FEEG2001 Design and Computing

# Technical Design Report

## Project Title: Eurobot

## Group: E06 – Indiana Drones


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**Date:**

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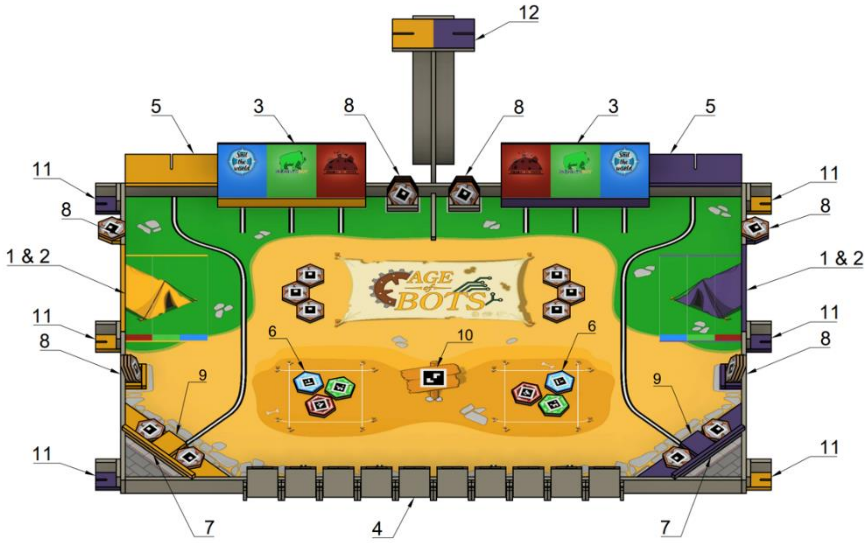
# 1. General Summary

## 1.1 Project Background and Contexts

*Eurobot* is an international amateur robotics competition created in 1998, with the aim to "foster and develop interest in robotics in young people on an international scale." **[1]** Teams of students compete to score as many points as possible within 100 seconds, by completing tasks on a competition table. As part of *FEEG2001 Systems Design and Computing*, teams from Southampton have had one semester to design and build robots to compete in the competition, starting with a national round before potentially moving on to the international finals.

The theme this year is *Age of Bots*, with all tasks being archaeology related. Points can be scored by manipulating samples (hexagonal tiles) across the board, moving, and displaying a statuette, flipping excavation squares, and returning to the campsite at the end of the match. Bonus points are given for correctly predicting the robots' points total.



1. Starting Areas
2. Campsite
3. Gallery
4. Excavation Squares
5. Exhibition Hall
6. Excavation Site
7. Work Shed
8. Dispensers
9. Pedestal
10. ArUco marker 42
11. Fixed Beacon Support
12. Central Tracking Device

**Figure 1:** Annotated view of the playing surface

## 1.2 Assumptions

The main assumptions for the project relate to the competition surface; that it is always within regulations, both with regards to overall dimensions and placement of playing elements. Additionally, the playing surface is assumed to be flat with constant and consistent roughness and no discontinuities. All playing elements are assumed to be the size specified in the rules within tolerance.

Some assumptions were made with regards to the robot components supplied to the team. The MD25 motor driver board and EMG30 motors with encoders were assumed to relay accurate positional feedback for the wheels, which is required for a consistent strategy.

## 2. Design Concept Development

### 2.1 Concept Generation and Selection

Key features for both robots were decided upon by estimating the performance, budget, and complexity of each concept. The names of robots 1 and 2, *Indiana* and *Boulder* are references to the movie Indiana Jones, in order to fit with the theme of the competition.

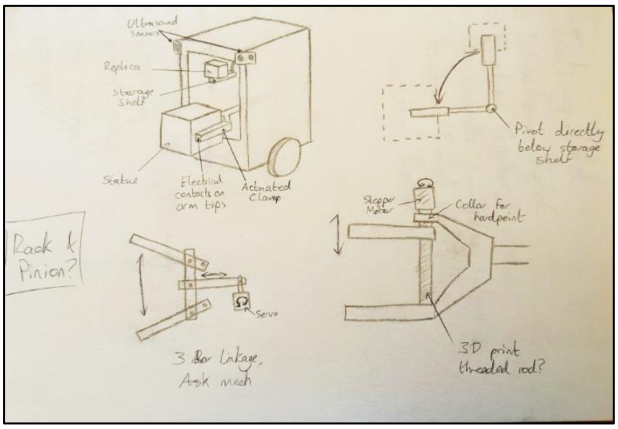



**Figure 2:** Concept drawings for *Indiana*.

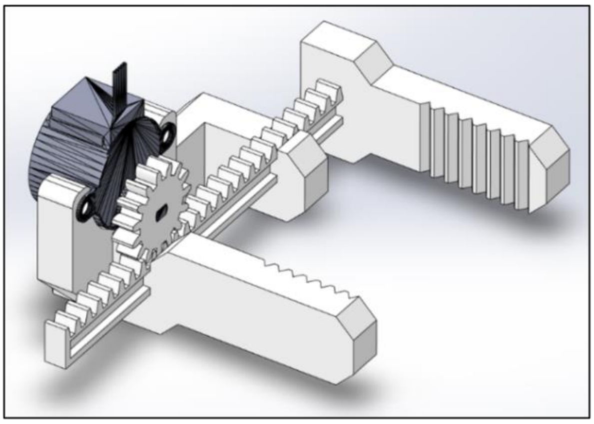


**Figure 3:** Rack and pinion CAD model

*Indiana's* design concept in **Figure 2** uses a single grabber to hold the statue; the replica is stored on a shelf above the grabber. The grabber pivots upward and collects the replica when required. *Indiana's* design was simple and reliable to produce, consisting of only four 3D printed parts. The cost for *Indiana* was small, as it mainly required materials provided by the workshop, while the arm was 3D printed by one of our group members. The concept takes inspiration from previous competition winners and Ocado fulfilment robots for storing goods.

*Boulder* is responsible for picking up tiles; initial concepts featured a suction cup grabber due to perceived ease of picking up tiles without having to be exactly centred on the tile **Figure 4**. This concept had a rack and pinion mechanism to release the tile. During later stages of concept generation, it was discovered that the tiles were textured, so, suction cups could not seal around the tiles and pick them. This caused the design to be changed to a linkage mechanism, picking up tiles by the edges **Figure 6**. The new screw driven linkage was created late in the design process, so was rapidly prototyped straight into the test chassis.

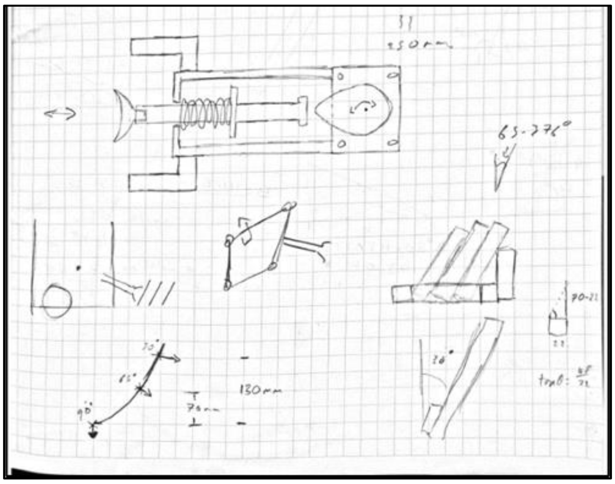


**Figure 4:** Suction cup grabber and tile storage concepts

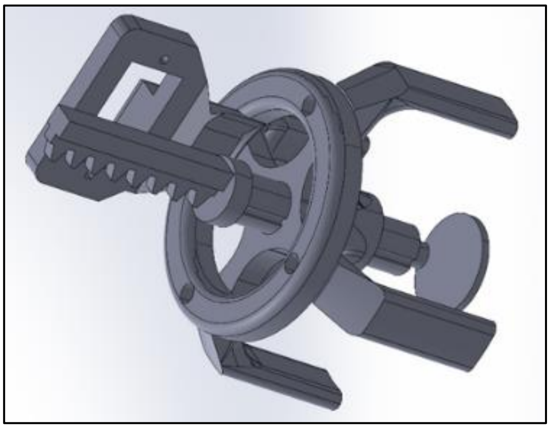


**Figure 5:** 3D model of the suction cup grabber with rack and pinion mechanism.

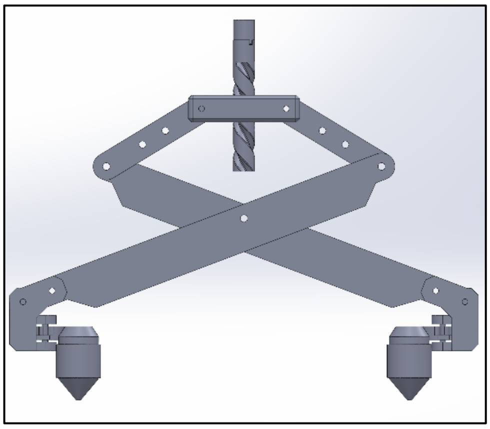


**Figure 6:** 3D model of new screw-driven linkage mechanism

**2.2 Design Development Milestones**

Development started off with a simple prototype of the base chassis, with a simple movement code implemented to demonstrate basic movement. A prototype for *Indiana's* chassis was assembled, with the robot being capable of moving forward, backward and rotating. By week 5, *Boulder's* prototype grabber worked with no issue, while *Indiana's* would pick up the statue occasionally as the claw would sometimes only partially close.

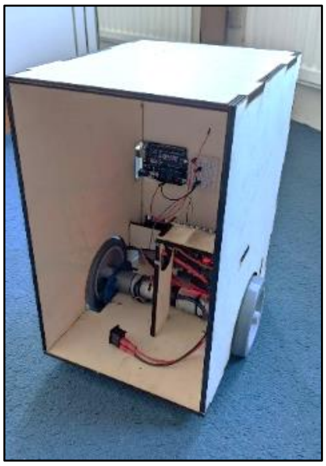


**Figure 7:** Prototype chassis for *Indiana.*

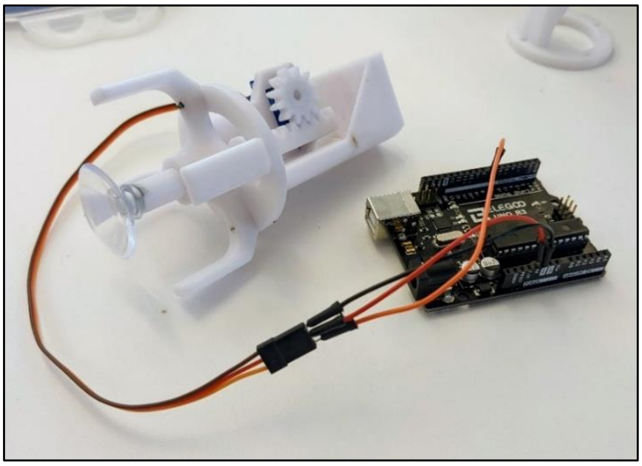


**Figure 8:** Prototype of *Boulder's* suction cup grabber.

By week 8, chassis for both *Indiana* and *Boulder* had been built, including a working display cabinet for the statue. *Indiana* had a firm grip on the statue and the cabinet lit up with no issue, however, issues with the movement meant that it could not consistently align itself with the podium. The shelf was non-functional, so the replica could not be collected. *Boulder* was able to move to the gallery before stopping, although it did not have a functional grabber equipped. As mentioned above, the grabber was redesigned so that *Boulder* used a mechanical claw, and a scoop was implemented at the bottom of the chassis.

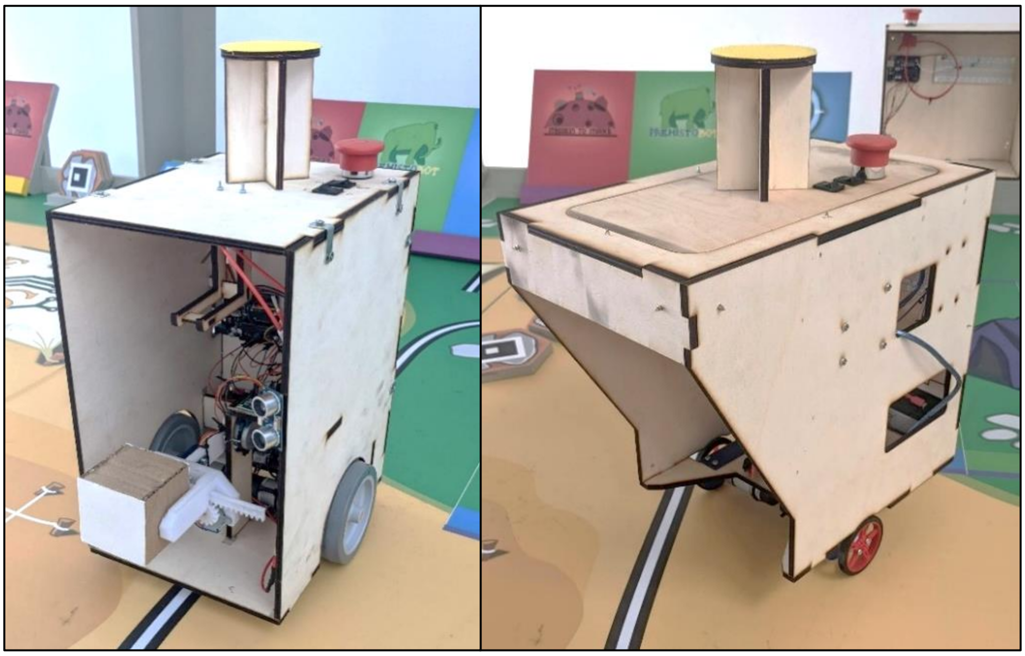


**Figure 9:** Assembly for *Indiana* (left) and *Boulder* (right) during homologation. The chassis for *Boulder* was redesigned after the new grabber was built.

The final iteration of *Indiana* featured new movement code so that it could align itself with the podium and tile more reliably. The shelf could pivot once activated, the length of the claws was increased to improve grip, and counterweights were added to the arm to improve its rotation moment. *Boulder* had a new fully functional grabber (seen in **Figure 10**), with a redesigned chassis to stay within perimeter regulations.


**Figure 10:** Feature complete assemblies for *Boulder* (left), the display cabinet (middle), and *Indiana* (right).

# 3. Final Design Review

## 3.1 Overview

Due to reasons outlined in above sections, the final design includes two robots moving on the playing surface simultaneously. Each robot is specialised for manipulating different game elements and completing different tasks; however, both rely on the same movement platform, utilising an MD25 motor driver module connected to two EMG30 gear motors with encoders.

Robot 1, *Indiana*, is designed to pick up and manipulate the statuette and replica. To do this, it is equipped with a rack and pinion grabber arm actuated by a stepper motor, that can rotate through an angle of 90°. Inside the robot is a small shelf for storing the replica which drops down to allow the grabber arm to grab the replica. *Indiana* also uses this arm to push over one of the excavation squares.

Robot 2, *Boulder*, is responsible for tile manipulation, so has a servo actuated screw driven grabber mechanism to increase the speed at which tiles can be picked up. It also has a bottom mounted rack and pinion scooper to push tiles around the board, as well as having smaller diameter wheels than *Indiana* with better tyres for more precise movement on the playing surface.

## 3.2 Performance Scenario

If both robots complete all planned tasks, they will score 93 points on the table plus 28 bonus points, for a total of 121. Bonus points are calculated from **Equation 1** below, where *score* is the points scored on the table and *delta* is the difference between the predicted score and the actual score. Of the 93 points scored on the table, *Indiana* scores 49, *Boulder* scores 24, and the remaining 20 is achieved by both robots returning to either the campsite or excavation site at the end of the 100 seconds.

$$Bonus = (0.3 * score) - delta \quad \textbf{(1)}$$

*Indiana* moves slowly but accurately, allowing it to line up with the pedestal to pick up the statuette. After picking up the statuette, it moves over to the display cabinet to drop the statuette off then returns to the pedestal to place the replica. The replica is stored inside *Indiana* from the start of the match as allowed in the rules. Lastly, *Indiana* moves to the second excavation square which is always the correct colour, before driving to the excavation site to end the match.

*Boulder* is equipped to pick up two tiles each time it reaches a vertical tile dispenser, as well as being able to push three tiles along the ground at once. Therefore, its performance scenario takes advantage of this in addition to its faster movement. First, *Boulder* picks up two tiles from the vertical dispenser at waypoint 4 (**Figure 11, overleaf**), then drops one on the gallery and one on the floor. After this it drives to three tiles on the table and pushes them under the work shed using the bottom mounted rack and pinion scooper. Finally, it picks up two tiles from the vertical dispenser at waypoint 12 and drops them in the campsite, where it also finishes the match.

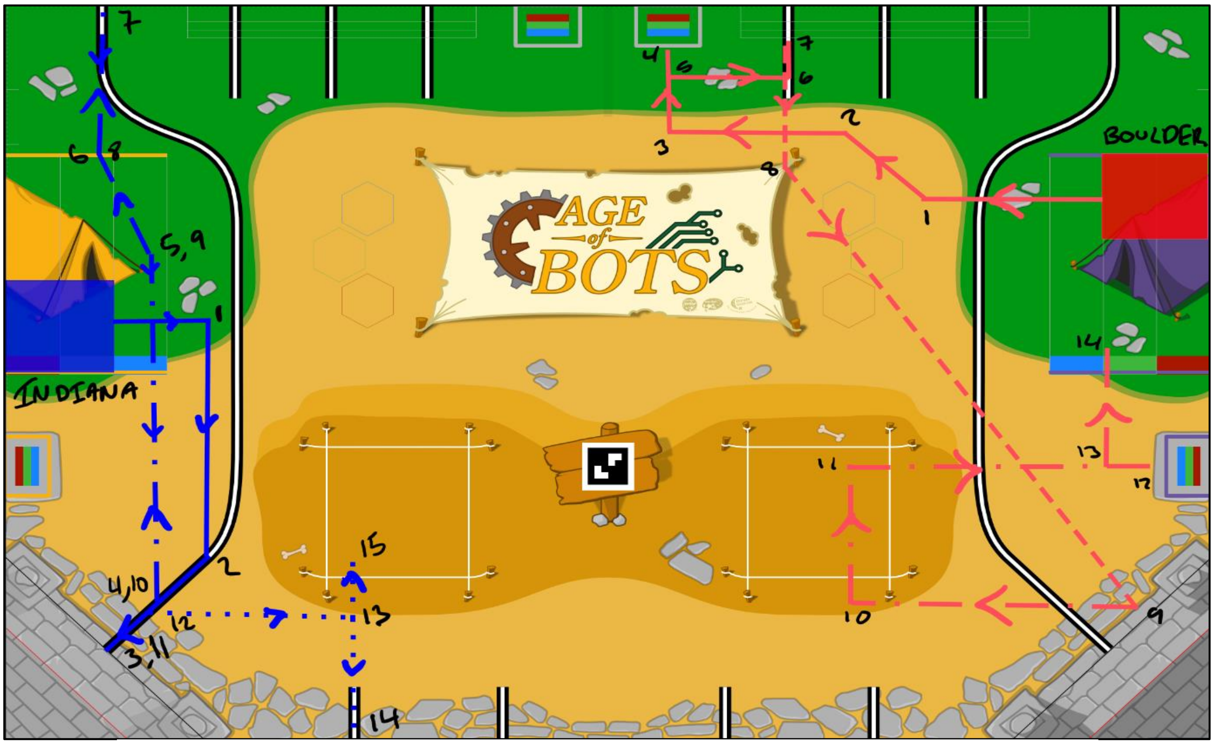



**Figure 11:** Map outlining the path for each robot in a match with numbered waypoints

## 3.3. System Requirements

Both robots were equipped with an MD25 motor controller and two EMG30 gear motors. These provided enough mobility to traverse the board effectively. Encoders within the motors were used to track distance travelled, allowing us to keep track of our position on the board. Both robots were powered by a YUASA NP2-12, 12 V 2 Ah battery which was sufficient for not only powering the motors, but also the Arduino UNO Rev3 board used to control the robots.

Both robots would need an object detection sub-system. For this, they were equipped with front and rear HC-SR04 ultrasonic sensors. As the two robots complete very different tasks, the sub-systems used for completing them have differing requirements. For *Indiana* there is one grabber arm which is actuated using two 28BYJ-48 stepper motors. *Boulder* handles the tiles around the board, calling for two sub-systems, one for moving tiles on the floor and one for picking up tiles out of dispensers. The system for moving the floor tiles was driven by another 28BYJ-48 stepper motor. The robot picks up tiles with a screw-driven arm using two MG996R servomotors (shown in **Appendix A.1**).

The display cabinet was a very simple system a HC-SR04 ultrasonic sensor to detect the presence of the statue and 3 LEDs to display. This also used an Arduino UNO Rev3 board. A diagram of the proposed circuit is seen in **Figure 12**.

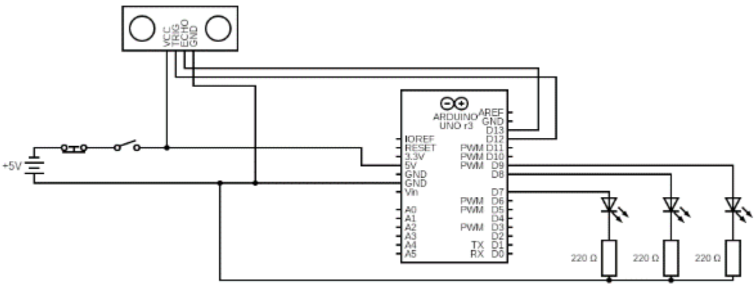



**Figure 12:** Circuit diagram of display cabinet system

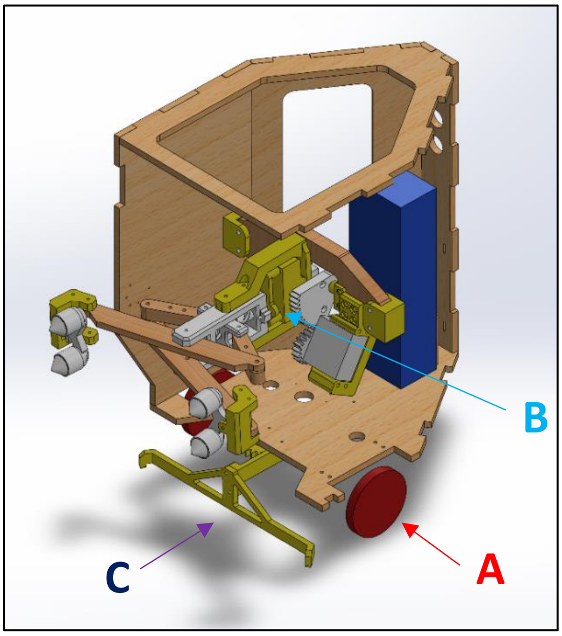



**Figure 13:** Transparent view showing the major sub-systems of *Boulder*

A) Drive system
B) Arm system
C) Scoop system

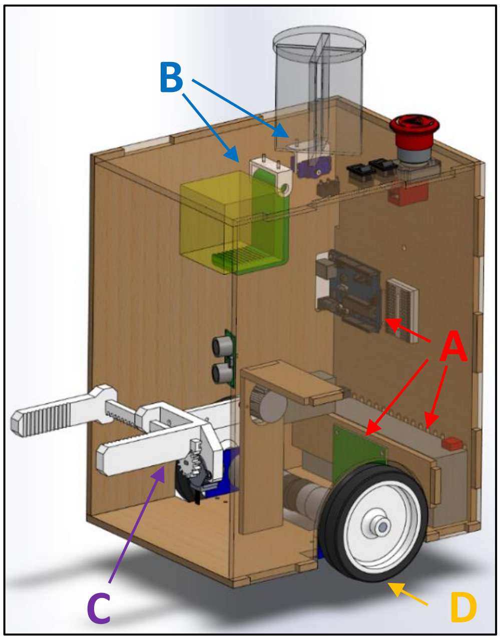



**Figure 14:** Transparent view showing the major sub-systems of *Indiana*

A) Control systems
B) Shelf system
C) Grabber system
D) Drive system

### 3.4 Technical Research Areas

Research was done into the type of wheels that the robots could use, in order to make the movement more precise by improving grip. This was relevant for *Boulder,* as it had more tasks to complete than *Indiana,* and therefore its path line was more complex. As a result, *Boulder* uses a pair of 60 mm wheels purchased online. It was not necessary to replace the set of wheels for *Indiana,* as its movement was repeated and easier to program, since it spent most of its time moving between the podium and display case.

For the mechanisms, we primarily investigated real world applications of robots for our design concepts. Prior to the final design, for *Boulder* we looked into robots in distribution and manufacturing facilities, and how they used an array of suction cups to pick up and move boxes. *Indiana* was inspired by previous Eurobot competition winners, and how they would store items inside the chassis in order to reduce run time, but it also took inspiration from grocery fulfilment robots, and how they would store goods inside the robot before moving to the next checkpoint.

### 3.5 Materials

The chassis for both *Indiana* and *Boulder,* as well as the display cabinet are primarily constructed out of 6mm plywood as it is provided by the workshop. It has a high strength to weight ratio allowing for decent manoeuvrability while being strong enough to keep the robots sturdy and intact. Plywood is a flexible material in terms of alterations, as it can be easily cut, filed, or drilled to help remove excess material, and add electronic mounts or other features, such as access panels. This helps reduce the overall cost of the robots to us by using more of the readily available workshop's resources and avoiding shipping costs. The plywood is laser cut so that the panels are accurately produced and properly fitted, making the assembly quick and easy. In terms of sustainability, plywood is made of thin wooden veneers bonded together by formaldehyde adhesive, **[2]** so it uses less resources and energy to manufacture compared to other woods. Spare pieces of plywood can be reused by the workshop or recycled, reducing the waste that the robots produce due to manufacturing.

The components for both grabbers were constructed out of 3D printed PETG, as the designs needed a strong grip to pick up and move items around the playing surface. PETG is an excellent choice for light weighting so that neither robot exceeds the weight limit. In addition, *Indiana* had numerous metal rods stuck to the back of the grabber to decrease the turning moment of the arm and ensure the grabber can reach the replica located at the top of the chassis. The 3D printing facility was provided by one of our group members, meaning parts could be produced outside of group sessions, and during the Easter holiday.

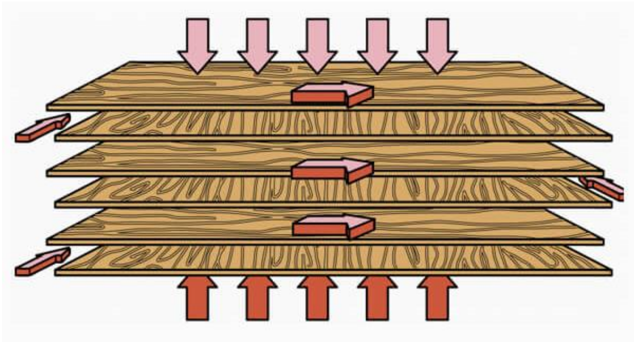


**Figure 15:** Composition and formation of plywood sheets **[3]**

### 3.6 Structural Design

The structural design of the chassis was dictated by budget and available materials instead of optimal structural performance. Nonetheless, the plywood available provided ample strength for the panelling. Both robot frames consist of 6 mm poplar plywood with finger joints. *Boulder* incorporates a triangular rear section - adding stiffness and reducing the robot perimeter to meet the Eurobot rules. All chassis joints were either glued (*Boulder*) or reinforced with metal brackets (*Indiana*).

*Boulder* had some structural members which required reinforcement for the load they experienced. **Figure 16** shows the grabber mechanism, where some of the cross beams were made to be 12 mm instead of 6 mm. The servo provides a torque of 0.922 Nm **[4]**, so a force of 230 N is applied to the nut (coefficient of friction of 3D printed PLA is under 0.2) **[5]**. The shear strength of plywood is 2 $N/mm^2$ **[6]** with the area of the original part being 72 $mm^2$, meaning a force of 144 N is the maximum it can withstand – 62.6% of the applied force. To solve this, two members were laminated together to double the strength, giving a safety factor of 1.25.

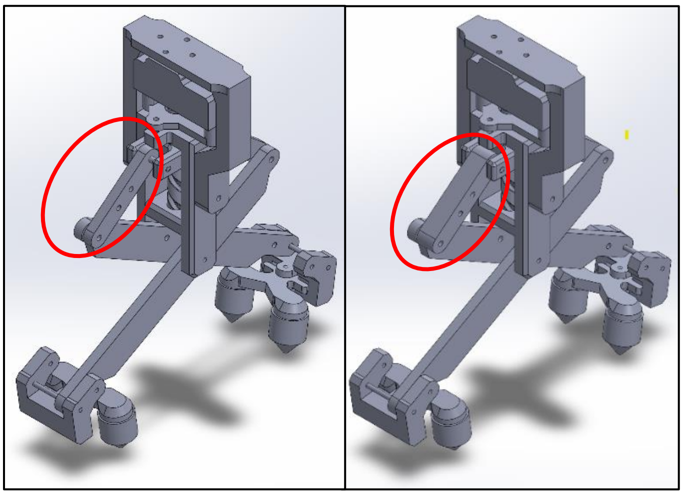


**Figure 16:** Circled show the old arm element (left)- 6 mm, and the new (right) - 12 mm.

The pivoting arm of *Indiana* encountered issues regarding the torque required to raise the gripper to the replica shelf. The stepper motor used is the 28BYJ-48 with 0.037 Nm of torque when fully stepped **[7]**. **Figure 17** shows the result of an analysis performed in SolidWorks to find the gripper's centre of mass. The 3D printed elements are custom PETG components with a density of 1230 $kg/m^3$ **[8];** the motor had a mass of 30 g **[9]**. The analysis showed the mass of 141 g would act 50.24 mm from the fulcrum. This would require a torque of 0.069 Nm, double that available. Therefore, it was necessary to add counterweight, made of cut steel bar scraps, to reduce the load on the motor.

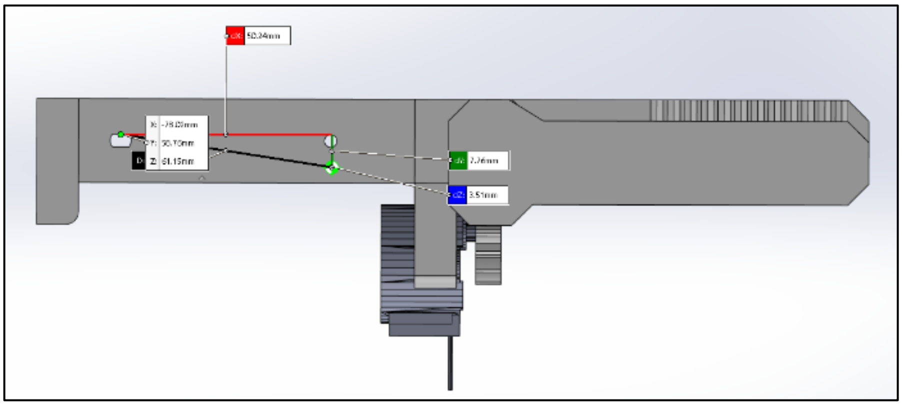



**Figure 17:** Analysis of *Indiana's* grabber

### 3.7 Design for Other Aspects of System Performance

Our solution for completing our objectives was as simplistic as possible. The robots did not have to react to any environmental factors, instead, all their movements were pre-programmed. Inputs to the robots were two switches and two ultrasonic sensors. One switch was for setting the side of the board the robot was placed on, and the other for determining if the release cord had been pulled yet. The ultrasonic sensors, when triggered, would stop the robot, and cause it to enter a paused state. When the stimulus was gone, it would resume the action it was carrying out before.

The biggest problem with our solution comes from the sampling rate of the Arduino as well as a problem with deceleration due to momentum. To travel certain distances, the robots read encoder data from their motors. However, due to the sample rate, the robots would often have travelled slightly over this distance before activating the stop function and then, once activated, they would travel even further due to not being able to instantaneously stop. To counter this, a correction function (**Figure 18**) was written where the robots would correct the few millimetres of error at a much lower speed so that the new margin of error would be far smaller than before.

```
void correctLeft(float difference){
  //takes an angle in degrees and roates right on the spot accordingly using a recursive algorithm
  float wheelOneD = -difference;
  float wheelTwoD = difference;
  DualSpeedValue = 130;

  Wire.beginTransmission(MD25ADDRESS);                          // Set MD25 operation MODE
  Wire.write(MODE_SELECTOR);
  Wire.write(2);
  Wire.endTransmission();




  while (encoder1() <= wheelOneD && encoder2() >= wheelTwoD){     // If statement to check the status of the traveled distance

    Wire.beginTransmission(MD25ADDRESS);                        // Sets the acceleration to register 1 (6.375s)
    Wire.write(ACCELERATION);
    Wire.write(1);
    Wire.endTransmission();

    Wire.beginTransmission(MD25ADDRESS);                        // Sets a combined motor speed value
    Wire.write(SPEED2);
    Wire.write(DualSpeedValue);
    Wire.endTransmission();

  }
  stopMotor();

}
```

**Figure 18:** Correction code snippet

*Indiana* had one major system for completing its role, the grabber arm. The arm was mounted directly onto one stepper motor so that it could rotate through 90° from vertical to horizontal. On the end of the arm was a grabber mechanism that opened and closed using a rack and pinion controlled by another stepper motor. The arm required a counterweight on the other end to the grabber because the first stepper motor did not have enough torque to lift the arm back up to vertical otherwise. The other system involved in *Indiana* was the shelf. This housed the replica and would retract using a servo motor and linkage when the arm was ready to lower onto the pedestal.

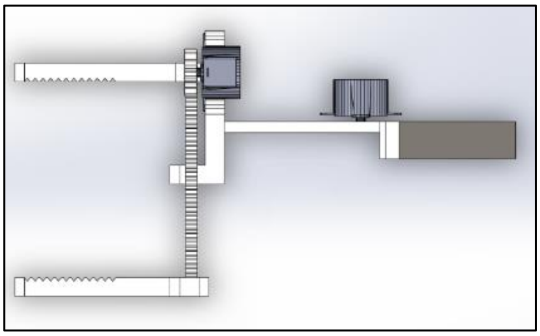


**Figure 19:** Top view of *Indiana's* arm, including the stepper motors for actuation

*Boulder* had two systems for interacting with the board: the scoop, and the grabber. The scoop was an extendable device using another rack and pinion that sat underneath the robot **Figure 20**. It would collect tiles as the robot moved around the board, then, when adjacent to the work shed, the stepper would extend the scoop, moving the tiles under the work shed. The grabber on *Boulder* utilised a scissor mechanism **Figure 21** as a compact, reliable design. The pitch of the grabber was adjusted with a standard spur gear and drive gear. The articulation was controlled by two high torque MG996 servo motors.

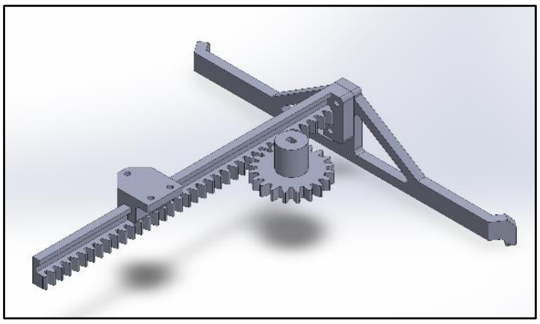


**Figure 20:** Pusher mechanism mounted underneath *Boulder*.

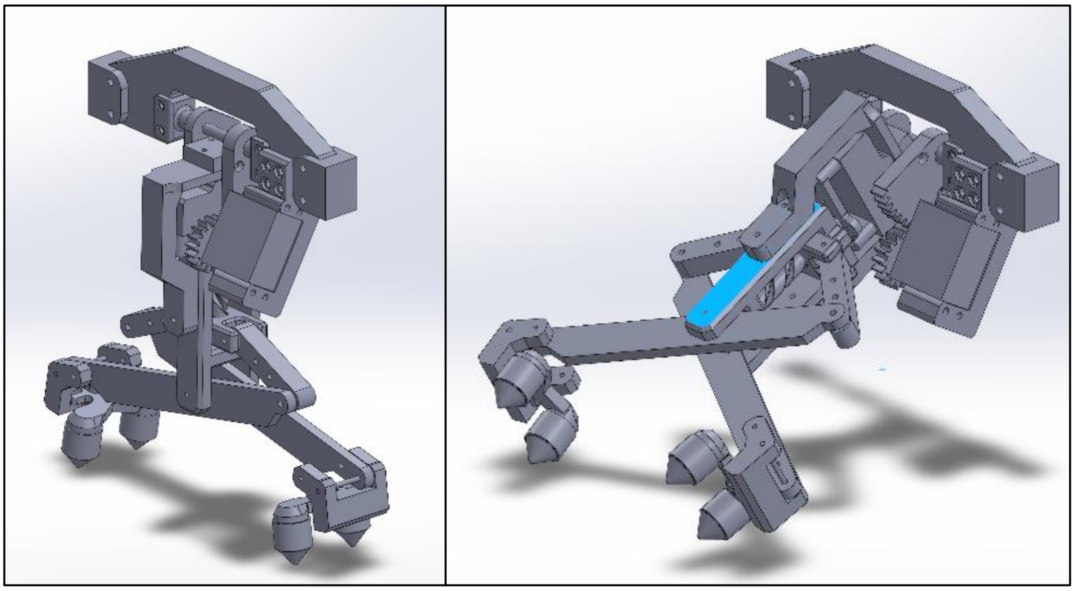


**Figure 21:** Grabber fully open, in down position (Left). Fully closed, in up position (Right).

### 3.8 Design for Manufacture

Both designs were created considering the manufacturing process - there were limited technologies available to us (laser cutting, 3D printing, and hand tools). Examples of this design for manufacture are found in the grabber mechanisms. Both grabbers were primarily 3D printed, with *Boulder's* grabber consisting of over 20 3D printed parts, connected with bolts. Designing for 3D printing meant that, where possible, all parts had a flat face (as seen in **Figure 22**) that acted as a stable base for printing. Where infeasible, the printing orientation was considered to ensure that the part was strong in the required directions, a result of directional additive manufacture.

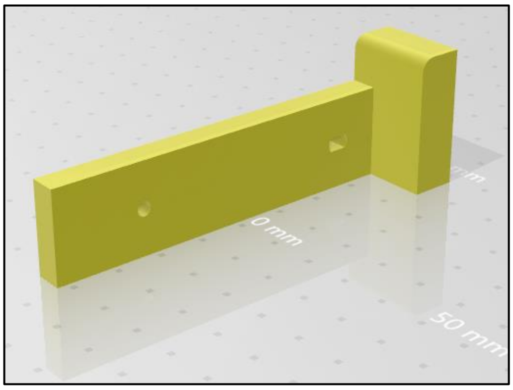



**Figure 22:** Flat-based part for printing

Tolerances of ±1 mm were designed into the 2D laser cutter files for the plywood panels to allow for the subtractive manufacturing method. Small scale tests were performed before cutting the final designs to gauge this tolerance for the finger joints and the bolt holes. All fasteners were purchased in standard sizes (M3 or M4), so all designs accommodated those size fasteners. The decision to use bolted assembly meant that access to bolt heads was important for integration, maintenance, and disassembly - the bolt positions were taken into consideration to allow for this (**Figure 23**).

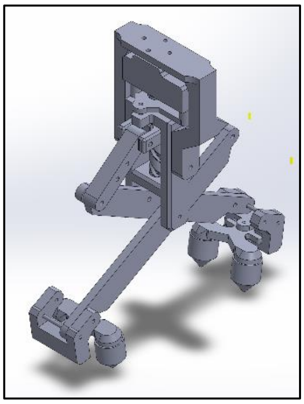


**Figure 23:** Grabber mechanism bolt hole placement, all heads are accessible when fully assembled - both with 3D printed and laser cut parts.

Finally, the 3D printing filaments and the plywood used were recycled, or able to be recycled at the end of their use. A combination of PLA and PETG was used to print with, the choice being made based on mechanical properties of each material. The PLA was recycled before use, while the PETG is a material that can be recycled in common recycling plants. The fasteners used can also be removed and used again on other projects.

### 3.9 Testing

The testing of the robot was straightforward. The first part of our process was prototyping. We assembled each of our sub-systems individually and ran them to make sure they worked as intended and then implemented the system into the final assembly. Once assembled, we could test the robots on the table. When testing, we would implement a change in software and do a run of the robot on the table. If the test was successful, we would run it again to check it was consistent, if it failed, we would adjust the code accordingly. Specifically, our aims for testing were to consistently score between 86 and 93 points when both robots were run together.

After our first few successful full runs, we noticed how inconsistent the robots were. As highlighted in section 3.7, we implemented a correction function for our movement and to start with, it did not have much of an impact but after many iterations, *Indiana* was performing its tasks every time without error. *Boulder* did not perform as well during testing, some of the ideas in our initial route had too little room for error and even our final route was not 100% consistent. However, it too was performing as designed an acceptable percent of the time in testing. Unfortunately, by the final, errors occurred which had not presented themselves previously during the tests.

### 3.10 Resource Use

**Table 1** details the material cost breakdown required to construct both robots. The items marked with an asterisk denote those that were provided by the University at no cost to the team, the total cost of such items comes to £421.36. This means that the total cost to the team for the project was £28.59, far less than the £100 budget we agreed upon at the beginning of the process.

| Item | Material | Quantity | Cost / £ per unit | Total Cost / £ |
|---|---|---|---|---|
| Case and chassis* | 6mm poplar ply | 5 sheets | 4.45 / sheet **[10]** | 22.25 |
| 3D printed parts | PETG | 0.12 kg | 27.82 / kg **[11]** | 3.26 |
| | PLA | 0.12 kg | 20.49 / kg | 2.44 |
| | TPU | 0.002 kg | 38.00 / kg | 0.07 |
| Fasteners (M3, M4 bolts and nuts)* | A2 Stainless Steel | ~ 4 packs | 2.89 / pack **[12]** | 11.56 |
| RD02 Robot Drive Kit* | - | 2 | 116.29 / kit **[13]** | 233.80 |
| Yuasa NP2-12 Battery* | Lead acid battery | 2 | 12.39 / battery **[14]** | 24.78 |
| Elegoo Arduino UNO R3 kit* | - | 3 | 42.99 / kit **[15]** | 128.97 |
| Beacon Velcro attachment | Velcro | 2 packs | 1.87 / pack | 3.74 |
| M8 Wingnuts | Steel | 1 | 2.19 / pack | 0.22 |
| 9V Battery | - | 2 | 3.25 / battery | 6.50 |
| New 60 mm wheels | ABS | 1 pack | 10.39 / pack | 10.39 |
| | | | **Final Cost:** | 447.98 |

**Table 1:** Project material cost breakdown

The time required to manufacture is mainly limited by the time taken for 3D printing and laser cutting parts and so depends on machine speed and availability. An approximate breakdown of time taken for each robot is:

- 3D printing parts – 5 hours
- Laser cutting – 1 hour
- Chassis assembly – 1 hour
- Attaching electronics – 1 hour
- Wiring – 2 hours

The software of the robots was iterated upon throughout the project and so it is difficult to estimate the time required to complete the code base. Testing, however, is easier to quantify and was by far the longest part of the process. From starting the robots for the first time, to being satisfied with their full sequence of operations, is on the order of 50 hours per robot. This primarily took place in weeks 8 through 10 of the project, enabled by having two operational, and fully homologated, robots ready before the Easter break.

The workshops inside Boldrewood and Highfield were used extensively to manufacture the robots, with tools that the team already owned being used off campus as well. Prototyping was completed using a 3D printed that Jonathan owns (**Figure 24**), enabling the team to print many more iterations of designs than would be possible with the 3D print service offered by the university or online.

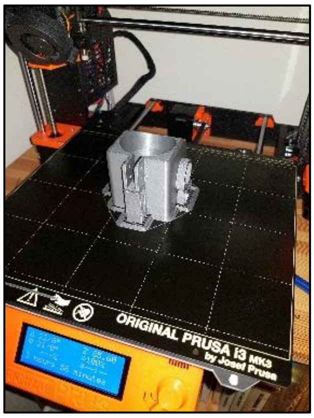



**Figure 24:** Prusa MK3S 3D printer

The modelling and 3D printing steps for manufacture required in depth knowledge of the process. Jonathan has over 5 years of experience with modelling for and printing with a 3D printer, this was used to rapidly develop and improve on the mechanisms inside each robot in an efficient manner. Various team members had knowledge of laser cutting, this was used extensively for the rapid manufacture of chassis and mechanism components.

## 4. Suggested Future Developments

Issues encountered with *Indiana* included accessing the breadboard and controllers to perform maintenance. Currently the whole left side must be removed, however access panels could be implemented to reduce the risk of causing accidental damage and decrease down-time. **Figure 25** shows where access could be made; implementation would be like the panels seen on *Boulder* (**Figure 26**).

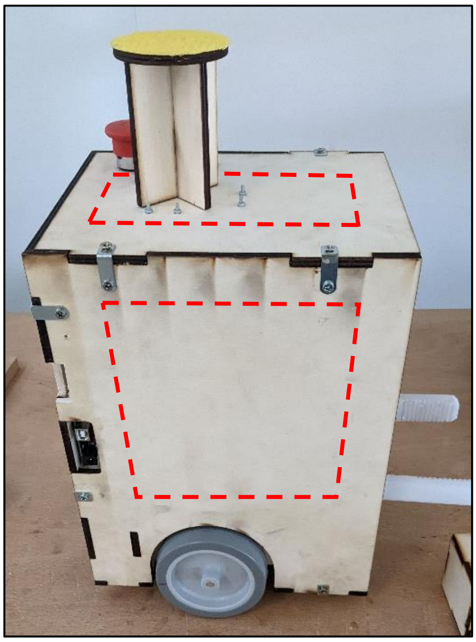


**Figure 25:** *Indiana* access panels

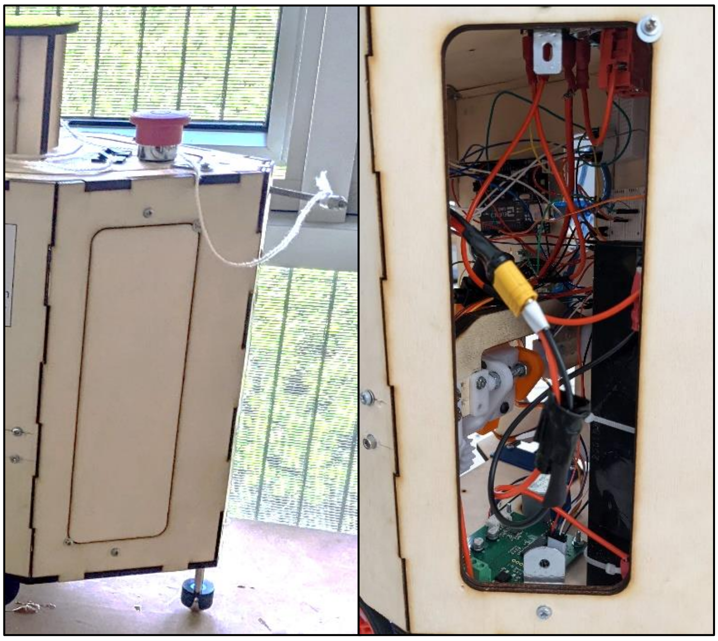


**Figure 26:** *Boulder* rear access, closed and open

The sensing suite requires improvement as we currently have two HC-SR04 ultrasonic sensors for fore and aft detection. There should be sensors for rotation (**Figure 27**), with larger beamwidth to reduce blind spots, decreasing the chance of collisions and thus likelihood of significant path changes or penalties. This requires a microcontroller with more pins, a detriment to the low-cost aspect of the brief.

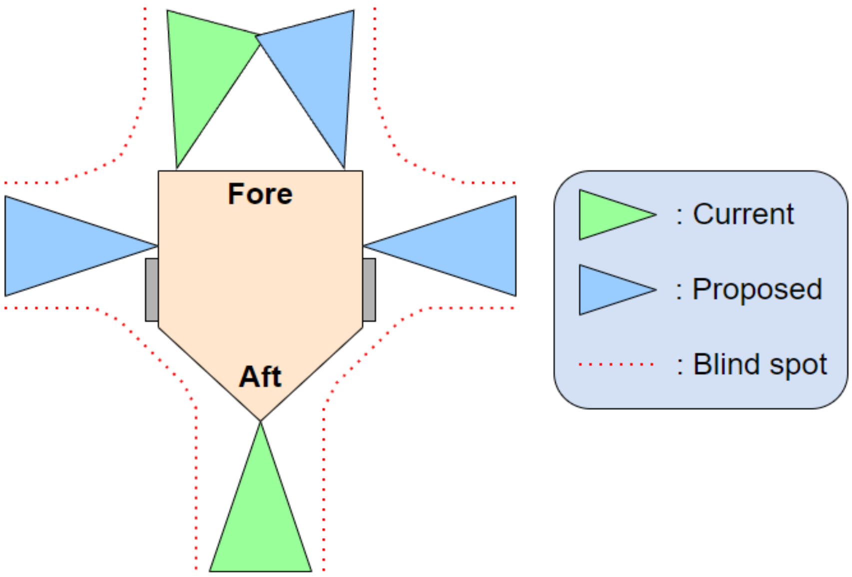



**Figure 27:** Proposed sensing suite

We would also source new wheels as those provided show significant slip, reducing movement accuracy. BaneBot T81 3-7/8" wheels **[16]** are our wheels of choice, along with 5 mm hubs **[17]**, but ultimately we chose not to purchase them due to high shipping cost (~US$60).

*Indiana's* grabber could be improved for rigidity and grip strength. The current design is very compliant, impacting object handling ability. Increasing member thickness (**Figure 28**) would reduce this effect. Higher torque stepper motors would improve grip strength and arm rotation which could lead to the elimination of the crude counterweight seen in **Figure 29**.

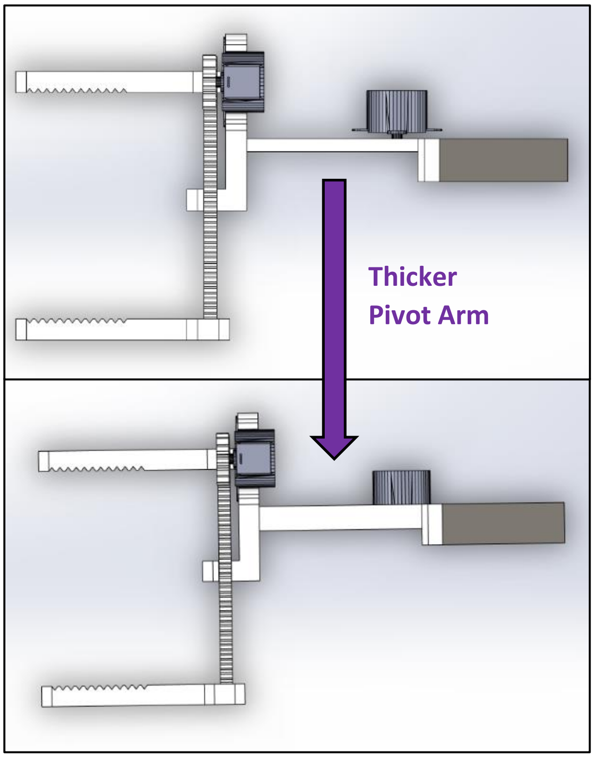



**Figure 28:** Proposed member thickening

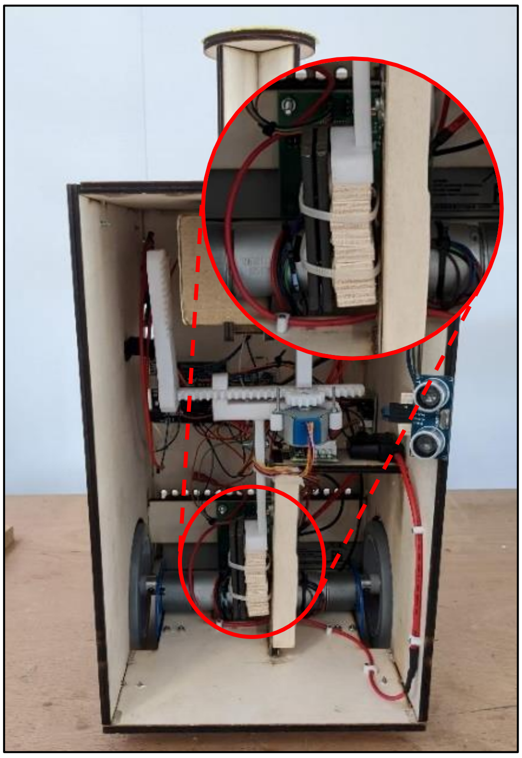


**Figure 29:** Current arm counterweight

# 5. Management

## 5.1 Team Structure and Roles

The leadership structure of our team is as follows:

- Michael, team leader - coordinating meetings and overseeing the development of the team throughout.
- Jonathan, 2nd in command - following up of anything that needed to be completed and giving some knowledge from previous experience in a similar competition - VEX Robotics.

The roles and practical applications of each team member were:

- Coding and software development – James, Tom
- Robot movement and point scoring logistics - Tom, James, Michael
- Design of mechanisms and 3D printed parts - Jonathan
- Design and manufacture of *Boulder* – Jonathan, Tom
- Design and manufacture of *Indiana* and display case- Michael, Sean

While the role outlines above were generally followed, the team was able to adapt and each team member able to take on a number of roles when needed. These roles were chosen at the start to enable all members to perform and operate within their strengths.

## 5.2 Project Management

Dividing the project into three subgroups (robot 1 design team, robot 2 design team, and coding/software development), allowed for work on the individual robots to occur in parallel with less dependency on the pace of development of each system and meant that issues on one vehicle didn't delay the whole project.

There was also an emphasis placed on milestone-focused development as the key submission dates were set from the first session (31st January 2022). This allowed us to plan our work schedule in advance and ensure that deadlines were met by defining and assigning tasks around the critical path. A consequence of having parallel working teams was that the critical path would only persist until the Interim Design Review (IDR) in week 5, seen clearly in **Figure 30**. This was highly beneficial in the end as it allowed for significant float time for tasks relating to the second and third versions of the hardware, which would prove to be necessary as some issues with components were encountered. The critical path consists of:

- Project Familiarisation – A
- Concept Generation – B
- Grabber Prototype Designs – F
- Grabber Prototype Manufacture – I
- Interim Design Review – J

| Task | Duration | Dependencies |
|---|---|---|
| A | 1 | N/A |
| B | 1 | A |
| C | 1 | A |
| D | 1 | A, C |
| E | 1 | A, B |
| F | 1 | B |
| G | 1 | A |
| H | 1 | C, D |
| I | 1 | B, F |
| J | 1 | H, I, E |
| K | 1 | G |
| L | 1 | K |
| M | 1 | I |
| N | 1 | L |
| O | 1 | H,N |
| P | 1 | M |
| Q | 2 | B |
| R | 1 | I |
| S | 1 | P |
| T | 1 | N |
| U | 1 | R |
| V | 1 | S |
| W | 3 | Q |
| X | 1 | T |
| Y | 2 | H,U,V,X, J |

**Table 2:** Key project activities

The tasks, their durations, and dependencies, were recorded in **Table 2** before being organised into the digraph: **Figure 30**. The critical path was found by identifying activities with no float time. This path was fundamental to our success as the IDR displayed our ideas, and our overall direction, for the project; allowing us to obtain valuable feedback from the supervisors and put it into action going forward. A description of all the activities can be found in the Gantt chart on page 20 which was generated from the critical path analysis and was used for project organisation.

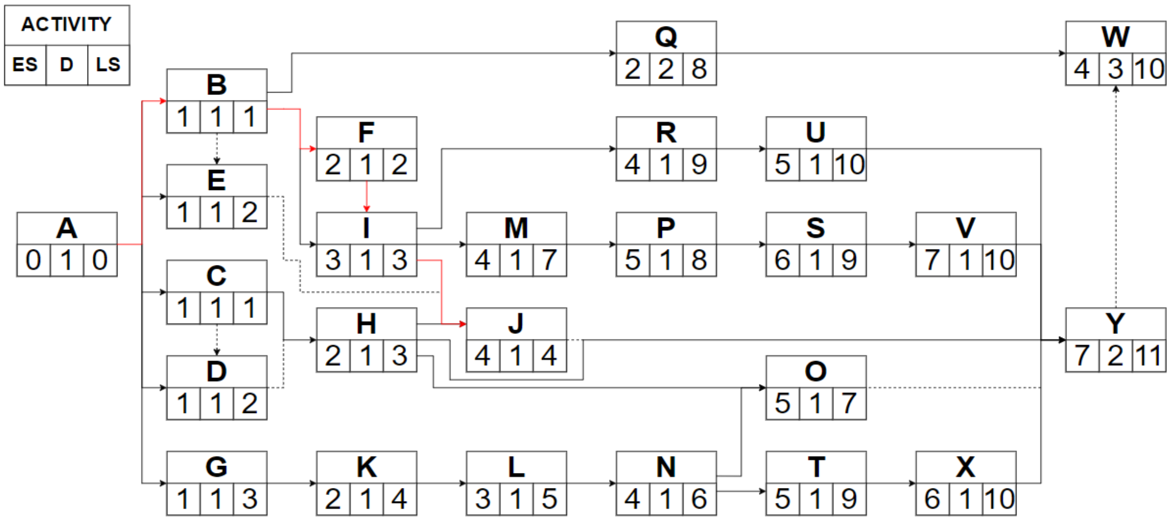
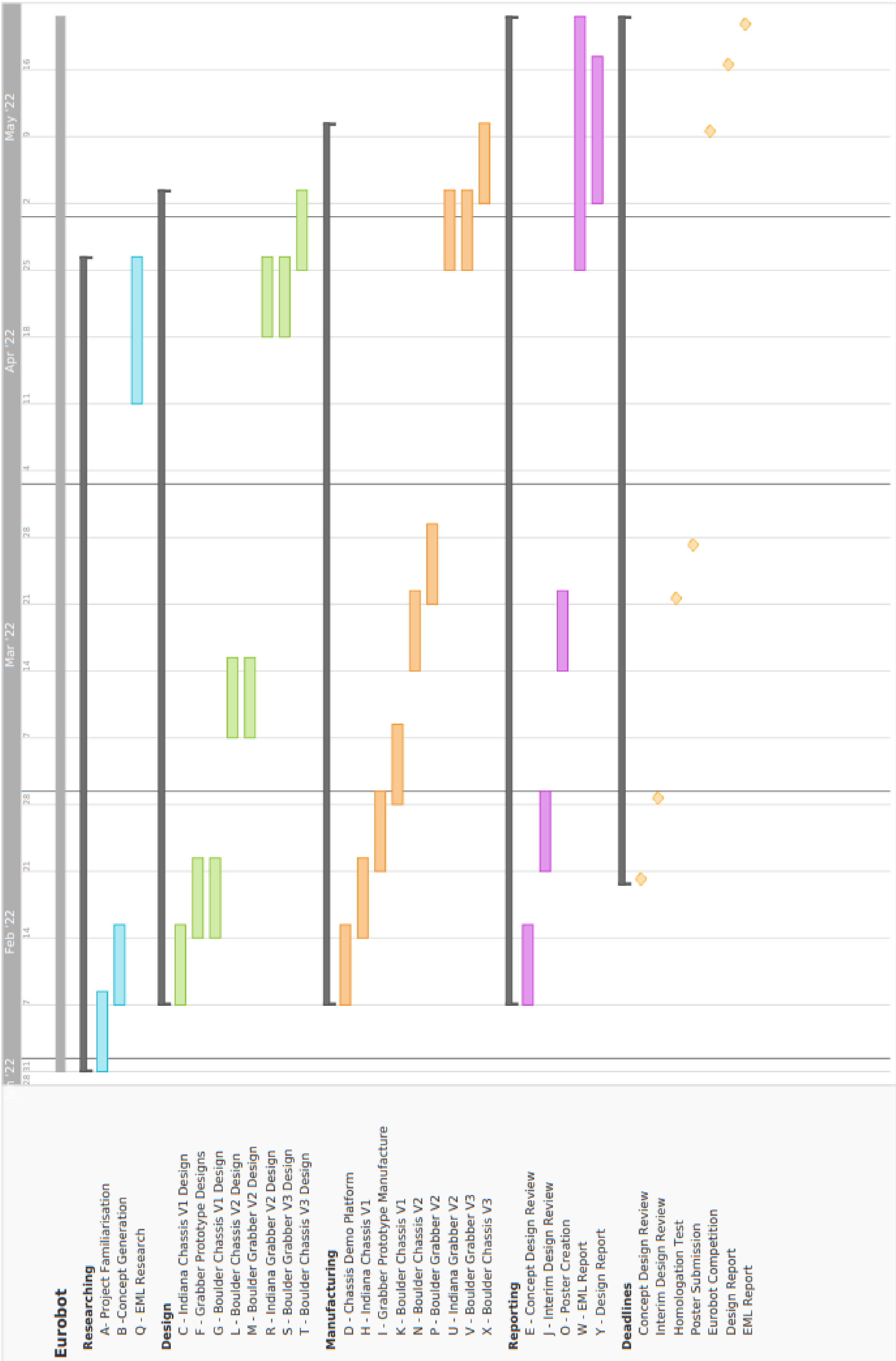



**Figure 30:** Digraph showing the critical path (red arrows) through the activities with early start time (ES), duration (D) and late start time (LS) of each task indicated

**Gantt Chart**



Feb '22
Mar '22
Apr '22
May '22
Eurobot
Researching
A- Project Familiarisation
B -Concept Generation
Q - EML Research
Design
C - Indiana Chassis V1 Design
F - Grabber Prototype Designs
G - Boulder Chassis V1 Design
L - Boulder Chassis V2 Design
M - Boulder Grabber V2 Design
R - Indiana Grabber V2 Design
S - Boulder Grabber V3 Design
T - Boulder Chassis V3 Design
Manufacturing
D - Chassis Demo Platform
H - Indiana Chassis V1
I - Grabber Prototype Manufacture
K - Boulder Chassis V1
N - Boulder Chassis V2
P - Boulder Grabber V2
U - Indiana Grabber V2
V - Boulder Grabber V3
X - Boulder Chassis V3
Reporting
E - Concept Design Review
J - Interim Design Review
O - Poster Creation
W - EML Report
Y - Design Report
Deadlines
Concept Design Review
Interim Design Review
Homologation Test
Poster Submission
Eurobot Competition
Design Report
EML Report

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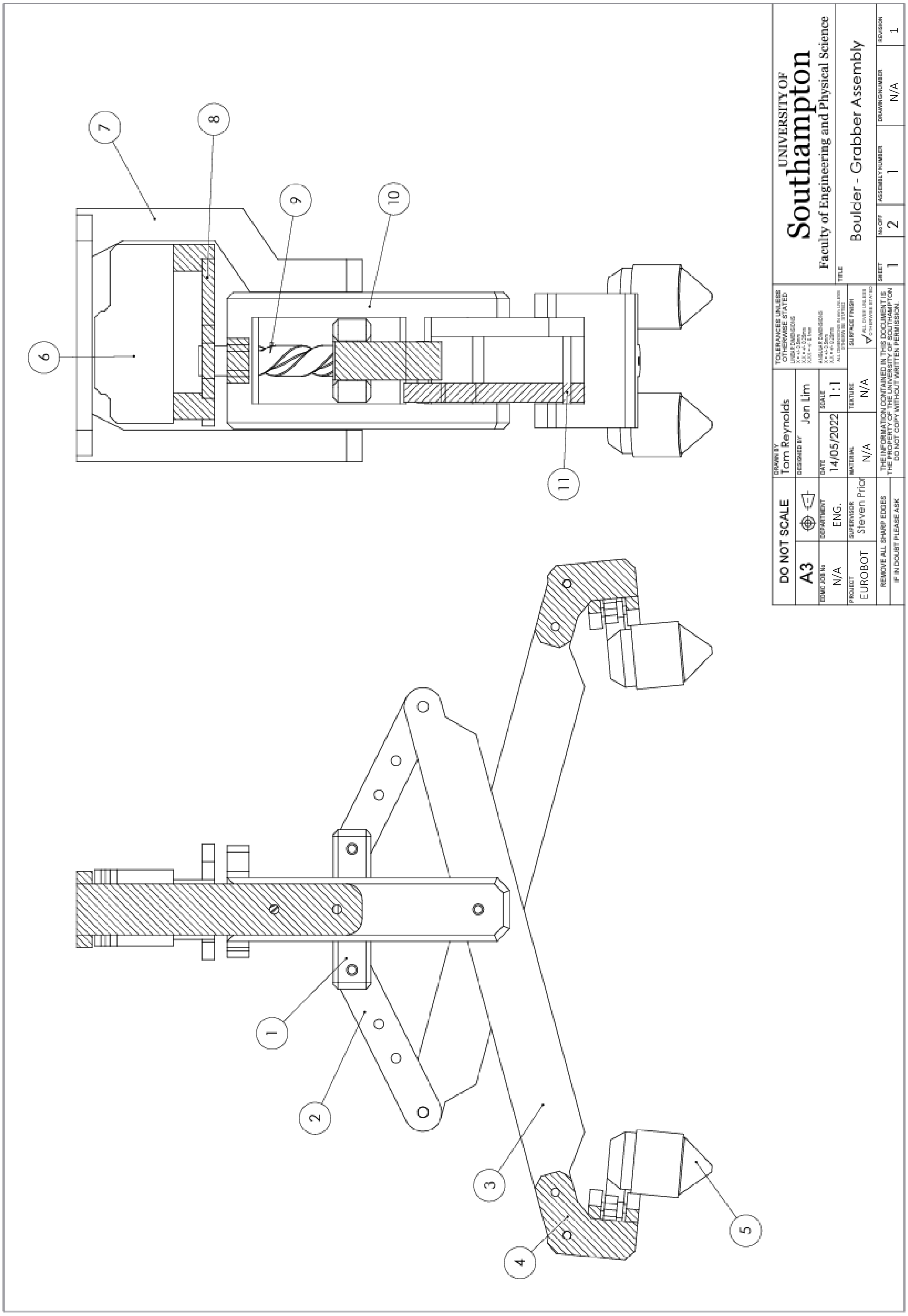
# Appendix A - Assembly Drawings

## A.1:



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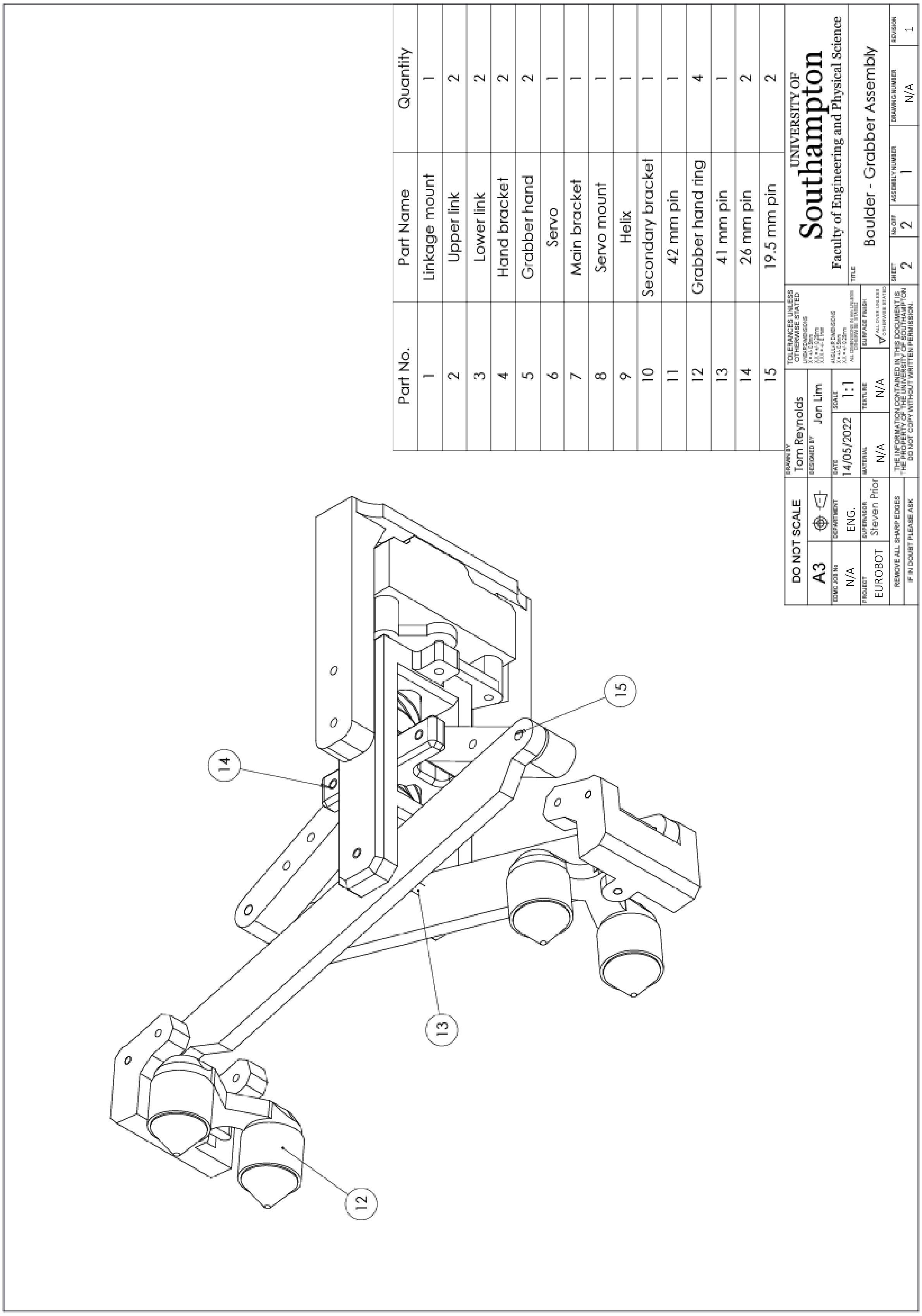
Part No.
Part Name
Quantity
1
Linkage mount
1
2
Upper link
2
3
Lower link
2
4
Hand bracket
2
5
Grabber hand
2
6
Servo
1
7
Main bracket
1
8
Servo mount
1
9
Helix
1
10
Secondary bracket
1
11
42 mm pin
1
12
Grabber hand ring
4
13
41 mm pin
1
14
26 mm pin
2
15
19.5 mm pin
2
DO NOT SCALE
A3
DEPARTMENT
ENG.
N/A
PROJECT
EUROBOT
SUPERVISOR
Steven Prior
REMOVE ALL SHARP EDGES
IF IN DOUBT PLEASE ASK
DRAWN BY
Tom Reynolds
DESIGNED BY
Jon Lim
DATE
14/05/2022
SCALE
1:1
MATERIAL
N/A
TEXTURE
N/A
TOLERANCES UNLESS OTHERWISE STATED
SURFACE FINISH
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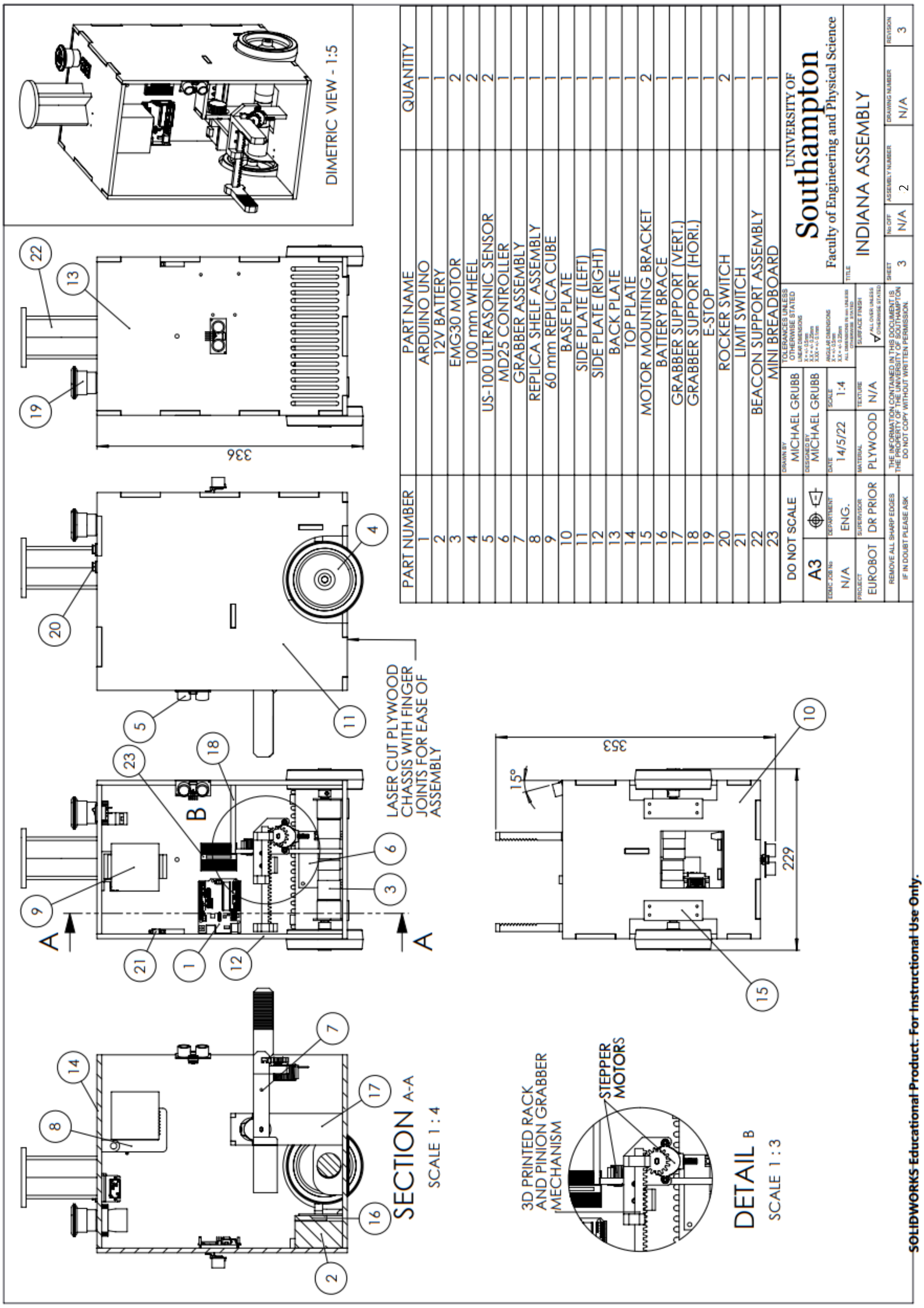
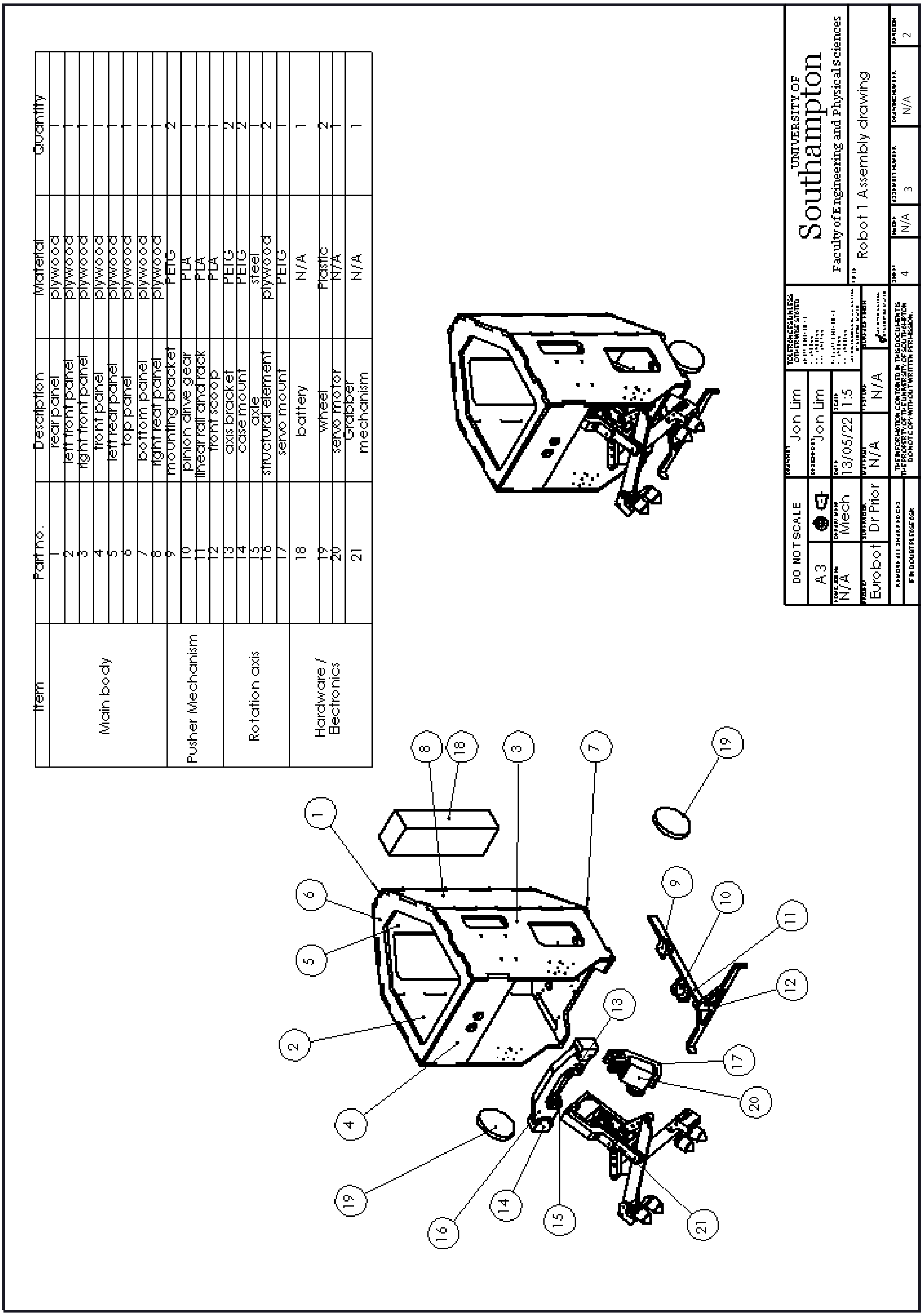
Faculty of Engineering and Physical Science
TITLE
Boulder - Grabber Assembly
SHEET
2
No OFF
2
ASSEMBLY NUMBER
1
DRAWING NUMBER
N/A
REVISION
1
12
13
14
15

**A.3:**



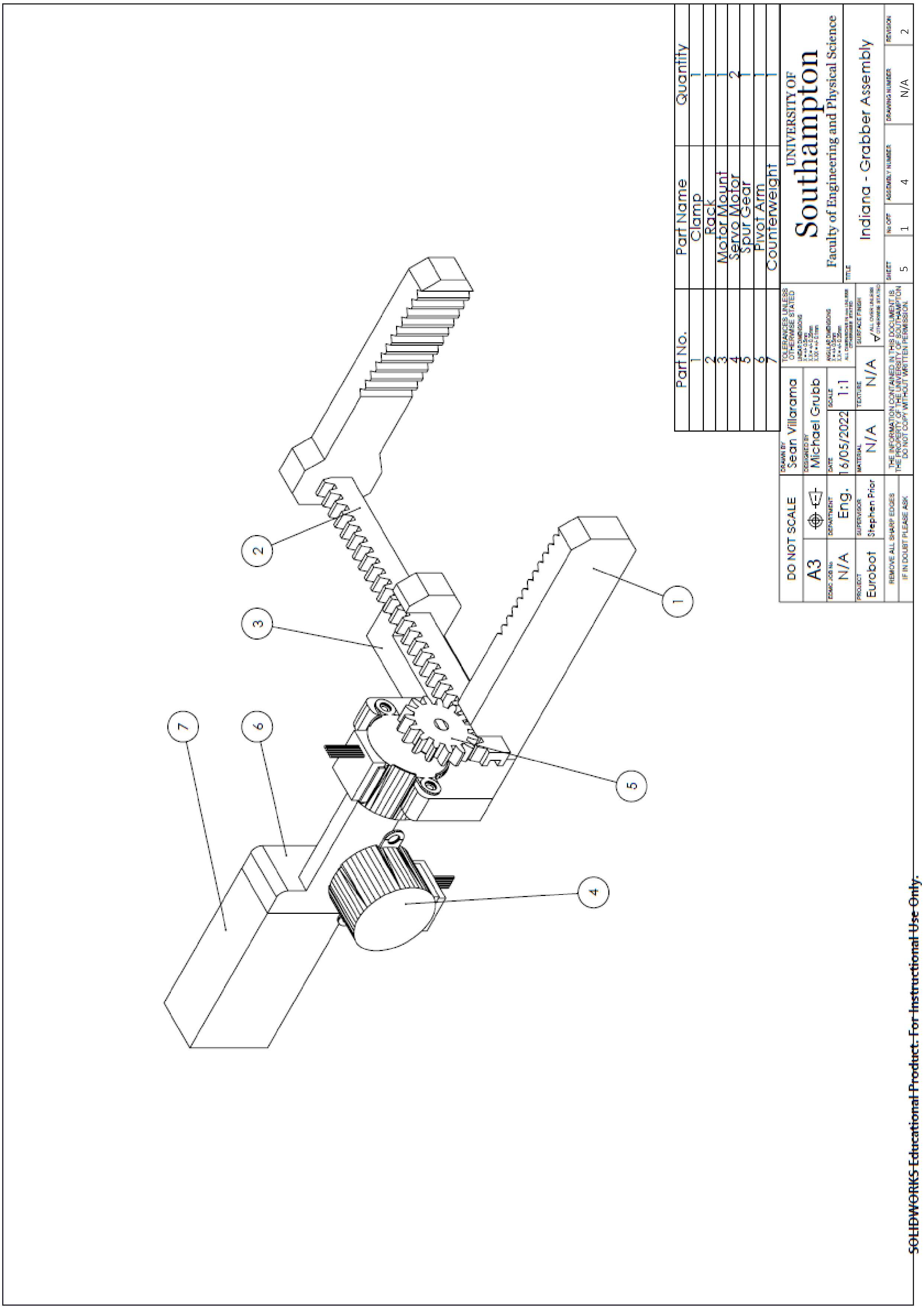

| PART NUMBER | PART NAME | QUANTITY |
|---|---|---|
| 1 | ARDUINO UNO | 1 |
| 2 | 12V BATTERY | 1 |
| 3 | EMG30 MOTOR | 2 |
| 4 | 100 mm WHEEL | 2 |
| 5 | US-100 ULTRASONIC SENSOR | 2 |
| 6 | MD25 CONTROLLER | 1 |
| 7 | GRABBER ASSEMBLY | 1 |
| 8 | REPLICA SHELF ASSEMBLY | 1 |
| 9 | 60 mm REPLICA CUBE | 1 |
| 10 | BASE PLATE | 1 |
| 11 | SIDE PLATE (LEFT) | 1 |
| 12 | SIDE PLATE (RIGHT) | 1 |
| 13 | BACK PLATE | 1 |
| 14 | TOP PLATE | 1 |
| 15 | MOTOR MOUNTING BRACKET | 2 |
| 16 | BATTERY BRACE | 1 |
| 17 | GRABBER SUPPORT (VERT.) | 1 |
| 18 | GRABBER SUPPORT (HORI.) | 1 |
| 19 | E-STOP | 1 |
| 20 | ROCKER SWITCH | 2 |
| 21 | LIMIT SWITCH | 1 |
| 22 | BEACON SUPPORT ASSEMBLY | 1 |
| 23 | MINI BREADBOARD | 1 |

**A.4:**




| Item | Part no. | Description | Material | Quantity |
|---|---|---|---|---|
| Main body | 1 | rear panel | plywood | 1 |
| | 2 | left front panel | plywood | 1 |
| | 3 | right front panel | plywood | 1 |
| | 4 | front panel | plywood | 1 |
| | 5 | left rear panel | plywood | 1 |
| | 6 | top panel | plywood | 1 |
| | 7 | bottom panel | plywood | 1 |
| | 8 | right rear panel | plywood | 1 |
| | 9 | mounting bracket | PETG | 2 |
| Pusher Mechanism | 10 | pinion drive gear | PLA | 1 |
| | 11 | linear rail and rack | PLA | 1 |
| | 12 | front scoop | PLA | 1 |
| Rotation axis | 13 | axis bracket | PETG | 2 |
| | 14 | case mount | PETG | 2 |
| | 15 | axle | steel | 2 |
| | 16 | structural element | plywood | 2 |
| | 17 | servo mount | PETG | 1 |
| Hardware / Electronics | 18 | battery | N/A | 1 |
| | 19 | wheel | Plastic | 2 |
| | 20 | servo motor | N/A | 1 |
| | 21 | Grabber mechanism | N/A | 1 |

**A.5:**



Part No.
Part Name
Quantity
1
Clamp
1
2
Rack
1
3
Motor Mount
1
4
Servo Motor
2
5
Spur Gear
1
6
Pivot Arm
1
7
Counterweight
1
DO NOT SCALE
A3
Sean Villarama
Michael Grubb
16/05/2022
1:1
N/A
Eng.
Eurobot
Stephen Prior
UNIVERSITY OF
Southampton
Faculty of Engineering and Physical Science
Indiana - Grabber Assembly
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1
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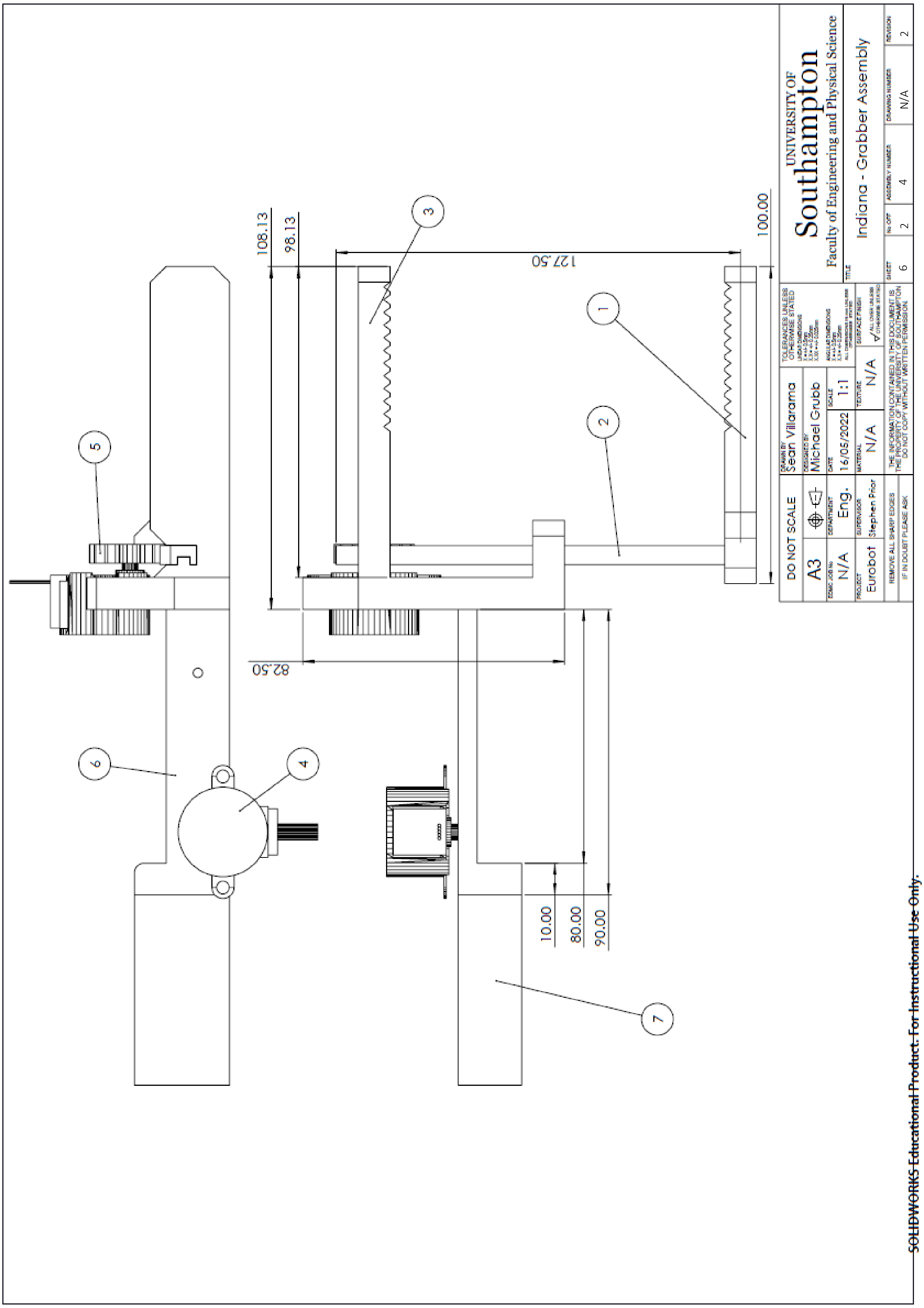
2
SOLIDWORKS Educational Product. For Instructional Use Only.

**A.6:**



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DO NOT SCALE
A3
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Eng.
Eurobot
Stephen Prior
Sean Villarama
Michael Grubb
16/05/2022
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UNIVERSITY OF
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Indiana - Grabber Assembly
6
2
4
N/A
2
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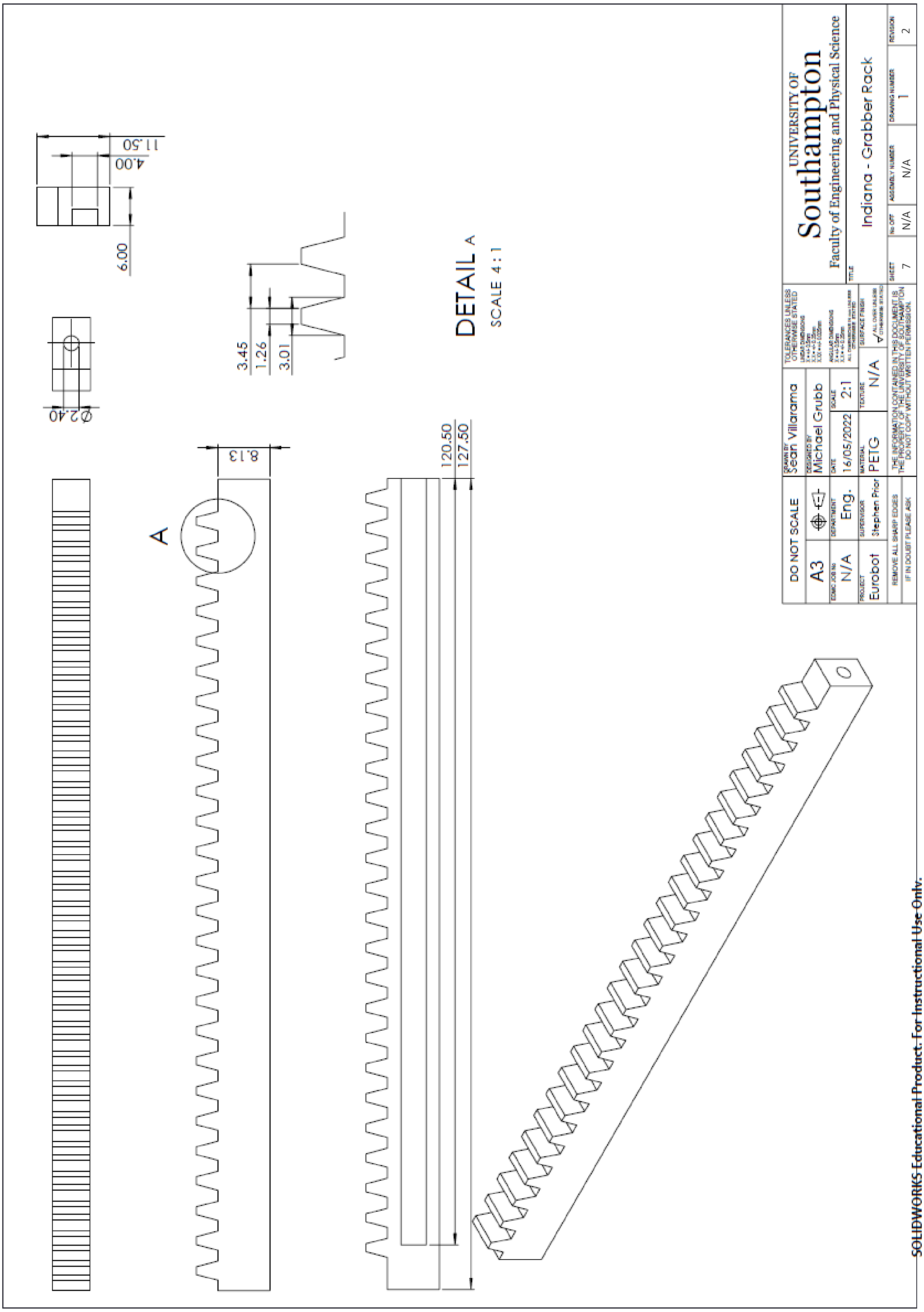
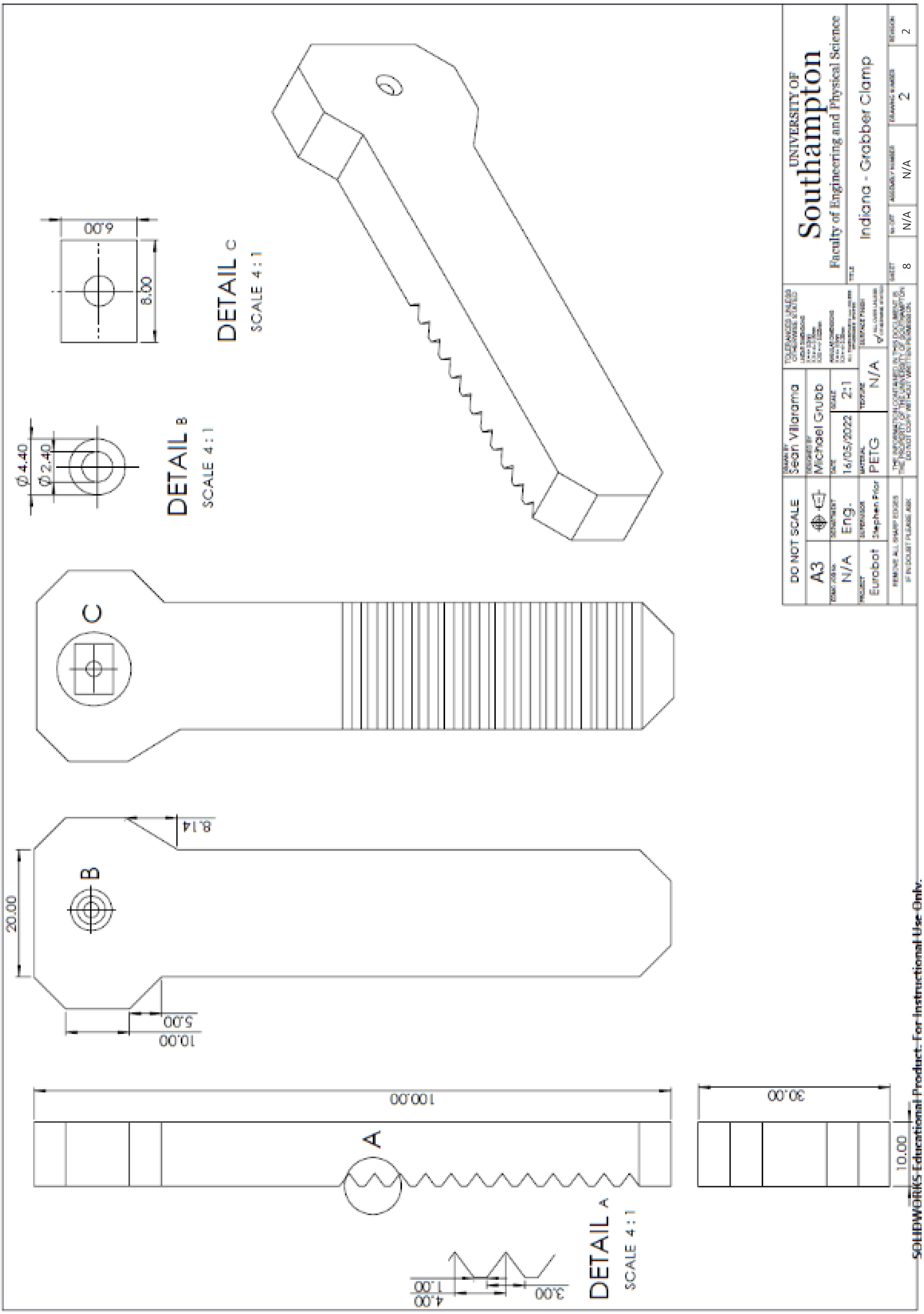
# Appendix B – Part Drawings

**B.1:**

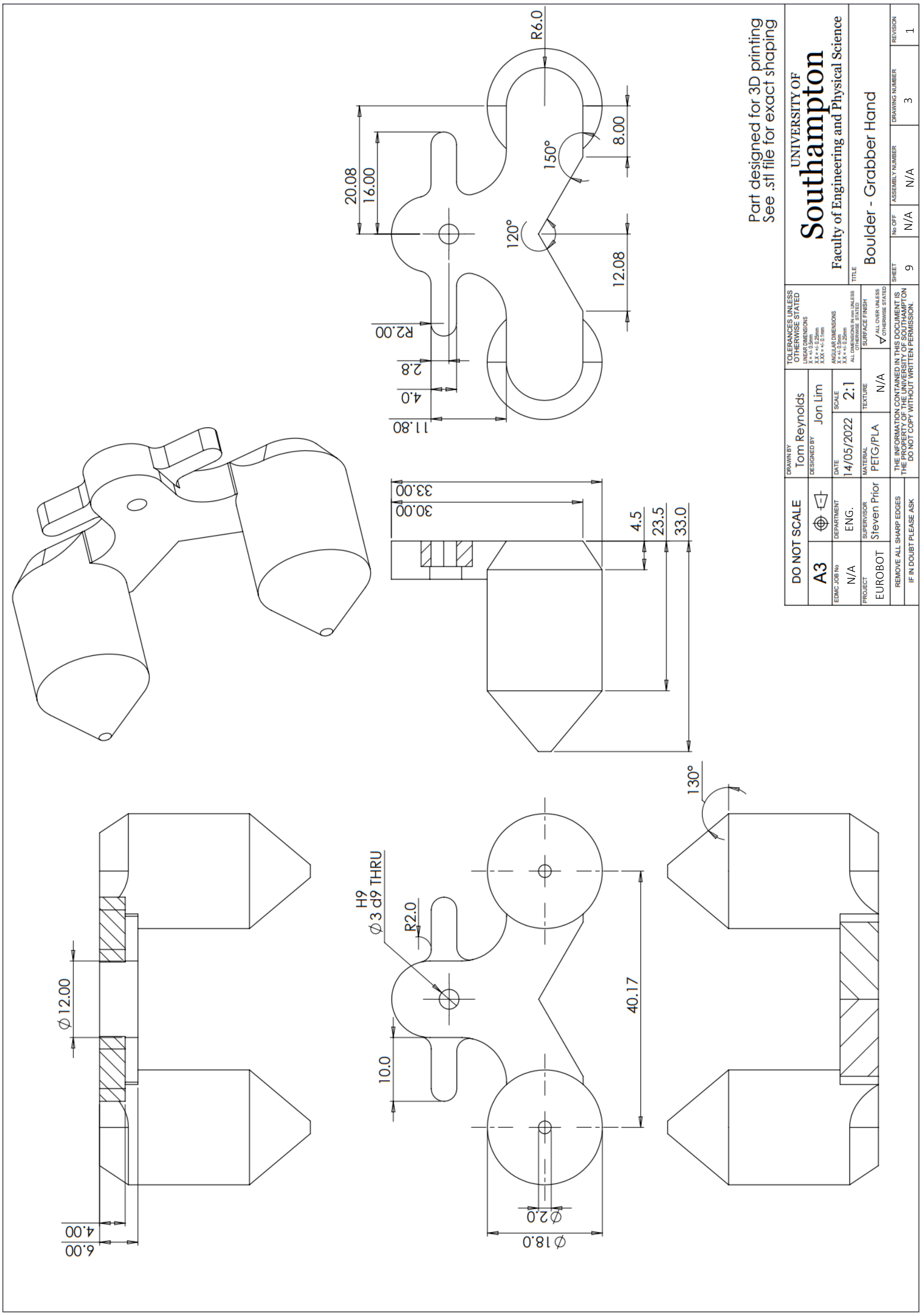


**B.2:**



DETAIL A
SCALE 4 : 1
DETAIL B
SCALE 4 : 1
DETAIL C
SCALE 4 : 1
A
B
C
100.00
30.00
10.00
20.00
5.00
10.00
8.14
Ø4.40
Ø2.40
6.00
8.00
4.00
1.00
3.00
DO NOT SCALE
A3
Sean Villarama
Michael Grubb
16/05/2022
2:1
PETG
N/A
Eng.
Eurobot
Stephen Prior
UNIVERSITY OF Southampton
Faculty of Engineering and Physical Science
Indiana - Grabber Clamp
8
N/A
N/A
2
2
SOLIDWORKS Educational Product. For Instructional Use Only.

**B.3:**


Part designed for 3D printing
See .stl file for exact shaping
UNIVERSITY OF
Southampton
Faculty of Engineering and Physical Science
Boulder - Grabber Hand
DO NOT SCALE
A3
DRAWN BY Tom Reynolds
DESIGNED BY Jon Lim
DATE 14/05/2022
SCALE 2:1
MATERIAL PETG/PLA
TEXTURE N/A
EDMC JOB No N/A
DEPARTMENT ENG.
PROJECT EUROBOT
SUPERVISOR Steven Prior
SHEET 9
No OFF N/A
ASSEMBLY NUMBER N/A
DRAWING NUMBER 3
REVISION 1
REMOVE ALL SHARP EDGES
IF IN DOUBT PLEASE ASK
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R6.0
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120°
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⌀3 d9 THRU
R2.0
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6.00

# Appendix C – Transparent/Exploded Views

## *Indiana* Final Design

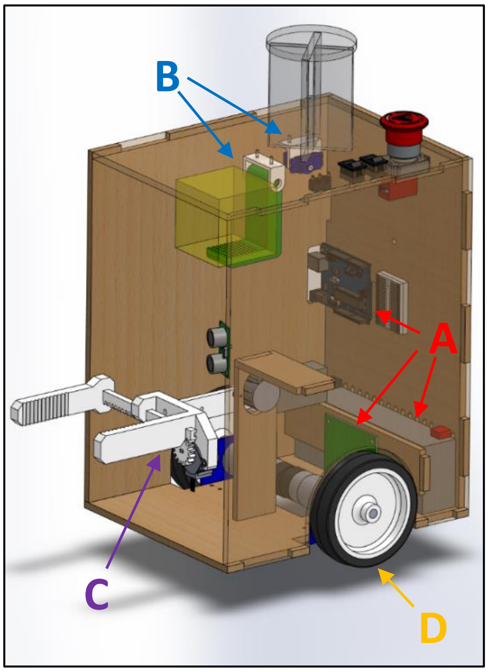


**Figure 31:** Transparent view showing the major sub-systems of *Indiana*

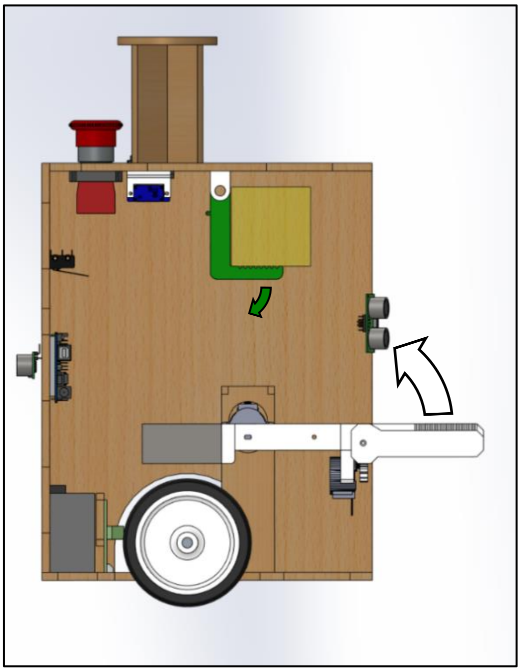

**Figure 32:** Section view displaying the movement of the grabber (white) and shelf

Major sub-systems:

A. Power and control (Arduino UNO, Battery, MD25)
B. Replica shelf assembly
C. Grabber assembly
D. Drive system

## *Boulder* Final Design

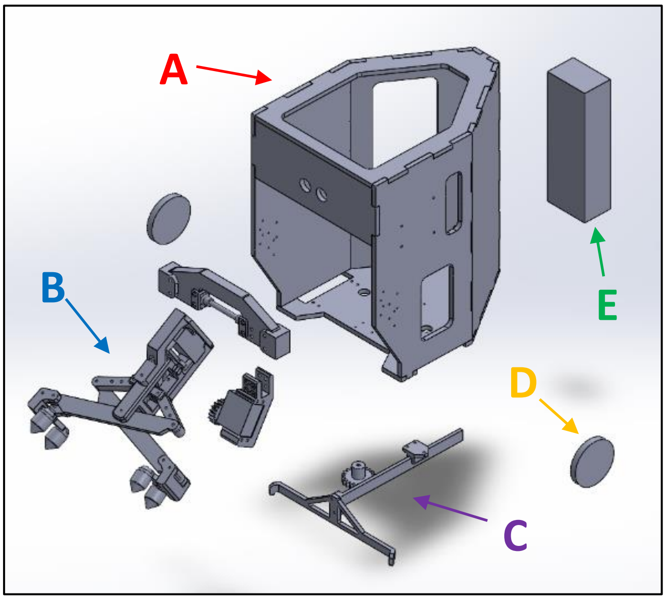


**Figure 33:** Exploded view showing the major sub-systems of *Boulder*

Major sub-systems:

A. Chassis
B. Grabber assembly
C. Scoop assembly
D. Wheels/drive system
E. Battery