METR4900 Project Proposal

Farmbot GrowRoom

Madison Beare

43939442

University of Queensland

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1 Project Definition

1.1 Introduction

AgTech is the ability of digital technologies to provide the agriculture industry with the tools, data and knowledge to assist in making informed decisions to improve farming productivity and sustainability [1]. With an increasing population, changes in demographic trends, depleting natural resources, climate change and consumer dietary demands driving the change of the agriculture industry, Australia has now been presented with an emerging opportunity for AgTech. Thus begs the question: 'How can technology be used to improve and assist the agricultural sector?'.

This project proposal will focus on the design of a robotic arm to be used in conjunction with a spherical structure (the GrowRoom) that enables individuals to grow and monitor their own food. To accomplish this, a review and analysis will be completed on past and current applications. From this, a preliminary design solution will be presented.

1.2 Statement of Purpose

The purpose of the FarmBot GrowRoom Project is to create and deploy a central controller that allows the application to be remotely controlled through a web portal interface [2]. More specifically, this project will focus on the design and build of a Computer Numerical Control (CNC) machine that is able to move vertically and horizontally to access plant beds in the spherical GrowRoom.

1.3 Goals

The goals of this project include the following:

- Design, prototype and build a 6 Degree of Freedom (DOF) robotic arm to be remotely controlled through a web portal interface;
- Create 3D CAD models of the GrowRoom and simulate movement of arm;
- Integrate the arm design with the current FarmBot Universal Tool Mount (UTM); and
- Ensure design is optimised, completed and functioning at project completion.

1.4 Scope

The scope of this project is outlined in Table 1.1.

Table 1.1: Scope of Project

In Scope	Out of Scope
Mechanical design of 6 DOF arm	Construction and assembly of Growroom
Electronic design considerations and build	End-effector design
Software development for arm functionality	
Selection of components	
Modifications to current Farmbot Universal Tool Mount (UTM)	
Physical prototyping	

2 Topic Definition

To understand the application to be designed, built and tested, relevant background information must be understood.

2.1 Project Description

Predictions from the Food and Agriculture Organisation of the UN (FAO) predicts that food supply will need to increase globally by approximately 60% by 2050 to sustain the estimated increase in the Earth's population [1]. Due to this, Australia must begin to look towards the country's ability for increased food production. This project focuses on the creation of an automated arm designed to fit inside a GrowRoom and assist in the production of crops in a more local setting and to tackle the rapidly increasing demand for more food in the future [3].

2.2 GrowRoom

Created by SPACE10, IKEA's external innovation hub, the GrowRoom is the spherical structure designed to promote local food production [4]. This structure is the basis of design for the robotic arm, and the topic of this proposal. The GrowRoom structure can be seen in Appendix A.

2.3 CNC Components and Architecture

A CNC machine can be described as a machine that creates three dimensional objects from a solid block of material through the use of multiple carving tools [5]. For the purposes of this project, only the chassis of a CNC machine will be replicated. That is, the standard end-effector (usually comprised of a mill, drill or lathe tool component) will not be required. For replication purposes, the main components of a CNC machine have been identified.

2.3.1 CNC Software

The controller/computer in a CNC machine are generally operated by means of three types of software programs. These can be described as the operating system software, machine interface software, and application software [6]. The primary function of the operating system is to drive the machine tool axes by generating and handling control signals, while the machine interface software acts as a communication link between the central processing unit (CPU) and the machine tool axes [6]. The application software dictates the position of the end-effector relative to the workspace provided.

2.3.1.1 Geometric Code (G-Code)

G-code is the most common CNC programming language that instructs machines where and how to move. To ensure the accurate movement of the system, transnational performance is described in three simple ways [7]:

1. Rapid move: linear movement to an XYZ position at the fastest speed possible.
2. Feed move: linear movement to an XYZ position at a specified rate.
3. Circular move: circular movement at a specified rate.

G-Code follows some variation of an alphanumeric code that are used as a simple way to define motion, declare a position, set a value, select an item and dictate power mode (i.e. on/off) [7].

2.3.2 Machine Control Unit (MCU)

A machine control unit (MCU) is a computer with related hardware that executes programs/instructions by converting each command into specific actions of the processing equipment [6]. A general configuration of this control unit is shown in Figure 2.1.

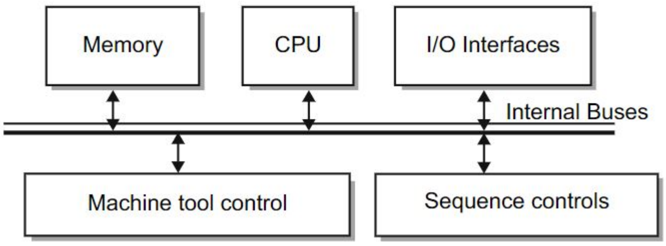

Figure 2.1: General Configuration of the MCU

Source: [5]

Each of these contributes to the effective motion of axes through reception and interpretation of translated data.

2.3.3 Drive System

Basic functionality of a CNC machine includes the requirement for automatic, precise and consistent movement [6]. A general co-ordinate system comprising of a standard axis must be used to define the position of the end-effector relative to the workspace to ensure driving system accuracy.

This system generally comprises of three linear axes (x, y, z) in the Cartesian coordinate system, plus three rotational axes (a, b, c) as shown in Figure 2.2.

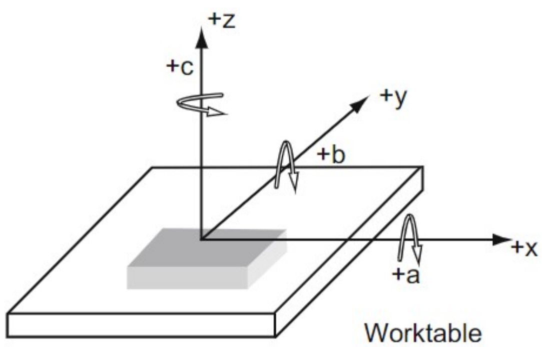

Figure 2.2: General Coordinate System

Source: [5]

Two common transmission systems to drive linear axes of a CNC controller can be comprised of either leadscrews or belts and pulleys - both powered by motors.

2.3.3.1 Leadscrew Transmission

A leadscrew is a threaded rod that turns rotational motion into linear motion. Transmission systems that make use of these rigid, threaded rods are designed to be accurate, strong and reliable [8]. Due to the high repeatability and accuracy, little ongoing maintenance is required.

2.3.3.2 Belt and Pulley Transmission

A belt and pulley CNC machine is commonly seen in 3D printer designs, and are significantly lighter than leadscrew transmission systems [8]. Not limited by size/length, a belt and pulley system can be fixed around a rolling wheel or fitted over gears if required.

2.3.4 Feedback System

Feedback systems relay data and information specifications during and after a process is completed [9]. Feedback devices include linear transducers, limit switches, direct position scales and linear/rotational encoders. Each of these devices aims to detect/monitor the presence of an object to indicate whether the movement limits of that object have been exceeded [10].

3 Literature Review

This section will outline and summarise existing works and developed applications with similarities to this project.

3.1 FarmBot

3.1.1 Overview

FarmBot is an open-source, automated CNC farming machine [11]. The CNC farming machine consists of a Cartesian co-ordinate, gantry style robotic system. FarmBot is capable of movement in the x,y and z planes.

There are two different models of FarmBot - FarmBot Express and FarmBot Genesis. FarmBot Express has been made to accommodate affordability and ease of construction, while FarmBot Genesis offers enhanced capabilities with advanced features and is able to service larger areas [12].

The core components of FarmBot Genesis are detailed below.

3.1.2 Hardware

3.1.2.1 Structure

Appendix B Figure B.1 gives a basic overview to the structure of FarmBot genesis, in relation to a specified workspace. From this, it is clear that x, y and z plane movement are governed through different physical structures.

Tracks allow the FarmBot genesis to move along the x-axis. These tracks are composed of 1.5m long aluminium extrusions, positioned end-to-end to allow for track lengths of 3m, 6m and 18m, depending on the size of the ordered kit [13].

The FarmBot gantry structure is comprised of linear guides created from V-slot aluminum extrusions and V-wheels from Open Builds [14]. This gantry rigidly bridges the tracks, spanning in across the y axis. These linear guides are incorporated with aluminium alloy plates and brackets, as well as ABS plastic components to assemble the FarmBot Genesis Structure shown in Appendix B Figure B.2.

The cross-slide moves along the y-axis (the fixed gantry). This serves as the base for the z-axis to attach to while the Universal Tool Mount is attached to the z-axis.

3.1.2.2 Transmission System

The FarmBot Genesis drive-train consists of four NEMA 17 stepper motors with rotary encoders. These allow for x, y and z translation. GT2 timing belts and pulley are directly attached to the stepper motors/driveshafts and assist in movement in the x and y directions. A stainless steel precision leadscrew (8mm ACME) is used to allow movement in the z direction [15].

3.1.3 Electronics

A Raspberry Pi 3 is used as the "host computer" of FarmBot [16]. This runs FarmBot operating system, communicates with the web application over ethernet or WiFi, and communicates to the Farmduino over a USB serial connection [16].

A 'Farmduino' is a customised electronics board that incorporates the functionality of a microcontroller (MEGA 2560) and a Reprap Arduino Mega Pololu Shield (RAMPS) shield [16]. This integrates with the stepper motors and monitors information from feedback devices whilst receiving commands from the Raspberry Pi.

3.1.4 Software

The FarmBot software system is comprised of external resources, the FarmBot web application, the user, and the FarmBot device [17]. Each component will be outlined below, with a high level overview shown in Appendix C.

3.1.4.1 FarmBot Cloud Services

FarmBot Web Application
The FarmBot web application allows for control and configuration of the Farmbot through smart devices [17]. This application includes features such as drag and drop farming and the graphical design of the garden to user specification.

Message Broker
This is a cloud application that acts an an intermediary between the external resources, the web application, the user and the FarmBot device. Socket connections, device identification and authentication are handled through this intermediary medium [17].

3.1.4.2 Device Software

FarmBot Operating System
A Raspberry Pi runs a custom operating system for the FarmBot to interact with the web application via the message broker [17]. This allows events to be controlled in real time. This operating system communicates with the Farmduino/Arduino to send G and F code commands and also receives and collects data from feedback systems [17].

Arduino Firmware
The firmware of the system is uploaded onto the Arduino/microcontroller and is used to configure and control stepper motors and rotary encoders, tools and peripherals, sensors and other electronic components. It receives G-Code commands and sends collected data from feedback systems to the Raspberry Pi.

3.1.5 Universal Tool Mount (UTM)

The UTM is a plastic component mounted to the z-axis that allows for the switching between different tools to complete tasks. This is the end-effector of the system and includes multiple piping connections/passageways for water, fertiliser and air to pass through [18].

3.2 KUKA

3.2.1 Overview

KUKA is one of the world's leading suppliers of intelligent automation solutions, and this includes applications of robotics, automation, logistics and electronics [19].

The KR IONTEC 6 DOF robot designed and manufactured by KUKA is shown in Appendix D. This robot arm is one of the newest applications, and has the desired reach for the proposed system.

The KR IONTEC has a payload of approximately 30-50kg depending on the model, and has a reach of up to 2100 - 2500mm [20]. For the purposes of this project, a no payload is required, however a reach of approximately 2500mm or greater is desired.

The KR IONTEC is equipped with both waterproof and dust-proof protected motors and its application is not limited to one area.In relevance to this project, KUKA.CNC has been researched to identify how a CNC application can be applied to a system that does not follow the standard CNC system/build.

3.2.2 KUKA.CNC

KUKA.CNC is a software system that can be linked to KUKA robots and allow them to be operated like a conventional CNC controller. This allows for CNC-based robot programming, improved robot path performance and offline programming options via CAD/CAM system [21].

To allow this operation, a Numerical Controller (NC) has been incorporated into the KR C4 - a controller/control system that incorporates robot control, programmable logic controller (PLC) control, motion control and safety control [22].

The KUKA.CNC option allows for KUKA robots to operate via G-Code. It can process complex programs from CAD/CAM systems due to CNC path planning and thus can integrate robots to play a direct role in the machining process [22].

The user interface of the KUKA.CNC allows for users to execute G-Code commands and CAD/CAM simulation without having to compile them into the robot language [21]

4 Progress

This section will detail the preliminary design of the arm, and current progress completed. It has been decided that a smaller scale GrowRoom (dimensions: height - 0.8m, diameter - 0.85m, ring spacing 0.2m) and arm will be designed and executed before a larger scale model is deployed.

The preliminary designs have been completed will the full-scale model in mind, under the assumption that any/all specifications met for the large scale design will be met for the small scale implementation.

4.1 Preliminary Design/s

There are three initial designs that have been considered potential solutions. These are outlined in the following subsections.

4.1.1 Extendable Arm CNC

This design features a design similar to a cantilevered 3D printer - this can be seen in Figure E.1 Appendix E. This design would incorporate much of the FarmBot mechanical components, and creates an inverted L-shaped arm. Difficulties associated with this is that the cantilevered arm must have an extension of some sort to be able to reach each planter box, as the edge of each is a different distance from the center (as the design tiers - shown in Figure E.2 Appendix E. The arm must also be able to move in and around the supporting structures that separate each box. This may require counterweight calculations to ensure the design is capable of the required extension. This design is fixed onto the bottom of the GrowRoom on a turntable device that allows the arm to rotate 360 degrees if required.

4.1.2 Multiple Extendable Arm CNC

This design mirrors the above cantilevered 3D design, with an arm at each tiered level of planter bed. Due to the dividers between the beds, this design would still need to incorporate an arm that is able to move/extend to reach the outer diameter of the boxes. This design means that arms can be fixed at each level and do not need to translate up and down the central arm. This design would keep the turntable as it's form of rotation. Although this reduces one axis of movement (by having fixed arms at each level), this design is also more complex in terms of setup, will require more components (more motors, electrical components, UTM's etc.) that may cause the design to become too mechanically complex.

4.1.3 6 Degree of Freedom Robot Arm

A KUKA 6 DOF robot arm can be seen in Appendix D. A design similar to this will require more calculation in terms of working out specific arm, shoulder and wrist lengths, and determining the inverse kinematics of the design to ensure it is possible to reach each planter bed. This design will not require any extendable mechanical parts, but will require extreme precision and potential complexity in terms of coding implementation. As the scale of this project is also large (approximately 2.5 meters fully extended) the arm lengths and subsequent torque requirements of motors may require components that are too expensive to be feasible.

4.2 Analysis and Feasibility

To determine the feasibility of each design, a decision matrix was created with the criteria of cost, design/build complexity and size. Before completing this, the following assumptions were made:

1. The multiple extendable arm (option 2) is approximately five times as expensive as the extendable arm option (option 1). This is because there will be five arms as opposed to one.
2. The 6 Degree of Freedom Robot Arm will be created from machined components.

Appendix F Tables F.1 and F.2 show the ranking parameters and the final rankings for each of the preliminary designs. As shown, the preliminary design with the lowest - and therefore most desirable - ranking is the Extendable Arm CNC. As each of the criteria were deemed equal in weighting, this design was chosen due to its potential low cost and size. From here, both this design and the 6 DOF robot arm should be developed further (as their rankings were extremely close) to determine which design is more feasible.

5 Project Plan and Resources

5.1 Key Milestones

The success of the project will ultimately be governed by the arm capability upon deployment. In order to achieve this outcome, milestones must be met along the project duration. These are outlined below.

5.1.1 Key Milestone 1: Design Finalisation

Date/s: 24/02/2020 - 13/04/2020
Resources: internet, research papers, CAD software.
Description: The preliminary design has been completed, and relevant adjustments made. All design choices have been justified and confirmed by theoretical calculations.

5.1.2 Key Milestone 2: Project Seminar

Date/s: 18/05/2020 - 22/05/2020
Resources: Internet, research papers, PCB software, CAD software, microcontroller software.
Description: This will be a presentation on the finalised design, with a full Computer-Aided Design (CAD) model completed. At this stage, all progress will be reported on and the theoretical design will be presented.

5.1.3 Key Milestone 3: Miniature Prototype Executed

Date/s: 03/08/2020 - 10/08/2020
Resources: Oscilloscope, general electronic components, microcontroller, motors, breadboards, hardware components, PCB manufacturer, power supply.
Description: The miniature prototype has been deployed, and any errors and areas of improvement have been identified. At this stage, changes are able to be made before the build and deployment of the full-scale model.

5.1.4 Key Milestone 4: Test/Completed Deployment of Full-Scale Model

Date/s: 05/10/2020 - 12/10/2020
Resources: All completed mechanical and electrical components.
. **Description:** A test of the full-scale model will occur. Any errors or areas of improvement will be identified for change before the final deployment occurs. Final demonstration will occur in both the thesis demonstration and the trade show.

5.1.5 Key Milestone 5: Thesis

Date/s: 19/10/2020 - 09/11/2020
Resources: Internet, final design and research completed.
Description: The final thesis will comprise of all research and design completed throughout the year. It will include a report detailing all progress completed and findings.

5.2 Project Schedule and Timeline

A more detailed breakdown of the project schedule is outlined in Figures 5.1 and 5.2.

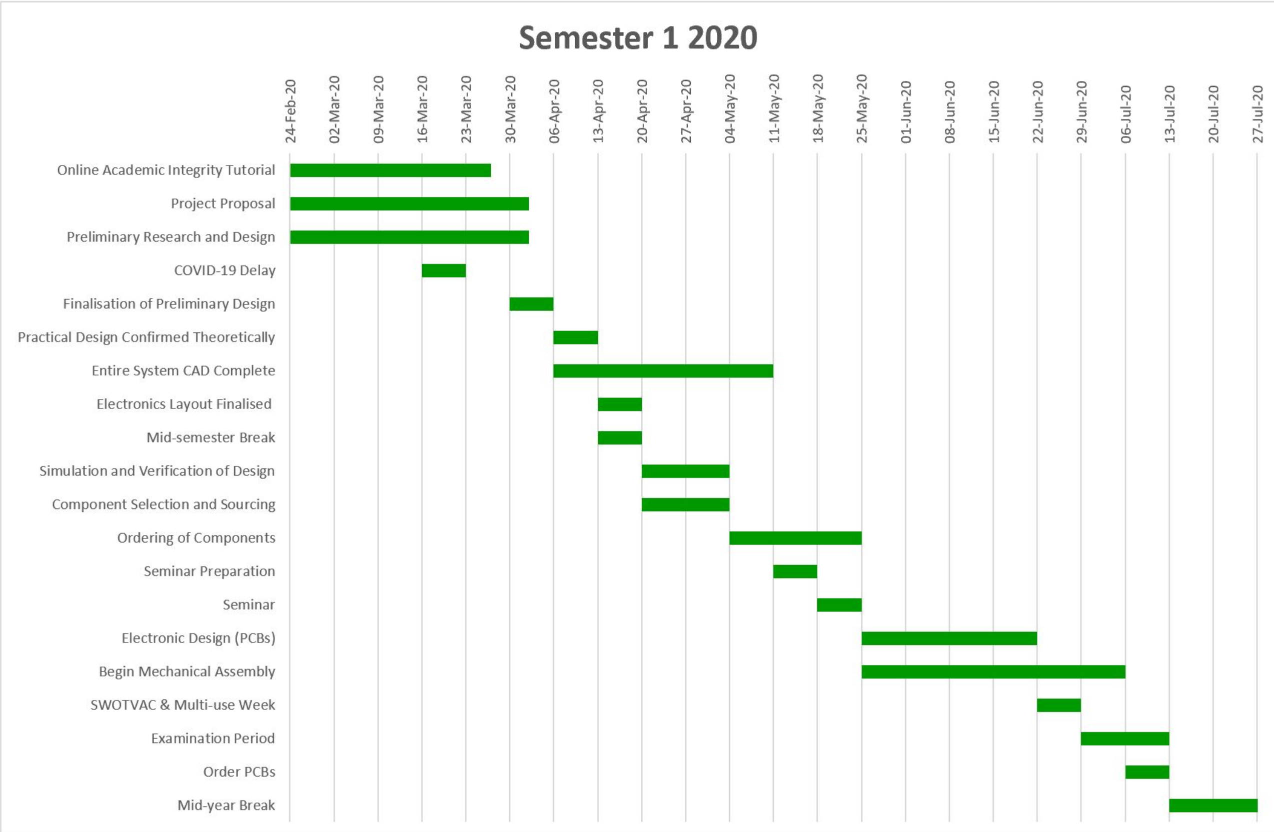

Figure 5.1: Semester 1 2020 Project Breakdown

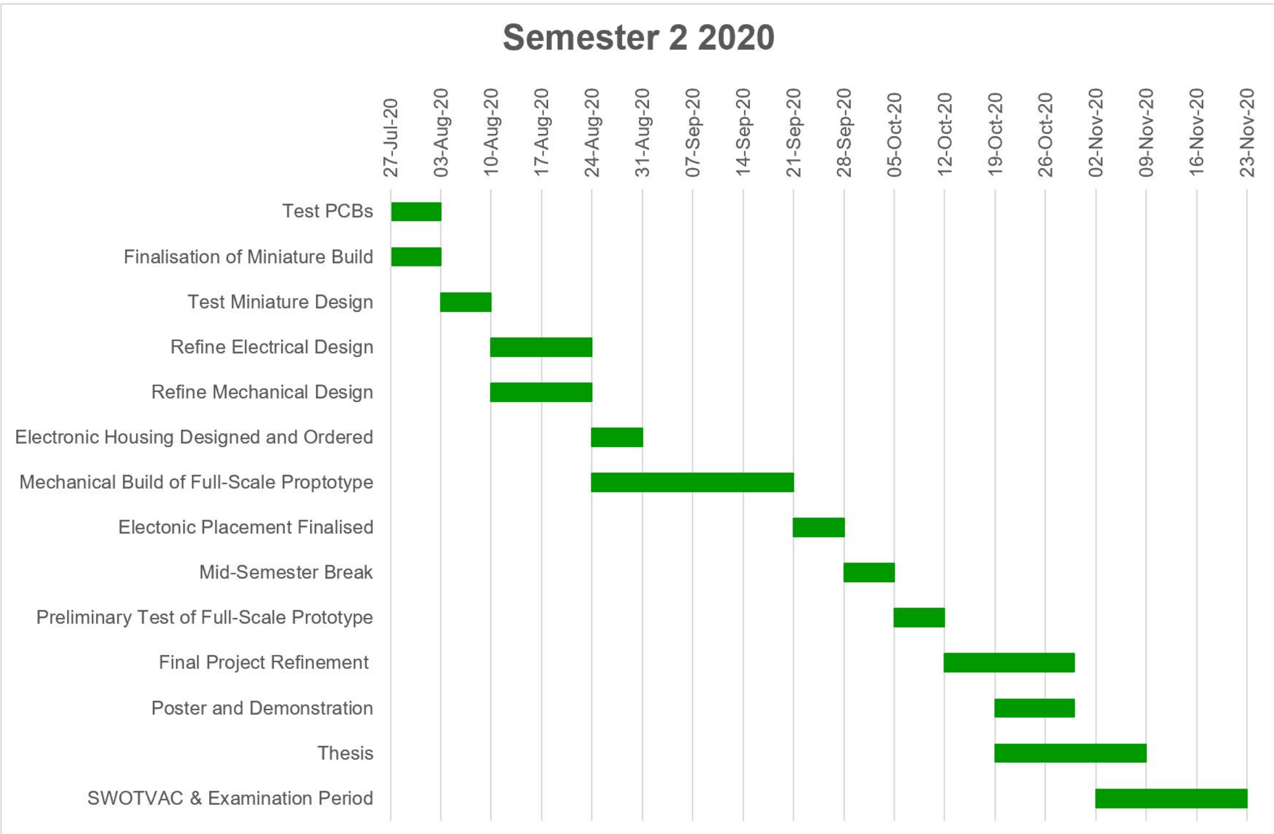

Figure 5.2: Semester 2 2020 Project Breakdown

5.3 OHS Risk Assessment

The Robotics Design Studio (50-C406) is a high risk laboratory, and the Electrical Engineering Project Laboratory (50-S105) is a low risk laboratory. OHS Laboratory Rules and Requirements have been completed to gain access to these labs, with Table 5.1 outlining the risks associated with completing the project in these locations.

Table 5.1: OHS Table

Hazard	Description	Risk Level	Mitigation Strategy
Electrical	Danger of electrocution due to electrical equipment malfunction	Medium	Ensure all electrical equipment is tagged and tested, no loose or fraying wires are present. Report all/any damaged equipment to supervisor.
Environmental	Slips, Trips and Falls	Low	Ensure all walk-ways are clear, and any spills are cleaned immediately.
Electrical	Burns due to component overheating or soldering	Medium	Keep hands clear of soldering irons at all times and turn power off to overheated components. Run burned area under cold water and seek further assistance if necessary
Environmental	Hazardous fumes from soldering	Low	Wear Personal Protective Equipment (PPE) when required, ensure soldering fans are on at all times.
Electrical	Danger of electrocution due to contact with water	Low	Ensure all components are waterproofed and care is taken when opening potentially wet component casings. Ensure all power is turned off prior.
Physical	Physical abrasions due to mechanical equipment (cuts, scratches, scrapes)	Medium	Ensure all cuts are made away from the body, take care when handling equipment and tools. Bandage area if need be, and seek further assistance if required.

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Appendices

A GrowRoom

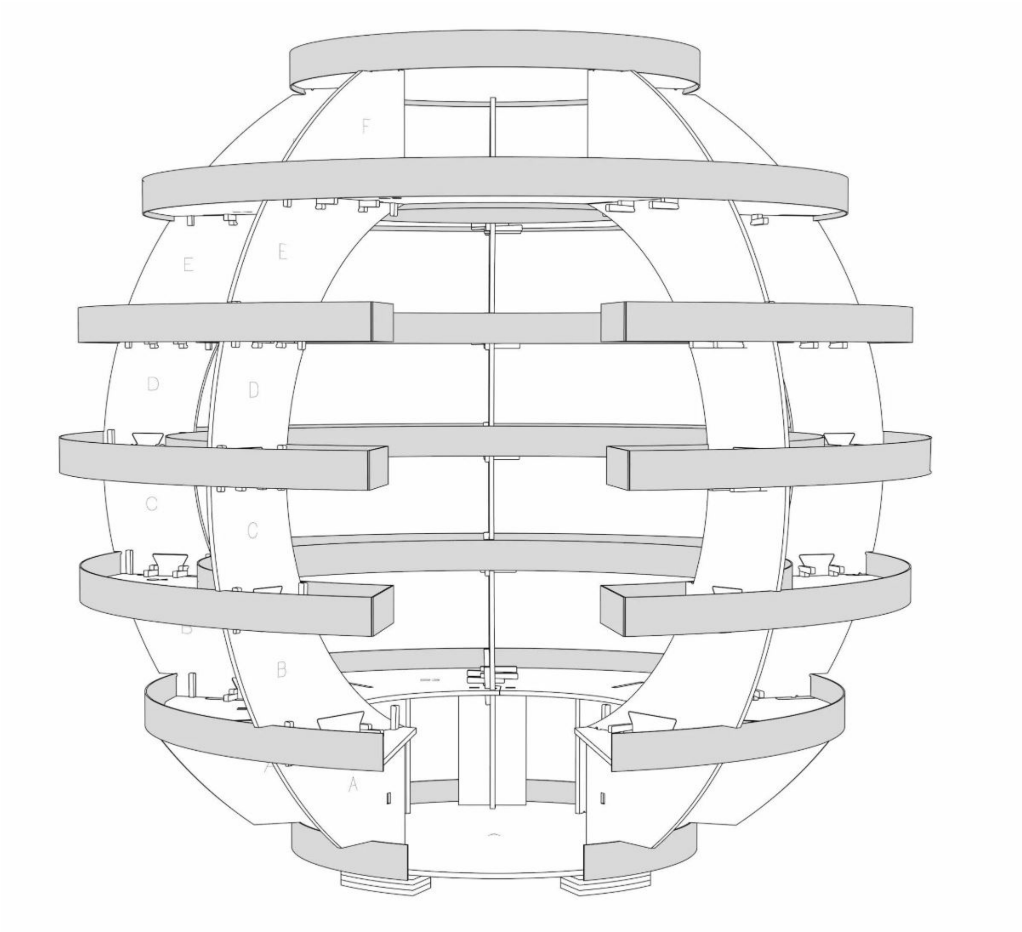

Figure A.1: Constructed GrowRoom

Source: [3]

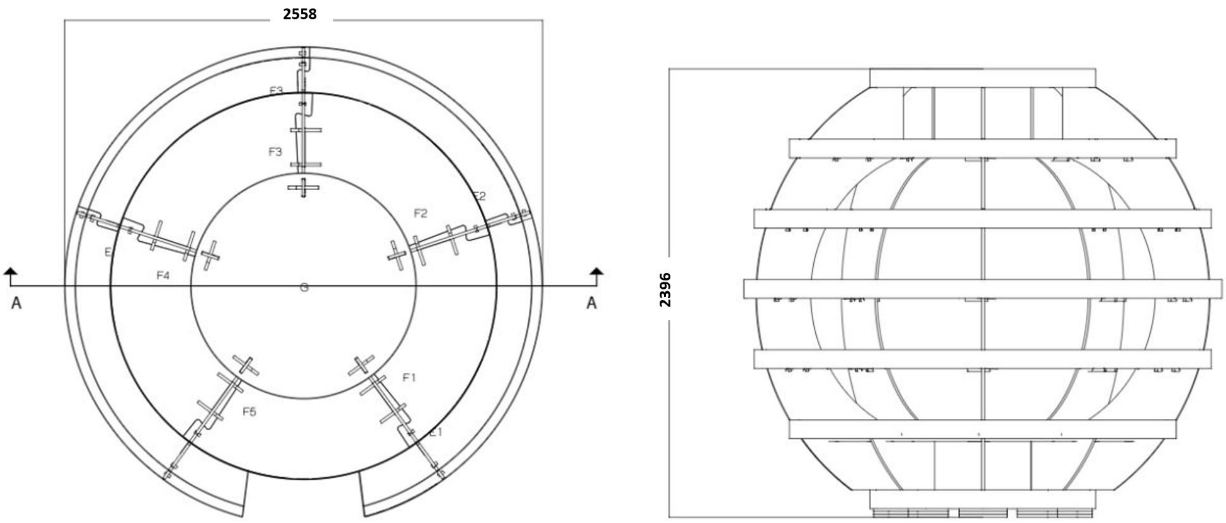

Figure A.2: Dimensioned Full-Scale GrowRoom

Source: [23]

B FarmBot Genesis Structure

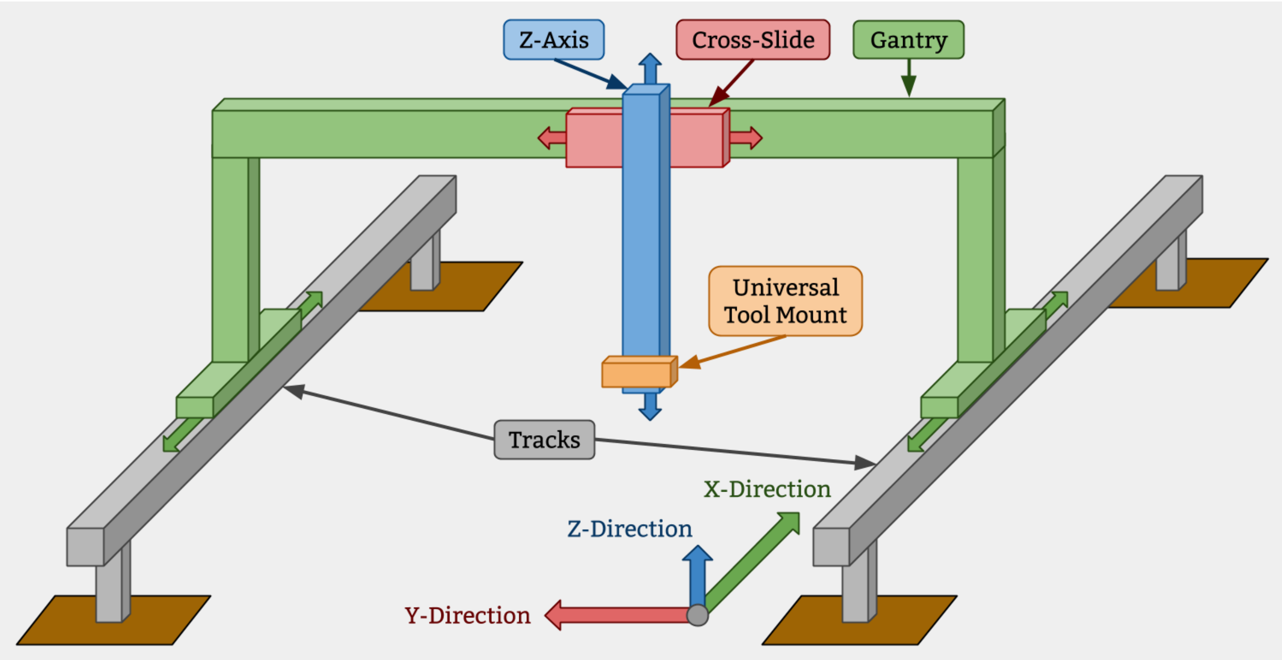

Figure B.1: High Level Structure Overview

Source: [24]

Figure B.2: Structure of the FarmBot Genesis

Source: [12]

C FarmBot Software Overview

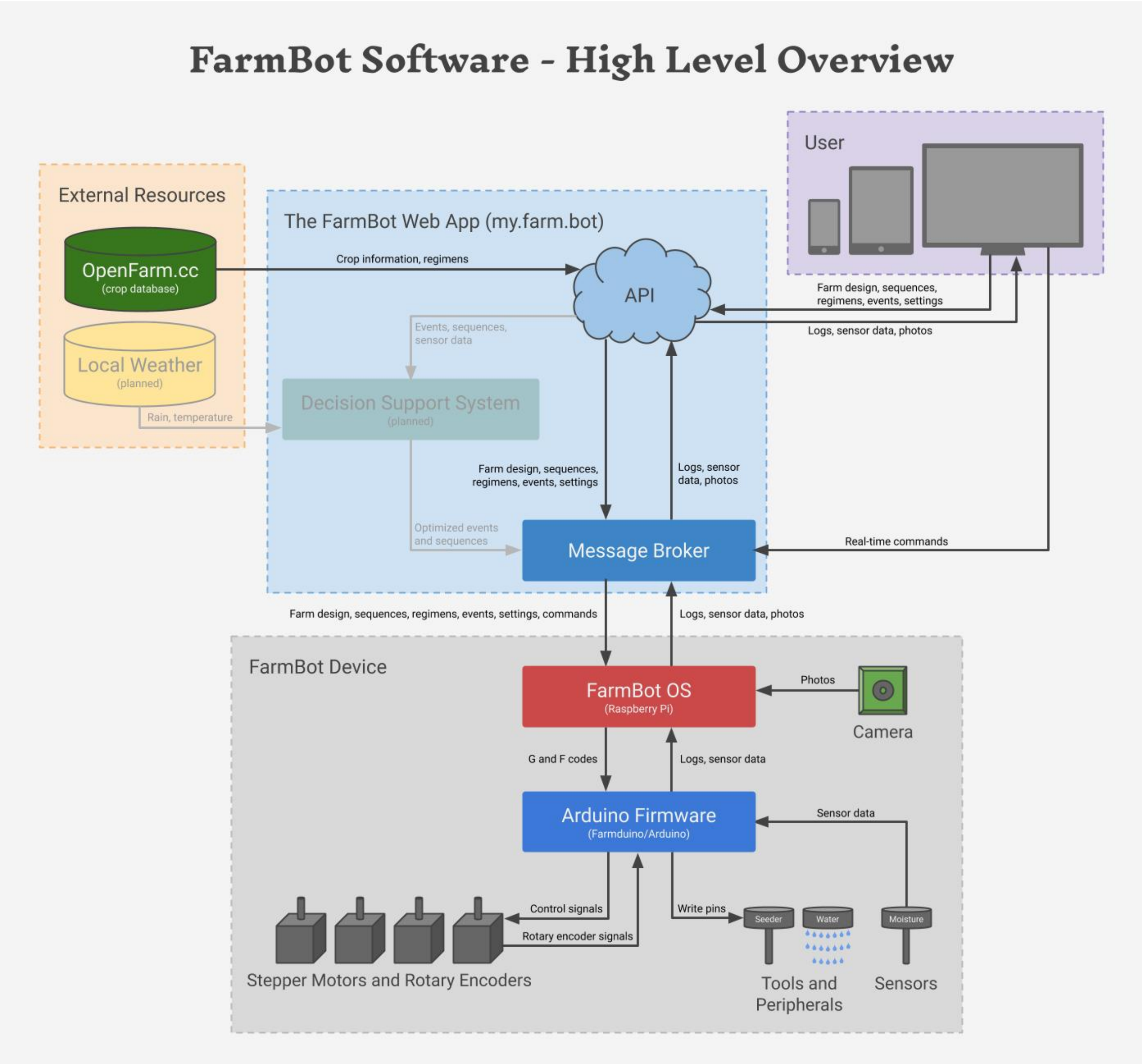

Figure C.1: High Level Software Overview

Source: [17]

D KUKA KR IONTEC

Figure D.1: KUKA KR IONTEC Isometric View 1
Source: [20]

Figure D.2: KUKA KR IONTEC Isometric View 2
Source: [20]

E Preliminary Design: Extendable Arm CNC

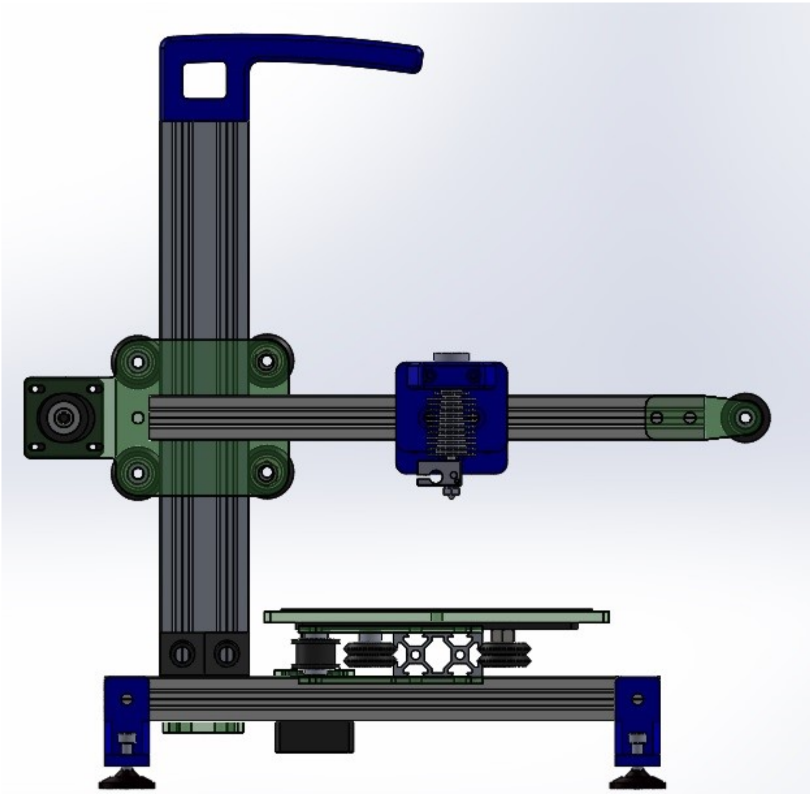

Figure E.1: Cantilever 3D Printer

Source: [25]

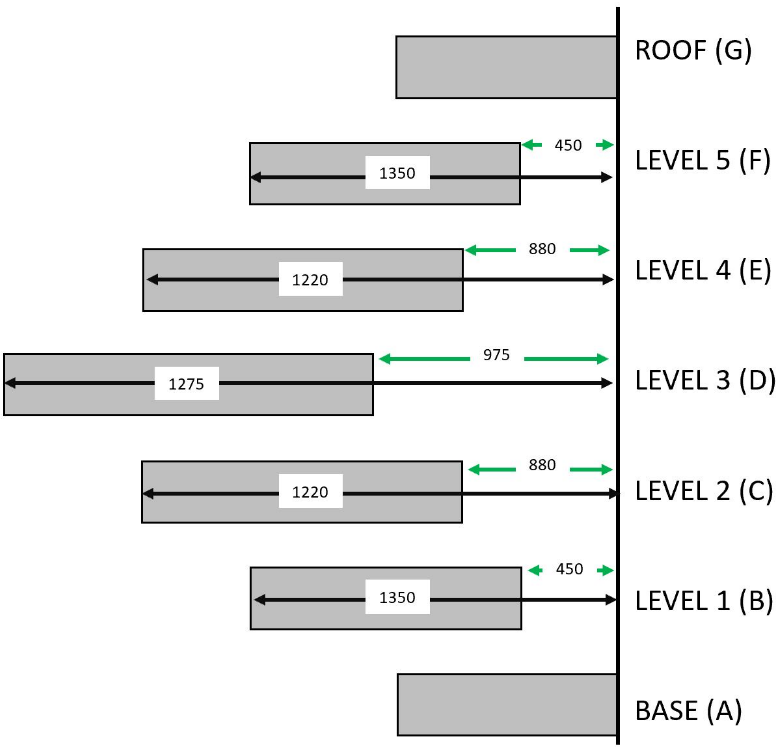

Figure E.2: Tiered GrowRoom Dimensions

Source: [26]

F Preliminary Design Analysis

Table F.1: Ranking Descriptions

	Rank				
Parameter	1	2	3	4	5
Cost	$0-$100	$100-$200	$200-$300	$300-$400	$400+
Complexity	Low complexity. The project is simple and can be completed well before submission deadline.	Relatively complex. The project is not extremely complex and can be completed well before submission deadline.	Adequately complex. The project is complex but can still be completed before the submission deadline.	Challengingly complex. The project is challenging but can be completed on/before the submission deadline.	Unfeasibly complex. The complexity of the project will hinder the ability to complete the project.
Size/Assembly	Compact in size/modular. The design can be assembled in <10mins and is modular and/or compact.	Relatively compact. The design can be assembled in <15mins and the size does not hinderance its ability to perform.	Adequately sized. The design can be assembled in (15-30mins) and the size is not overwhelming/a hinderance.	Oversized. The design is large but can still be assembled in 30-45 mins and is not overwhelmingly large.	Extremely oversized. The assembly of the project is too time consuming (45mins+) and the size is a hinderance for arm capability/performance.

Table F.2: Preliminary Design Rankings

Preliminary Designs [1]	Cost [2]	Complexity	Size	Total
Option 1	3	4	3	10
Option 2	5	4	5	14
Option 3	4	4	3	11

[1] Option 1 (Extendable Arm CNC), Option 2 (Multiple Extendable Arm CNC), Option 3 (6 Degree of Freedom Robot Arm).

[2] Based on makerstore component prices, and potential/predicted machining and manufacturing estimations from UQ EAIT Workshop.

Source: [8], [27]