Resistor sorting robotic arm

We could have an image of our arm here maybe?

|  |  |
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|  |  |
| --- | --- |
| Nomenclature | Meaning |
| RSA | Resistor Sorting Arm |
| V&V | Verification and Validation |
| MVP | Minimum Viable Product |
| V&V | Verification and Validation |
| RMP | Risk mitigation plan |
|  |  |
|  |  |
|  |  |
|  |  |

# Introduction

## Purpose of the report

Due to the complex nature of the project and the high level of interest from stakeholders this report was created showing the process’s taken to ensure the products feasibility and suitability to the problem proposed and the project scope laid out later. Each section will aid in the completion of future project as well as show the suitable steps in an engineering projects lifecycle were completed to a high level. Important parts of the project management are included and the last key section of the report allows a deeper dive into what could be improved for future projects and what lessons were learnt.

## Scope of the project

The resistor sorting arm (RSA) needed to quickly and accurately sort through a group of resistors with minimal human assistance. The arm needed to measure resistor resistance in a set location, pick the resistor up and move it to the correct box. While our MVP works with the E12 resistor series modifications to the code would allow an easy change to a different set of resistors and with more altering additional boxed could be added allowing more different resistors too be sorted.

## All necessary documentation

GitHub was used extensively throughout the project allowing all pertinent documentation to be stored in one location. Use of software similar to GitHub allows excellent version control and advanced team collaboration and allowing individuals to produce documentation at their own rate. The link to this projects GitHub repository is XXX, and the can be found in the uploaded documentation on blackboard. The necessary password is XXX

# Project management

## Risks and Management

From the onset of the project risks were being assessed and added to the risk mitigation plan. Initially a comprehensive list of all related risks was created and then added to through the project, each team member regularly reviewed the plan and made sure it was still suitable. The risk was categorised using Figure XX & XX2, then using conditional formatting in excel it was it was simple to understand which risks were most dangerous to the project. Each of the initial risks were use in creating the Gantt chart and allowing additional time to events which had a higher likely hood of being delayed.

Table

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Figure 1 - Risk Characterisation Table

Text

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Figure 2 - Risk Key

Graphical user interface, application

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Figure 3 - Risk's and Mitigation Plans

The Verification and Validation (V&V) plan (covered later in this report) was vital to the success of the project. V&V allowed the confirmation that all sections accomplished were traceable to the system and high-level design, and also completed their intended outcome, without adding bloat to the project. As V&V was so vital to the project the robust plan was formed early on and rigidly maintained throughout the venture.

The Design risks heavily rely on a vigorous V&V plan, through this the likelihood of a project delaying/cancellation issue is extremely unlikely. This is further evidence of the need for a competent V&V plan. Legal and contractual issues would be a greater issue past this project’s scope and after the production of the minimum viable product (MVP) but designing the arm from scratch will minimise these issues. Economic issues are largely out of the control of the start-up, however suitable mitigation in the case of an issue is still needed and provided. Through continued discussion with the stakeholders, described in the High-level design section, there is an undersaturated market for this product and minimal competition. However, if the market decreased/becomes oversaturated this could financially cripple the company so continued talks are necessary. As with any product, a suitable look into health and safety in the manufacture and use of the product is necessary and the necessary documentation will be provided for both.

The RMP was regularly updated periodically in conjunction with the project and GitHub as used for version control ensuring all different stages of the plan were saved and could be accessed if needed. As the RMP was created originally at the beginning of the project all team members knew what the risks were and how to avoid them happening allowing the project to complete smoothly with minimal issues.

## Team allocation

At the start of any project, it is vital to determine and define the team structure and roles, making sure everyone in the team understands their responsibility and roles. This breakdown is detailed in Figure XX 4). To further emphasise each team members roles and responsibility a responsibility matrix was created (Figure XX 5). This level of planning allowed team members to know what they needed to complete and who had the information to help them, also allowing individual members to make sure everyone else had completed their section.

Diagram

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Figure 4 – Team structureA screenshot of a computer

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Figure 5 - Responsibility matrix

## Planning and Scheduling

- Planning and scheduling

Diagram

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Figure 6 - Work Breakdown Structure

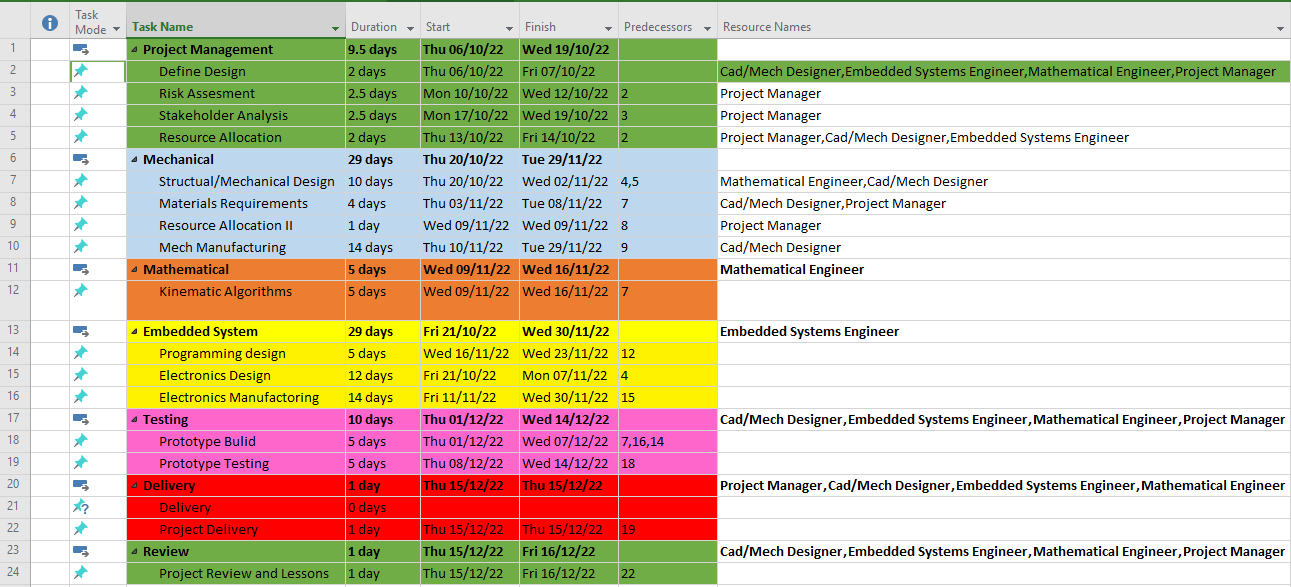


Figure 7 - Project Gant Chart 1

Timeline

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Figure 8 - Project Gant Chart 2

## Progress monitoring and Coordination

During the project weekly meetings were held and comprehensive meeting minutes were taken, as seen in the GitHub repository. This allowed everyone to know what had been discussed and also what they need to complete in order to stay on track and complete the project in time. Any task that was not completed for any reason was moved too the next weeks minutes and the project manager followed up with help to make sure they were completed. This use of meeting minutes on GitHub gave clear instructions to every team member on what was necessary to be completed, when uploaded to GitHub the meeting minutes document was available to everyone and any changed that were made would be visible.

# High-level design

## Top-Level System Design

*- Presentation of top-level system design. Clear presentation of top-level system design. Clear presentation of high-level design of the main subsystems (e.g. software, electronics). High level designs address all requirements appropriately.*

Table

Description automatically generatedTop level system design and high-level design require conversation with the stakeholders, to ensure all stakeholders are considered each team member had a template stakeholder analysis , Figure XX, which allowed multiple stakeholders and their importance along with other metrics which decided their allocation in the stakeholder management document. With each team member independently conducting a stakeholder analysis the likelihood of a potential stakeholder being missed is drastically reduced allowing a more exhaustive management of the stakeholders. All members included the electronics technical help team at the University of the West of England as a key stakeholder providing the unique possibility to have their opinion every week during the meetings held. This close management of a key stakeholder allowed the project to stay on track and gave very good system and high level design criteria.

Figure 9 - Stakeholder Analysis

Utilising the stakeholder analysis and either talking directly to the stakeholder or using our tutor as that stakeholder a list of all the requirements (Figure XX) was created and the stakeholder sign off was used. This stakeholder requirements analysis created the requirements list document which allowed for a clear view of what was desired by the clients and what was needed to complete the project to satisfaction. Once the stakeholders, the UWE Fet Team and a representative group of hobbyists, had read the requirements list any changes were made and the document was signed off. The requirements meant that three sub systems were needed – Mechanical, software and electrical sub-systems. The Mechanical sub system will control the redesign of the arm, the new gripper, the wooden base and the kinematic algorithm used to more the arm. The software subsystem will translate the kinematic algorithm created in the mechanical subsystem into readable code for the controller configured in the electrical subsystem, as well as any other programming needed i.e. WiFi control. The electrical subsystem will configure the setup for the processor, peripheral components and then any wiring and calibration.

A screenshot of a computer

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Figure 10 - Requirements list

## High-Level Mechanical Design

The key change made to the arm was the gripper design, the team went through multiple iterations of designs after having completed a comprehensive Concept development document a seen in the GitHub repository. The designs rudimentary designs can be seen in figure XX.

Table, Excel

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Figure 11 - Original ideas for Concept development

Figure 12 shows a gripper design allows for the mounting of a pcb on the top, an electromagnet and strips of copper to allow for measring and picking up resistors.

Diagram, engineering drawing

Description automatically generatedDiagram, engineering drawing

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Figure 12 – Robot arm redesigned gripper on Fusion 360

Background pattern

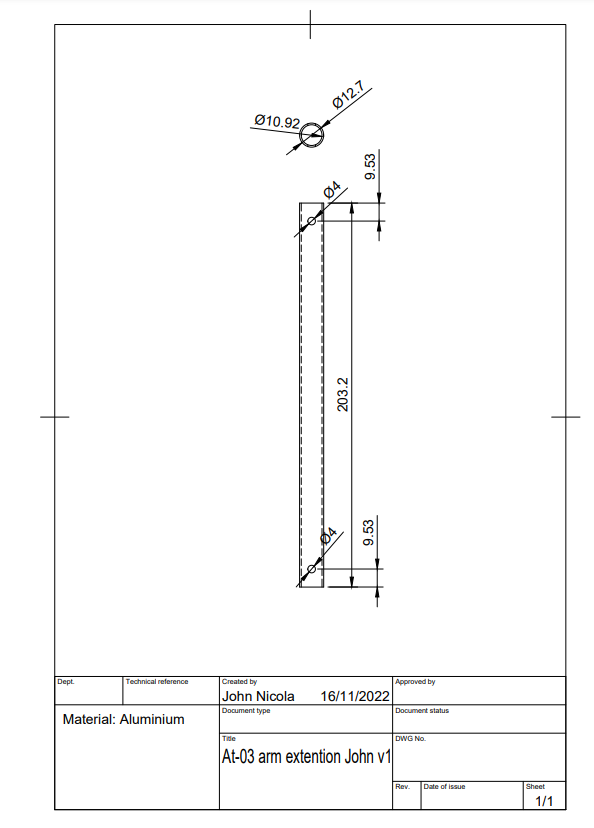
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Figure 13 – Robotic Arm Extension on Fusion 360

This arm extension was designed on fusion 360 and manufactured in the metal workshop at UWE Frenchay Campus. This was completed to allow the arm to have a 50 cm working envelope.

## High-Level Embedded System Design

First the documentation for the Lynxmotion ‘SSC-32u’ arm controller board was analysed. The control system uses a UART serial connection to receive control commands and to send some return data back as well. The UART connection could be configured to a desired baud rate and then controlled from any other device with a serial port.

A basic serial message to move all the servos on the robot arm can be sent in the form of a string, beginning with # and ending with a carriage return <cr>

#0P1425#1P1500#2P1500#3P700T2000<cr>

The first part of the command:

#0P1425

#0 means that servo 0 is being controlled, then p1425 sets that servo to that position. So 1P, 2P, 3P is then controlling another servo.

The last command:

T2000

Sets the travel speed in milliseconds, so in this example the motors will allow move to their desired positions in 2 seconds.

The absolute (maximum) control command was measured to be no greater than 34 Bytes, therefore that is the total length of a message in our system and memory allocation considerations going forward were based on that measurement.

To read the value of resistors, the gripper design is based on 2 probes which act like ohm meter probes to read the resistance of the gripper and an electro-magnet which then picks the resistor up for it to be sorted to a predefined location. For reliable measurements, the PCB to read the value must be mounted as close to the probes as possible, as noise and resistance could affect the analogue reading over longer distances.

Due to the reliability of serial communication over the working envelope of the robot arm:

**REFERENCE**

(<https://www.digikey.com/en/articles/uarts-ensure-reliable-long-haul-industrial-communications#:~:text=With%20appropriate%20line%20drivers%2C%20a,485%20or%20RS%2D422%20interfaces>.)

*“With appropriate line drivers, a UART can work over long distances: from 15 meters (m) for the RS-232 serial data bus to 1000 m for RS-485 or RS-422 interfaces” [22 May 2019]*

The proposed design utilises an ohm meter on the arm itself, to read the value of the resistor and increase the reliability of that analogue reading, then send the processed reading to another “master” microcontroller which can then activate the robot arm. This will mean making 2 PCBs, one which could be mounted on the gripper and one to remain at the base acting as a master controller.

Given that the SSC-32u controller used serial messages to control the board, a serial connection would be needed for communication with the gripper and considering that the system may want to have flexibility to communicate with other devices such as a desktop computer alongside the arm controller. A microcontroller

Due to the recent upsets in the global semiconductor supply chain, certain, more popular microcontrollers, such as STM32F103vgt6 (core of the STM “blue pill”) and Atmega328p (core of the “Arduino Nano”) have become increasingly difficult to source, with back order waiting times sometimes over a year. Thus a microcontroller was chosen that was readily available with no foreseeable break in supply chain.

### High-Level Software Design

For communication:

* OhmMeter/Mag Board – **Atmega328p**
* Main Board- **Atmega328p**
* SSC-32u – **Atmega328p**
* Desktop PC Serial port

Communication protocol:

Setup:

* **Main board** *INIT position commands***>>** **SSC-32u**

Looping:

* **Main Board** *Move to starting position command* **>>SSC-32u**
* **Main board** *pick up/test position command* **>>** **SSC-32u**
* **Main board** *TEST ohm command* **>>** **OhmMeter/Mag Board**
* **OhmMeter/Mag Board** *Send AvgValue* **>>** **Main Board**
* **Main Board** *MagnetOn* command **>>** **OhmMeter/Mag Board**
* **Main Board** *Move to box position command, based on AvgValue* **>>SSC-32u**
* **Main Board** *MagnetOff* command **>>** **OhmMeter/Mag Board**

Settings:

**Setting 1:**

* **Main board** *send data log* **>>****Desktop PC Serial port**

**Setting 2:**

* **Desktop PC Serial port** *send box assignments* **>> Main board**

**Setting 3:**

* **Main board** *Read ohm meter (for testing)* **>> OhmMeter/Mag Board**
* **OhmMeter/Mag Board** *Return ohm reading (for testing)* **>> Main board**

**Setting 4:**

* **Main board** *Turn magnet on (for testing)* **>> OhmMeter/Mag Board**
* **Main board** *Turn magnet Off (for testing)* **>> OhmMeter/Mag Board**

Diagram

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### High-Level Electrical Design

The project required a system of reading values of resistance into a microprocessor, the value then denoting what box to sort the resistor in to.

Utilising an analogue to digital converter (ADC), resistance could be read from an unknown resistor by creating a voltage divider with that and another resistor of known value. Reading the voltage from that divider will give the resistance.

The resistance of known value is not random and does need to be within a relative range of that which is being tested. Thus, a feature which is seen in most multimeters, an auto ranging feature must be implemented to allow a wide range of values to be read without manually changing the resistor of known value.

The auto ranging design was chosen, using five PNP transistors, acting as switches between different known values of resistance, due to its small layout size compared to some other methods such as using an analogue multiplexer and some peripheral logic.

The system can be broken down as seen in **FIG**

Diagram

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Then a schematic was designed using Autodesk Eagle

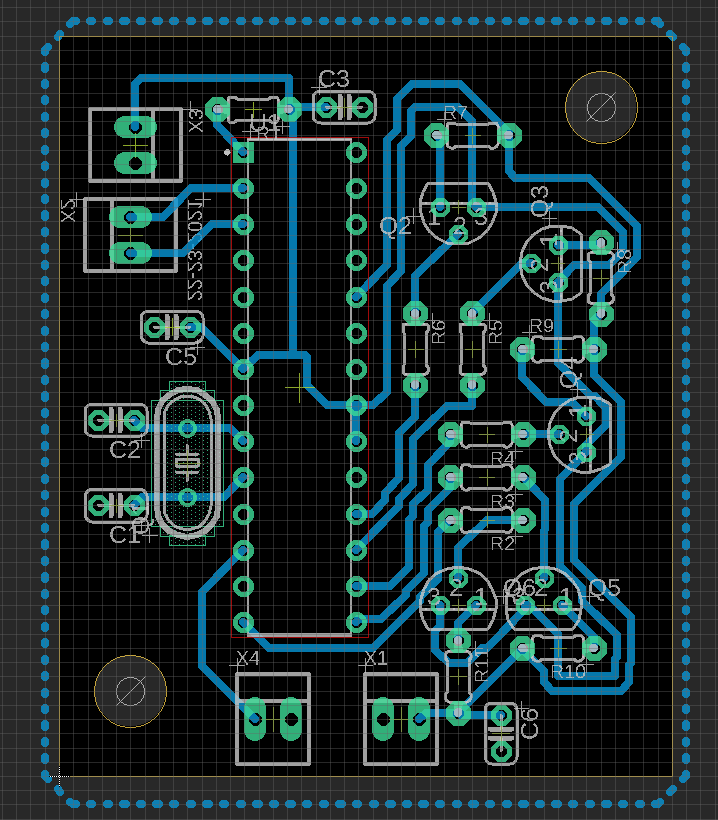
Diagram, schematic

Description automatically generated

The PCB was designed in eagle, and then pushed to fusion 360 to allow and 3D mounting holes and supports to be properly aligned.

A picture containing text, electronics

Description automatically generated



Diagram

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## Requirement Analysis

'- Requirements analysis

## Traceability

The High-Level design requirements were specified from user requirements, as is corroborated by the Requirements list. This list was form in collaboration with various stakeholders to produce a comprehensive idea of what the robot was required to complete. Each high-level design has a direct link to s system level design validating that the stakeholders would want it.

# Financial, Regulatory and Intellectual Property considerations

IP for the gripper electromagnet design and the code that goes with it

# Low-Level Design

## Implementation

'- Lower-level specifications and implementations to address the requirements.

* description of the process for developing and implementing the low-level designs, including justification of key decisions.

Designing the Base

The design of the base has two requirements from the Requirements List. - Figure 10. Requirement 1 and 5 from the list will need to be met for the design of the base to be a successful design.

A custom-built base was designed and manufactured. Wood was selected as the material as it is cheap and readily available. Since there is no significant load carrying or chances of wear, this was the optimal choice of material. This helps us to meet requirement 11 from the requirements list.

The base was designed to meet requirement 1 for the minimum working envelope of the robot.

The E12 family consists of 12 resistors, which means the robot should be able to sort resistors into a minimum of 12 different storage compartments. From the stakeholder analysis, we can see that UWE laboratory technicians are a very important stakeholder for this project. With this in mind, it was decided to have additional storage compartments to facilitate the storage of any resistors that are not part of the E12 series. As a result, the robot becomes a more convenient product as the user is not limited to only a handful of resistor values. The final design of the base includes 12 storage compartments for the E12 series, and two additional storage compartments for any resistors that the robot is unable to identify, or its value corresponds to a resistor value outside of the E12 series. The base design ensures requirement 5 has been met.

Designing a new Gripper

Requirements to be marked against 2,4 and 9

The team produced conceptual sketches shown in figure 11 of gripper designs to meet the requirements listed above. Although all designs met requirement 2, meeting requirement 9 became virtually impossible. This is because designing a gripper that would pick up a resistor by the ends, is extremely difficult and any rotation of the resistor will further decrease the chances of the gripper picking up the resistor. Therefore, to ensure the arm would pick up and sort the resistors correctly over 99% of the time, a new design was required. One that would be able to pick up resistors even when the resistor is not perfectly aligned. To solve this issue, an electromagnet was used to pick and place the resistors. The main advantage of the electromagnet is that the orientation of the resistor becomes a minor concern, as the electromagnet should pick up and place the resistor as required. Requirement 2 and 9 has been met.

The electromagnet gripper meets requirement 4 more efficiently than the other designs in figure 11. The designs consistently illustrate a necessity of movement of the gripper to pick up a resistor. Since there is movement required, the time taken for the process of sorting is increased, reducing efficiency. This is eliminated with the use of an electromagnet since there is no gripper movement required when sorting. Thus, requirement 4 has also been met.

INSERT GRIPPER IMAGE HERE, maybe the manufacturing of it?

How the gripper works – electrical – having to make sure the electromagnet is turned off while measuring the resistance because it would affect the results

Resistor Feeding Conveyor Belt?

To further improve chances of meeting objective 4, it was decided that a resistor feeding belt should be made. The user will place all the resistors onto the belt, and the belt would present the arm the next resistor to sort. To do this, an IR sensor was attached to ensure that the belt stops once a resistor is ready to be sorted. The belt allows for the resistor sorting process to be semi-autonomous, reducing sorting time, therefore allowing us to meet requirement 4 efficiently.

MORE detail about the design of conveyor belt would be nice

Measuring the Resistance

To meet requirement 4 and 9, it was decided that the optimum time of measuring the resistance would be when picking up the resistor. This is because it means that we can avoid an extra step of transporting the resistor to a measuring device first, then placing it in the correct storage compartment. By measuring the resistance before picking and sorting, we have saved time, improving efficiency which helps us to meet requirement 4. Also, there is a likelihood for the resistor to drop whilst being transported to a measuring device, and then to its box. As well as this, the gripper has to pick each resistor up twice before it reaches its final destination, which could decrease life expectancy.

Furthermore, there is a possibility that when the resistor is placed on a measuring device, it moves due to its speed or the force it is placed with. This means that the resistor will presumably not be in the exact same place where it was placed. This means that there is a higher chance of error and a lower success rate. By measuring the resistance before sorting, this is eliminated and requirement 9 is met.

In the following circuit diagram, the resistor being measured is connected between the A1 pin and GND on an Arduino board. A 100nF capacitor is included to steady the voltage across the unknown resistor. The circuit also includes five PNP transistors, which are all of the same type (BC559 or 2N3906) and function as electronic switches for the ohmmeter. The emitters of the five transistors are all connected to the 5V pin on the Arduino board. Each transistor's collector is connected to a different resistor, with only one transistor turned on at a time. For improved accuracy, it is recommended that each of the five resistors has a tolerance of 1% or lower. The base of each transistor is connected to an Arduino digital pin via a 4.7k ohm resistor. Additionally, the AREF pin on the Arduino board should be connected to the 5V pin and have a 100nF capacitor between it and the GND pin.  
Diagram, schematic

Description automatically generated

Each row in this array is in the order, (x, y, resistance in ohms), and can be configured to any value between 100R to 2M

long BoxCoordinatesXY[10][3] = {

    // Row 1

    {0, 260, 1000},       //1k

    {0, 330, 4700},       //4.7k

    {0, 390, 10000},      //10k

    // Row 2

    {80, 270, 20000},     //20k

    {80, 330, 47000},     //47k

    {80, 390, 86000},     //86k

    // Row 3

    {160, 270, 100000},   //100k

    {160, 330, 180000},   //180k

    // Row 4

    {240, 270, 470000},   //470k

    {240, 330, 1000000}}; //1M

Calibration function

void startAndCalibrateArm()

{

  Serial.println("#0P1425#1P1500#2P1500#3P700T2000\r"); // starting position

  Serial.println("#2PO-100\r");                 // calibrate

  // DEBUG

  delay(2000);

}

Kinematics string function  
char \*getArmCode(float x, float y, float z)

{

  float grip\_angle\_d = 68;

  // grip angle in radians for use in calculations

  float grip\_angle\_r = radians(grip\_angle\_d);

  // Adjustment so that the gripper hits the floor at z=0;

  z += 70;

  // Base angle and radial distance from x,y coordinates

  // float d = sqrt( x\*x + y\*y );    //distance from base center to x,y coordinates

  float phi = 90.00;

  float bas\_angle\_r = atan2(x, y);

  float L = sqrt((x \* x) + (y \* y));

  // L is y coordinate for the arm

  L -= cos(phi) \* GRIPPER;

  y = L;

  // Grip offsets calculated based on grip angle

  float grip\_off\_z = (sin(grip\_angle\_r)) \* GRIPPER;

  float grip\_off\_y = (cos(grip\_angle\_r)) \* GRIPPER;

  // Wrist position

  float wrist\_z = (z - grip\_off\_z) - BASE\_HGT;

  wrist\_z -= sin(phi) \* GRIPPER;

  float wrist\_y = y - grip\_off\_y;

  // Shoulder to wrist distance ( AKA sw )

  float s\_w = (wrist\_z \* wrist\_z) + (wrist\_y \* wrist\_y);

  float s\_w\_sqrt = sqrt(s\_w);

  // s\_w angle to ground

  // float a1 = atan2( wrist\_y, wrist\_z );

  float a1 = atan2(wrist\_z, wrist\_y);

  // s\_w angle to SHOULDER

  float a2 = acos(((sh\_sq - el\_sq) + s\_w) / (2 \* SHOULDER \* s\_w\_sqrt));

  // shoulder angle

  float shl\_angle\_r = a1 + a2;

  float shl\_angle\_d = degrees(shl\_angle\_r);

  // elbow angle

  float elb\_angle\_r = acos((sh\_sq + el\_sq - s\_w) / (2 \* SHOULDER \* ELBOW));

  float elb\_angle\_d = degrees(elb\_angle\_r);

  float elb\_angle\_dn = -(180.0 - elb\_angle\_d);

  // wrist angle

  float wri\_angle\_d = (grip\_angle\_d - elb\_angle\_dn) - shl\_angle\_d;

  // Servo pulses

  float bas\_servopulse = 1500.0 - ((degrees(bas\_angle\_r)) \* 11.11);

  float shl\_servopulse = 1500.0 + ((shl\_angle\_d - 90.0) \* 6.6);

  float elb\_servopulse = 1500.0 - ((elb\_angle\_d - 90.0) \* 6.6);

  float wri\_servopulse = 1500 - (wri\_angle\_d \* 11.1);

  // Set servo pulses

  // create string for output

  // Added some offsets here, not sure if they are correct, they seem to work though

  sprintf(output, "#0P%ld#1P%ld#2P%ld#3P%ldT2000\r", ftl(1500 - bas\_servopulse + 500), ftl(shl\_servopulse), ftl(elb\_servopulse), ftl(wri\_servopulse + 400));

  return output;

}

Order of Operations / Sequence Table

|  |  |
| --- | --- |
| Events | Duration / Seconds |
| Power On | 0.5 |
| User places resistor onto conveyor belt | 1 |
| Sensor Detects Resistor | 1 |
| Conveyor Belt Stops | 0.5 |
| Gripper Measures Resistance | 1 |
| Electromagnet turns on | 1 |
| Arm moves to allocated position | 2 |
| Arm returns to start position | 2 |

## Low-Level Documentation

- Clear and accessible documentation of low-level designs.

Gripper, base design, maybe some electromagnet stuff

Chart

Description automatically generated with medium confidence

Diagram, engineering drawing

Description automatically generated

Figure 12 - Engineering Drawing of the base

## Traceability

Diagram

Description automatically generated

Figure 13 - High -> Low level design with traceability

# Verification and Validation (V&V)

## V&V Plan

The V&V plan ensures that the end product is designed and built well and what the customer desired. To accomplish this a competent V&V plan was created at the onset of the project and strictly adhered to, this relied heavily on the V&V matrix (Figure XX) and the individual sign off.

A V&V matrix (Figure XX) allows for every key aspect of the project to be officially tested and verified to both work, and contribute to what is desired by the stakeholders. Each of the high-level designs and the lead team member(s) are listed with the ID of the verification used and whether this provided full of partial coverage. The different verifications used are found on the next sheet (Figure XX) and these describe the actions taken and are referenced using ID tags for ease of use. The V&V plan was used throughout the project and shows how successful the project was.

Graphical user interface, application

Description automatically generated

Figure 14 - V&V Matrix

Graphical user interface, text, application

Description automatically generated

Figure 15 - V&V Methods

At the end of each project management document a box is displayed which has a location for each member of the team to sign indicating they have reviewed the document and agreed that it is up to standard. Figure XX shows the document sign off box, it is a clear indication that the document has been reviewed and quality checked. In addition to the team member sign off certain documents have a stakeholder sign off which shows a stakeholder has checked the document and that it reaches the standards that are expected (Figure XX). These two boxes verify that what they represent is verified to what is wanted from the customer and also that it is a good solution to the problem.

Table

Description automatically generated

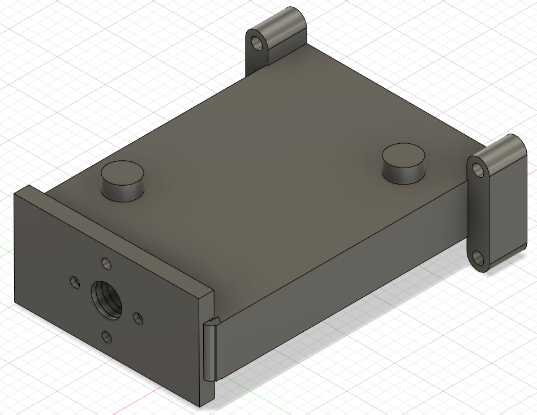
Figure 16 - Document sign off box



Figure 17 - Stakeholder sign off

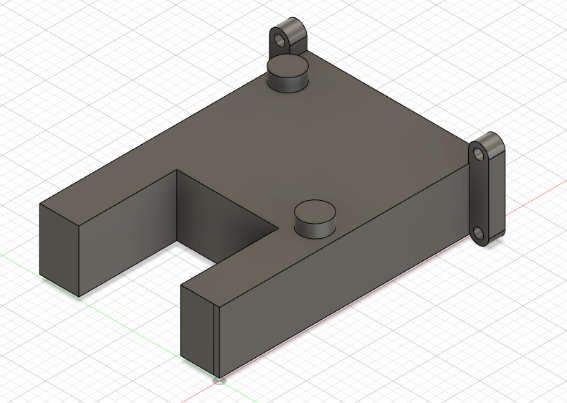
Diagram, engineering drawing

Description automatically generatedThis was the first variation for a gripper design that allowed for mounting of a pcb and the electromagnet:



Diagram, engineering drawing

Description automatically generatedThe second design allow for measuring the resistors by attaching copper strips to the ends:



## Diagram, engineering drawing Description automatically generated

## Evidence

Both the Document sign off’s and the V&V matrix provide evidence that the whole of the project has been quality checked and meets the standards of both the team and the stakeholders.

# Reflection and Evaluation

## Strengths of our project

- Thoughtful and accurate assessment of strengths and weaknesses in your group's design process.

## Weaknesses of our project

- Thoughtful and accurate assessment of strengths and weaknesses in your group's design process.

## Next steps in our start-up

What we would do to make the product more viable

- Identification of key lessons in generalised terms that can be applied to future projects.

## What we would do differently next time

- Identification of key lessons in generalised terms that can be applied to future projects.

For future projects a more indepth review into what the customer wants as well as a larger V&Vplan would be beneficial.

# Appendix

If we need it