesis XL):

https://youtu.be/60htrqei_U0

We need to develop new tools for FarmBot. We have several tools that need some engineering design and research and we could certainly use your help to develop the ideas and potentially use the designs in our production units.

These are a few examples of Proof of Concept projects that Liberty University has completed for FarmBot.

Liberty University Seeder Pod Tool - Proof of Concept

https://youtu.be/URjMCEnDowc

Liberty University Weed Trimmer Tool - Proof of Concept

https://youtu.be/nfteqo_ALzo

These proof of concept projects have developed into actual tools in our development pipeline.

For your project and timeline, I would suggest these FarmBot Tool Project Options:

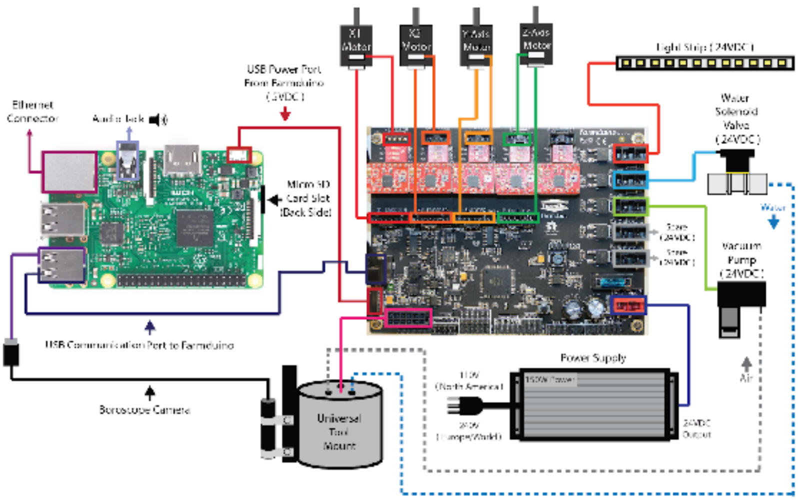
1.**Laser Weeding Tool**

This tool would work for the elimination of unwanted vegetation and potentially pests in the garden strong burn through leaves and kill small insects. The laser would need to operate on 24V DC and off the shelf components to interface with the FarmBot UTM tool.

This laser or something similar is available online.

https://www.amazon.com/Creality-Engraver-Engraving-Attachment-Blue-Violet/dp/B08SHCJ7V4/

Your objective would be to create a reliable and sturdy laser tool attachment for the FarmBot. This tool would energize and operate from a 24V power connection from our peripheral ports on the Farmduino control board. These ports are noted in grey as Spare (24V DC) on the right hand side of the control board.



2.**USB based weather station for the FarmBot**

This is a software integration along with some hardware project. We are looking to create an Open Source Farmware module for the FarmBot so that users would get complete logging capabilities of the weather conditions.

We would suggest using an “off the shelf” weather station and integrate it into the FarmBot software using Farmware. This weather station would connect to the Raspberry PI via USB and it would collect temperature, pressure, humidity, wind direction, and solar intensity. (Not all of these measurements are required but at least Temperature and one other measurement would be desirable)

Here are some example USB weather stations:

https://www.raspberrypi.org/learning/weather-station-guide/
https://www.bc-robotics.com/tutorials/raspberry-pi-weather-station-part-1/

https://www.acurite.com/pro-weather-station-with-pro-plus-5-in-1-sensor-pc-connect-wind-and-rain.html

https://www.oregonscientificstore.com/p-355-oregon-scientific-wmr89a-full-weather-station-with-usb-and-7-day-data-logger.aspx

https://www.firstlightoptics.com/astronomy-cables-leads-accessories/astromi-ch-mbox-meteostation-usb-weather-station-with-usb-cable.html

Please let me know if I can be of further assistance with respect to the FarmBot.

Marc

Marc from FarmBot