MECH2110

Warman Final Report

Group – W01-07-team-2

Due 5:00 PM, Friday 9th June 2023

Semester 1

Name: Joshua Wall

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Introduction

For the 2023 Warman Design and Build Competition the objective is to design, build and demonstrate a scale prototype of an autonomous transportation system for handling hazardous materials within set parameters (Engineers Australia, 2023).

The competition requires the autonomous system, that is constrained to a build volume of 400mm³, to successfully complete a series of tasks across the zones shown below in Fig. 1. It will begin operation within the “Setup/Start Zone”, separately collect both “Propellent” and “Oxidizer Fuel Vessels” from their respective “Drop Zones” and deposit them within their respective “Silos”. This series of tasks must be completed as successfully as possible within the shortest amount of time to maximize points receivable (Alec S. et al., 2023).

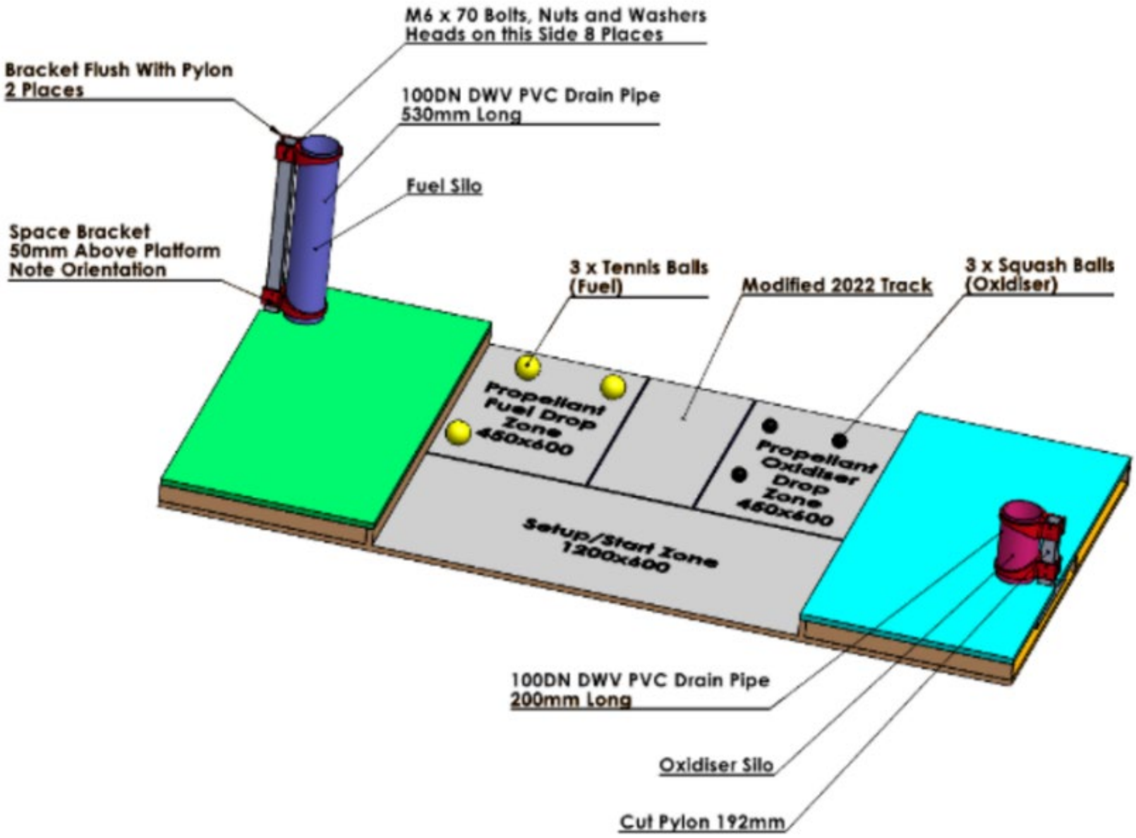


Figure 1 - 2023 Warman Design and Build Competition Track (Warman, 2023, p.18).

To successfully compete in the competition, the final Warman device consisted of a static, cascading crane system with passive vessel handling. This report will detail the operation alongside relevant safety analysis of the final design and documentation of the construction process.

Documentation of the construction process aims to provide a comprehensive understanding of the engineering considerations taken pertaining to component selection, manufacturing techniques, and the testing & evaluation that followed. In turn, observation into the potential areas for future improvement can be made through self-reflection.

Final Solution

In operation, the Warman device performs the required actions under a series of hardcoded movements, with the vessel locations being coordinated during setup to correspond with said movements (Alec S. et al., 2023). The initial stage position of the device, shown below in Fig. 2, is constrained within the build volume, and held statically while unpowered.

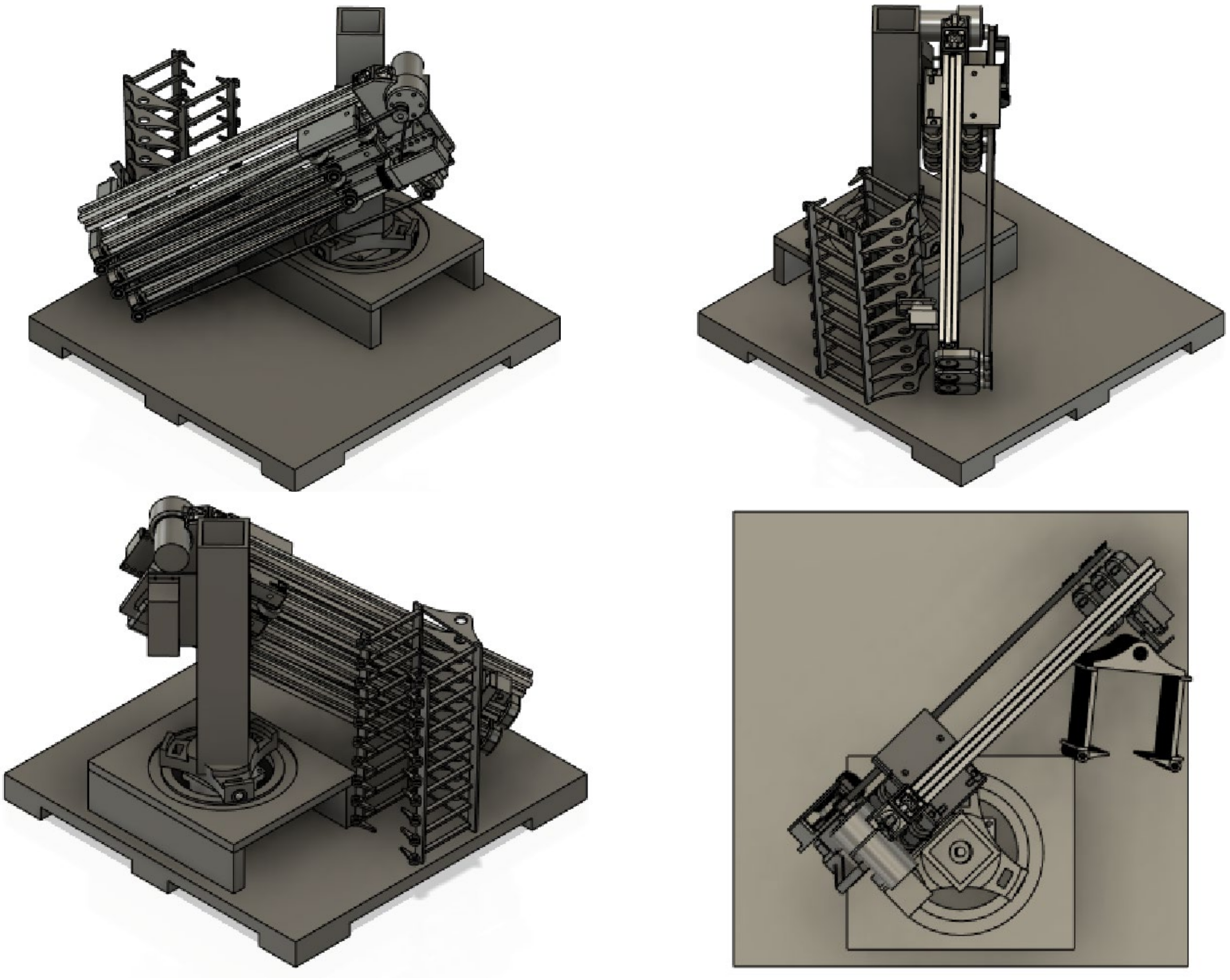


Figure 2 - Initial stage position of the Warman Device. Images courtesy of Josh Wall.

When the system begins operation, it initialises to the starting position in which the linear arm's pitch and the crane base's rotation are zeroed, as shown below in Fig. 3.

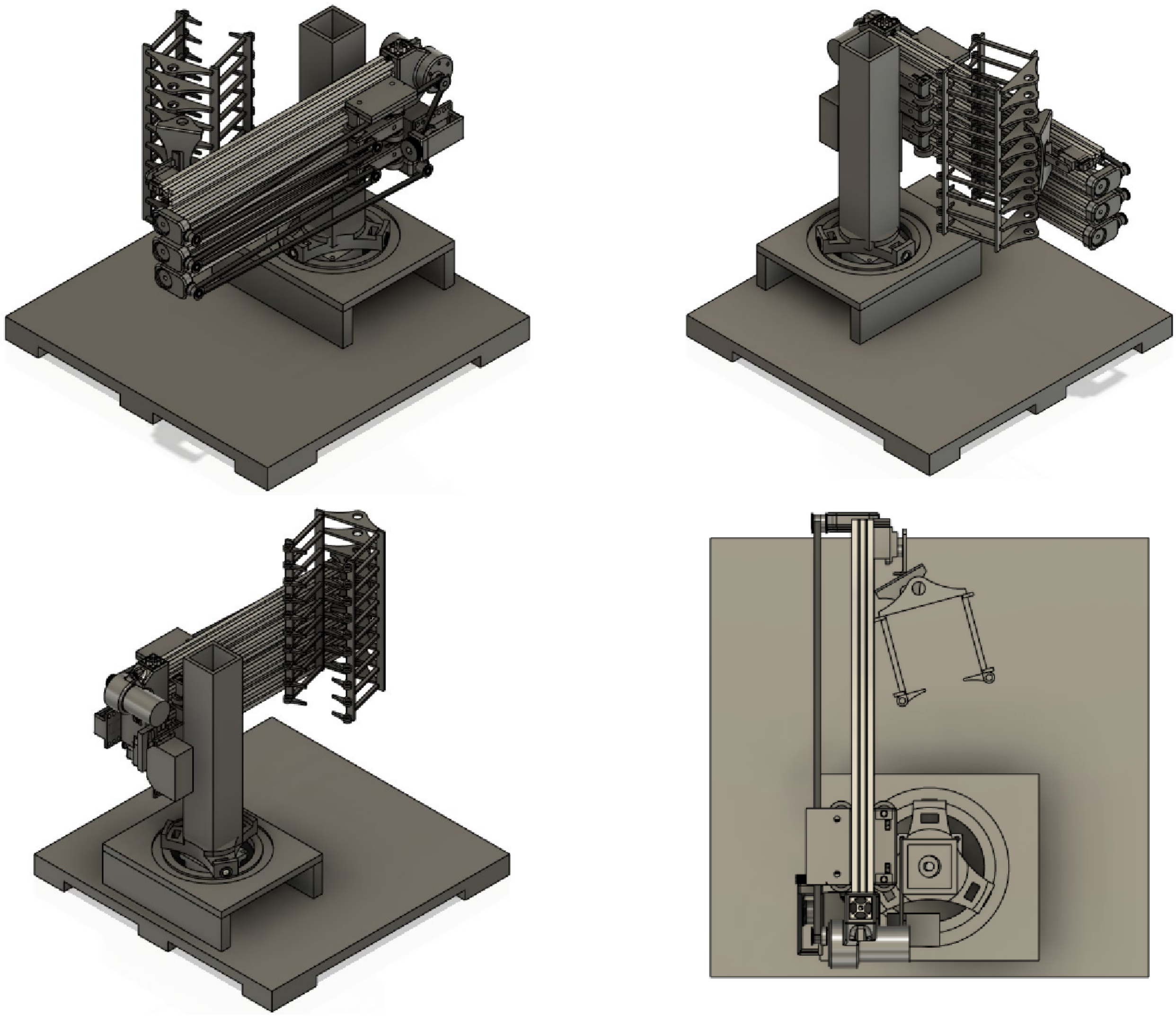


Figure 3 – Warman device commencing operation. Images courtesy of Josh Wall.

From this point, the linear arm pitches upward to avoid any potential collision, and then cascades outwards. Simultaneously, the tool head rotates vertically to become parallel with the track, as shown below in Fig. 4.

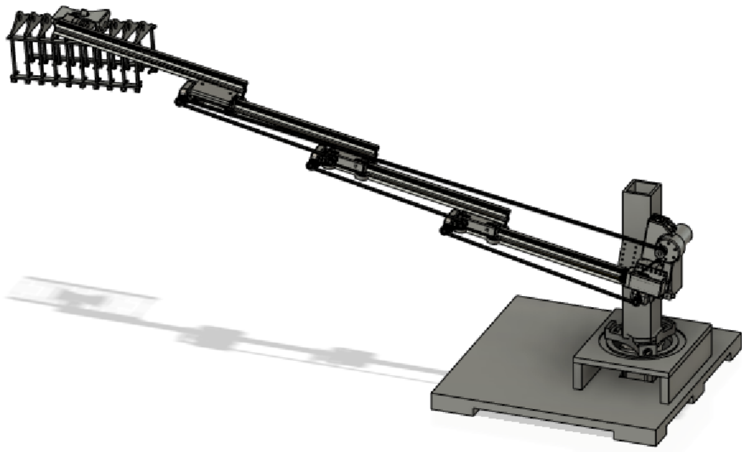


Figure 4 – Linear arm extension outward & vertical rotation of toolhead. Images courtesy of Josh Wall.

Once fully extended, the crane base rotates to allow the linear arm and toolhead to align with a row of vessels. Alignment consists of the spine of the toolhead being centred and parallel to a row of vessels. Once it is aligned, the linear arm pivots downward, and the toolhead descends with it. The toolhead simultaneously rotates vertically to maintain parallel orientation relative to the track, as shown below in Fig. 5.

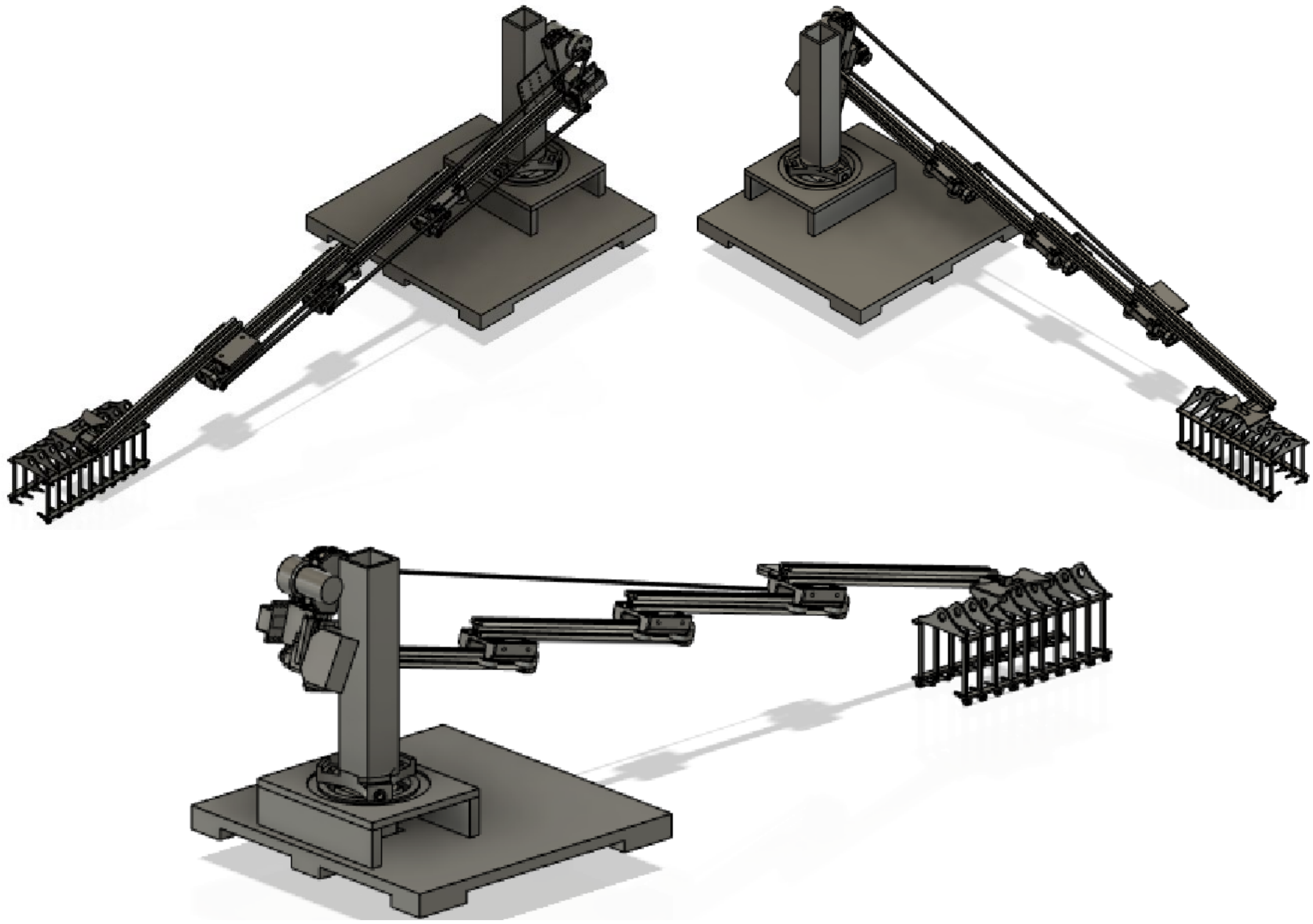


Figure 5 – Linear arm pitching downward for vessel collection. Images courtesy of Josh Wall.

The toolhead utilizes multiple sets of loose pivots organised like a comb (Alec S. et al., 2023) that pivot upwards, about an axel when the combs contact the row of vessels. Once the comb tips pass a “goldilocks zone”, they pivot downwards, returning to their initial position. When lifted, the combs do not allow the vessel to pass back through, as illustrated in Fig. 6.

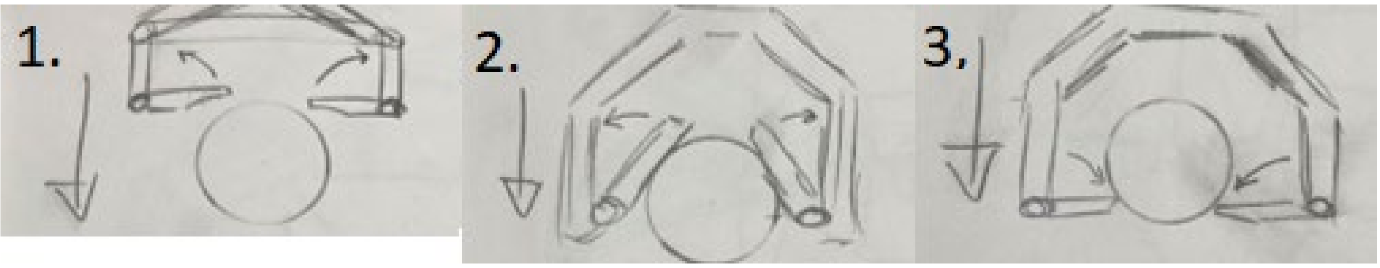


Figure 6 – Toolhead vessel collection demonstration (Alec S. et al., 2023, p.18).

For the toolhead to engage in collection and retention of both vessel types, a “goldilocks zone” of 1.33mm was calculated for the comb tip’s length. Within this deviation of 1.33mm, the combs pass over both vessel types while also catching on both vessel type’s edges upon lifting the toolhead. This “goldilocks zone” is illustrated below in Fig. 7, highlighted in yellow, with each vessel type’s assigned representation signified with a dotted blue outline.

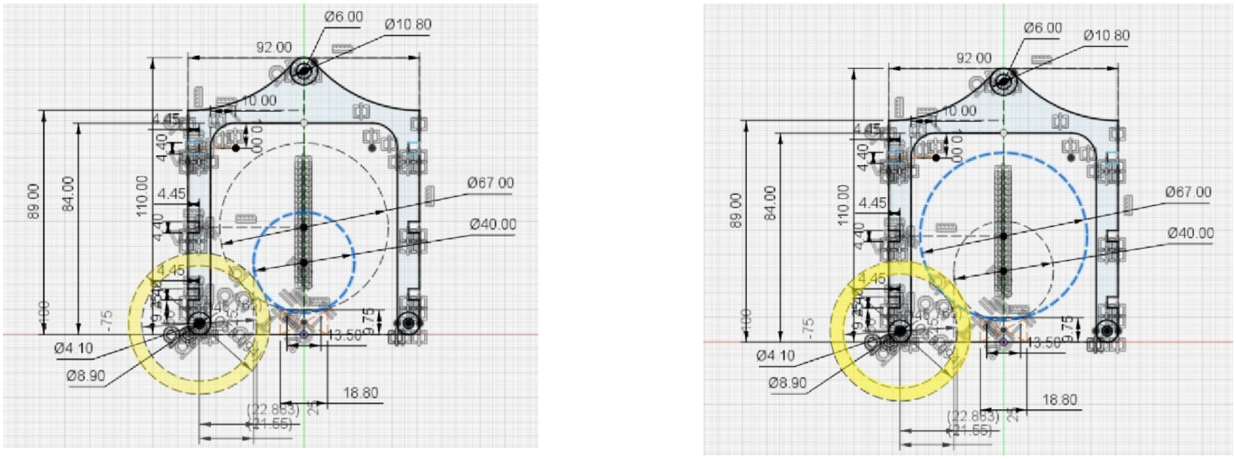


Figure 7 – Comb length calculation. Left: Squash ball. Right: Tennis ball. Images courtesy of Josh Wall.

With all vessels of the same type collected, the linear arm pivots upward whilst rotating the crane base, allowing alignment of the end of the toolhead with the collected vessel’s respective silo. During this process, each vessel is kept in position as they each rest between two pairs of combs. Once in position, the toolhead rotates vertically, as shown below in Fig. 8 (left), and in-turn deposits the vessels into the silo, as shown below in Fig. 8 (right).

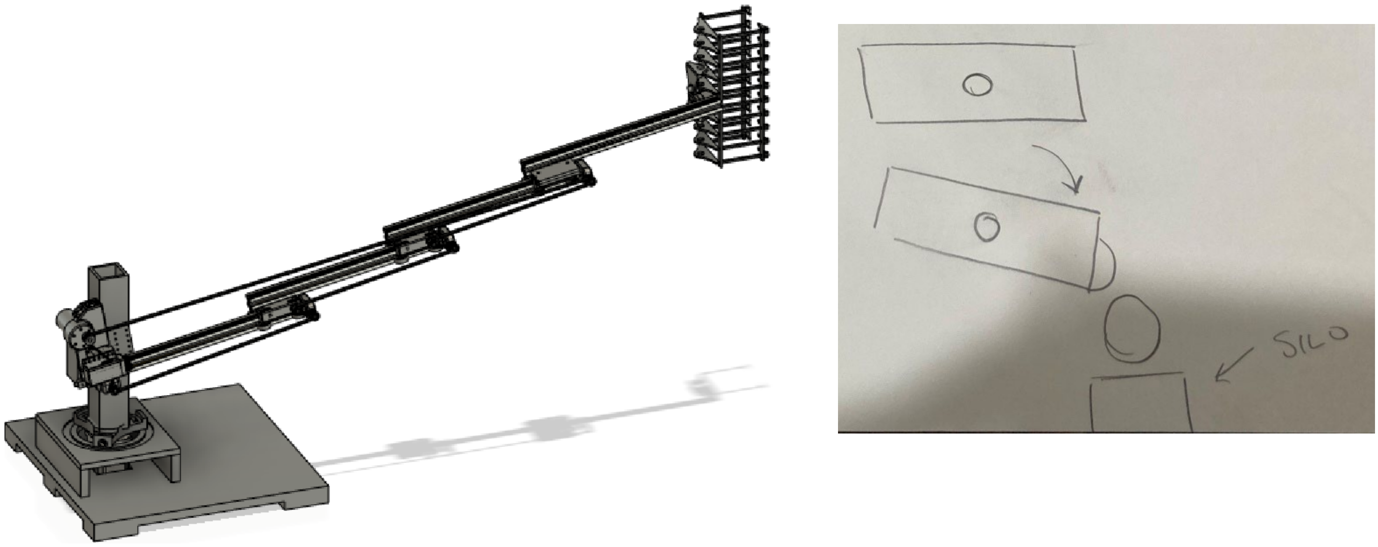


Figure 8 – Vessel deposition. Left: Warman device’s overall deposition position. CAD image courtesy of Josh Wall.

Right: sketch of toolhead deposition orientation, courtesy of James W.

Once the vessels are deposited, the linear arm retracts while pitching downwards, the toolhead returns to parallel relative to the track, and the crane base rotates to align the toolhead with the remaining uncollected vessels. The collection & depositing process will be repeated for the uncollected vessels before returning to the initial stage position, completing the run (Alec S. et al., 2023).

Components, Hardware, & Materials

A detailed table of all components, hardware & materials along with their cost, quantity, and links to all relevant data sheets can be found in appendix A. The out-of-pocket cost for the final Warman device was $409.56 which was kept low thanks to various components, hardware & materials already being on-hand.

Motors

The motors used throughout the Warman device were chosen based on what was close to estimated requirements while still affordable, or on-hand. For all motors, the recommended driver was purchased or already available.

- **Linear arm belt-driver motor**: A continuous rotation was required, hence, a geared DC motor with a digital encoder was chosen. This allowed significant acceleration, as it is a DC motor, while still having adequate torque due to the gearbox. The encoder additionally allowed accurate measurement of extension.

  An estimated requirement of 19 $kg \cdot cm$ was calculated for an extension 330 mm to 1500 mm across 5 rails which would have allowed guaranteed coverage of requirements. The motor that was within budget, *Pololu 37D Metal 30:1 Gearmotor,* was capable of 15 $kg \cdot cm$ which in theory allowed extension to 1200 mm across 4 rails. Which would have been sufficient given moderate toolhead weight.

  A *150W DC-DC Boost Converter* was required for this motor, as a regulated 24V voltage source was not available on the custom PCB.

- **Vertical pivot servo**: As the vertical pivot was restricted to a 90° range of motion, a servo was chosen. 50 to 70 $kg \cdot cm$ torque was calculated based on the estimated total weight of 2 kg for the linear arm & toolhead at an extension of 1200 mm. Hence *DS5180 Servo Motor High Torque 80Kg* was purchased with the capability of 80 $kg \cdot cm$ of torque.

- **Crane base rotational motor**: As the crane base rotation required a high degree of accuracy, a stepper motor was chosen, along with an additional gearbox to meet the torque required. The stepper motor, *Nema 17 Stepper Motor 560mN.m*, was on hand and had a capability of 5.71 $kg \cdot cm$, with the addition of *Planetary Gearbox* with a 10:1 gear ratio to provide 51 $kg \cdot cm$.

- **Toolhead vertical rotation servo**: Similarly, to the vertical pivot, the toolhead's vertical rotation only required a restricted range of motion, hence a servo was chosen. The *9g micro servo (1.6kg)* was chosen, capable of 1.6 $kg \cdot cm$, and while it was claimed to be suitable for the toolhead's initial estimated weight of 200 g, it would be unsuitable for a functional toolhead design.

Electrical subsystem

For the electrical subsystem, the Raspberry Pi Pico (H) was selected as the primary microcontroller for use within the final design of the Warman device. This controller was decided for the final design since through the MECH2110 course content (Carr, 2023) all team members are familiar with the device (Alec S. et al., 2023).

The system relies on a 24V battery and includes the capabilities to power up to 6 stepper motor drivers, in addition to 3 regulated voltage sources (12V, 5V and 3.3V). The circuit is additionally protected by a reverse polarity PnP transistor gate. As per design specification, accommodation for a switch and appropriate (20x5mm) fuse has been included (Alec S. et al., 2023).

The electrical subsystem circuit diagram, PCB design, and final assembled state can be found in Appendix C.

Hardware & Fasteners

A variety of hardware & fasteners were used through the subsystems, mostly chosen based on what was on-hand.

- X-rail was both readily available for initial prototyping, and affordable when additional lengths were required. It is sturdy, lightweight, and consistent in profile for smooth running of bearings which made it suitable for the requirements of the linear arm.
- A standardised M5 bolt was chosen for the linear arm construction, as it was the most compatible with the X-rail fasteners such as T-nuts. The remaining fasteners used in the general construction were source from what was on-hand to those responsible for the manufacturing of their respective components.
- 608 2RS bearings were used as they were on-hand, a standardised size, and suitable for the required applications i.e., linear arm gantries, belt tensioner, the rotational section of the crane base, etc.
- GT2 timing belt, and pulleys were used for the linear arm's belted pulley system, as it was available from a defunct 3D printer.

Materials

The manufactured components materials were split between PETG, 20mm thick plywood, MDF, and steel tube. All of these were on-hand, hence their inclusion in the final design, but were also suitable in where they were utilised.

- 20mm thick plywood was chosen for its adequate strength-to-weight ratio, ease of machinability, and reducibility if the final assembly required weight reduction. Due to the strength-to-weight ratio, its use in the design of the base allowed it to span the build volume, as shown below in Fig. 9. This provided suitable weight distribution and stability for the device.

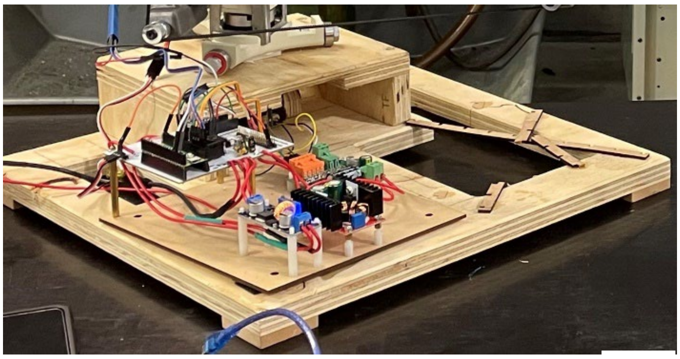


Figure 9 – Plywood base. Photo courtesy of Callen N.

- MDF was chosen for its lightweight properties and its ability to be laser cut. Its use in the toolhead minimised weight and allowed rapid prototyping of the design. The fixture for the vertical pivot motor to the crane base's steel tube, shown below in Fig. 10, benefitted from MDF construction due to the material's mechanical properties. This allowed a compact design that could not be achieved as easily via traditional method or 3D printing.

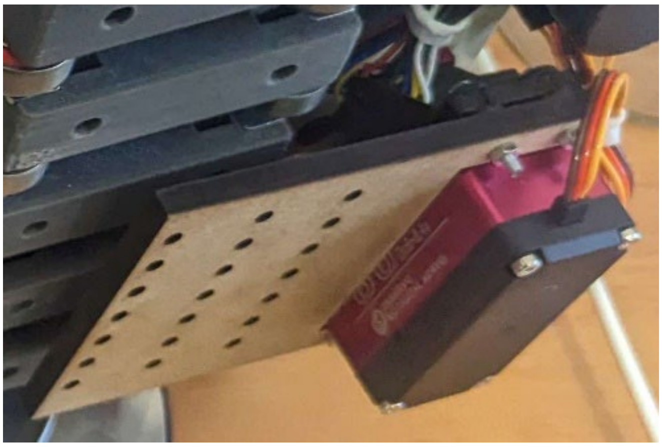


Figure 10 – MDF fixture to steel tube from vertical pivot motor. Photo courtesy of Josh Wall.

- Steel tubing was chosen for its strength. This property was crucial as the tube served as the crane base's upright rotational fixture to the vertical pivot mechanism and in turn the linear arm & toolhead. This allowed a lightweight and adjustable design, shown below in Fig 11., which utilised multiple fasteners without compromising structural integrity.

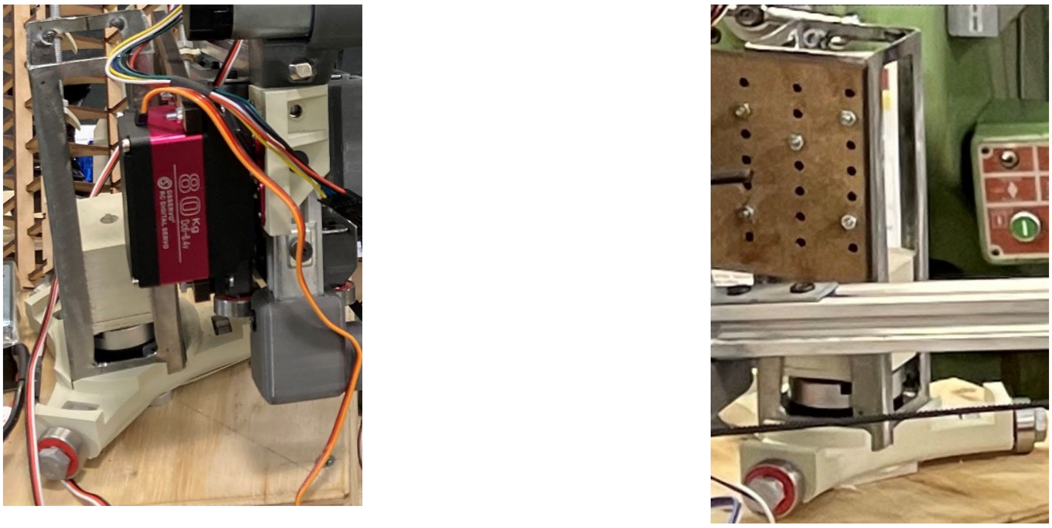


Figure 11 – Steel tube & natural coloured PLA+ components. Left: pictured at rear of device. Photo courtesy of James W. Right: pictured at device's right. Photo courtesy of Callen N.

- PETG filament has a bending stress, modulus, and strain capability above that of most affordable 3D printer filament materials when printed with optimised parameters (Valvez et al., 2022). This allowed for cost & time efficient rapid prototyping of the relevant linear arm components without compromising weight, strength, or accuracy.
- PLA+ filament was used for various components across the device, such as those shown above in Fig. 11, as it was accessible to the group members responsible for these components. These components had static stresses or less weight constraints than other components, therefore an infill of 100% was used alongside designs that utilised rigid materials such as steel bolts where necessary. In the case of the toolhead bracket for mounting onto the linear arm, shown below in Fig. 12, minimal forces were imparted onto it and hence a lower infill was used to save weight.

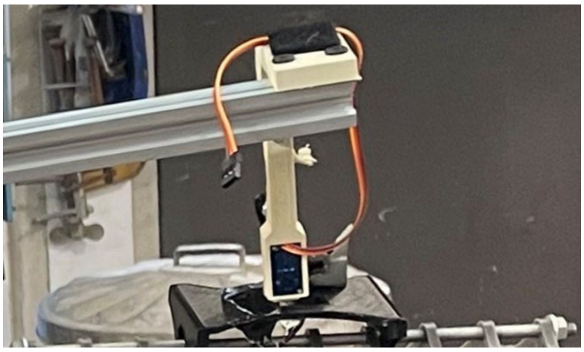
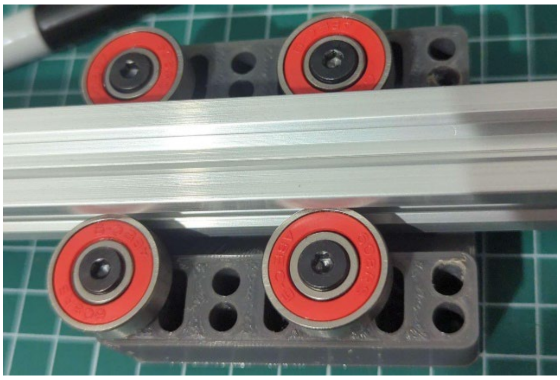


Figure 12 – Toolhead mounting bracket constructed from natural & black PLA+. Photo courtesy of Callen N.

Manufacturing

3D printing

Rapid prototyping in the form of 3D printing was crucial to the overall design of the device, as there were many non-standard parts that required an elevated level of accuracy. For example, the linear arm gantries, shown below in Fig. 13, required several design iterations to achieve an adequate tolerance between the bearings and X-rail. Fine tuning allowed minimisation of friction between the relevant surfaces, and mitigation of problematic deflection when the rail was under load.



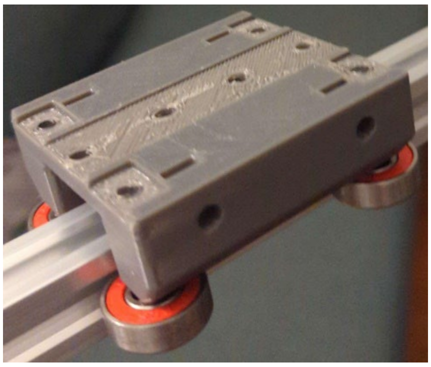


Figure 13 – Linear arm gantry. Left: underside of linear arm gantry. Right: topside of linear arm gantry without X-rail attached. Photos courtesy of Josh Wall.

Laser cutting

Laser cutting was primarily used for the construction of the toolhead, as it allowed time-efficient rapid prototyping of features such as the comb lengths, shown previously in Fig. 7 & 6. These combs required optimisation of the position of the comb tips within the "goldilocks zone" to compensate for real-world errors. The vertical pivot mechanism required an MDF fixture to the steel tube and laser cutting allowed optimisation of the linear arm's position within the build volume to the extent in which the material was capable.

Carpentry

The main base of the Warman device, shown previously in Fig. 9, was constructed using general carpentry skills. As the team member responsible for the construction of this component worked at a timber recycling business, they had access to both the equipment and skillset required. This also allowed flexibility with adjusting position of the rotational base, mounting for the electrical system, overall design, etc.

Metal working

The steel tube used within the rotational crane base required several forms of metal working for it to be a functional component within the device. The mounting points on the steel tube required usage of the drill press, to have accurate, precise, and perpendicular holes. The overall tube had to be cut to length with the cold saw, and the weight had to be reduced by removing panels from three sides using angle grinding and the drill press. This left a frame to maintain overall rigidity & structural integrity.

Risk Assessment

Throughout the design and construction of the Warman device, the core design ethos was the production of a safely operating device. But there are always hazards, so those that could not be eliminated in the design process, were identified and a full, formal risk assessment, which can be found in Appendix B, was undertaken.

Throughout the risk assessment, all hazards have been either eliminated or reduced to "LOW" when measured against the provided risk matrix. Of these hazards, the most catastrophic have been identified as fire & burns, and electrocution & shock. These have been minimised by always using a Lipo safe bag and through quality electrical subsystem design & craftsmanship e.g., in-line fuse, cable management & sheathing, LED operational status signal, etc.

Additionally, safe operating practices have been established which in-turn reduce the lesser hazards identified i.e., cuts, pinch points, crush, bruising, and being struck by moving parts. These safe operating practices are as follows:

- When setting up the Warman device, all hands and tools will be accounted for during the placement and orientation of the device.
- All jigs, tools and parts accounted for during following setup.
- Keeping clear of the device until it is confirmed to be powered off.
- Like when setting up, all hands, tools and parts are accounted for when packing down the device from the Warman track.

Testing & Evaluation

As the Warman device consisted of various subsystems, testing was undertaken separately per each subsystem. First testing mechanically then electrically, and finally as an interconnection of subsystems.

Linear arm

Initially, the design of the linear arm was given an estimated weight based on components that would be persistent throughout prototyping i.e., X-rail, motors, vertical pivot motor mount, etc. and an estimate value for the fluctuating components. As a result of testing, various design changes outlined below were required, with subsequent additions increasing the final weight.

The gantries, pictured below in Fig. 14, required several design iterations and changing of components to achieve an optimal design. Initially, rubberised wheels containing inadequate quality bearings were used, which resulted in a problematic amount of deflection between X-rails under a load of approximately 250 grams, as shown below in Fig. 14(a) & 14(c) respectively. Subsequently, the wheels were replaced by bearings resulting in reduced deflection, as shown below in Fig. 14(b) & 14(d) respectively, but at the cost of additional weight per rail.

While the change to bearings reduced deflection, several design and manufacturing changes were required to optimise looseness or tightness of the gantry on the X-rail to achieve optimal operation. Design changes such as refinement of the tolerance between the bearings, and overall structural redesign, shown below in the variation between Fig. 14(a) & 14(b), assisted in achieving this. Additionally, manufacturing adjustments such as optimisation of printing parameters to allow enhanced design accuracy (Deswal et al., 2019) and adequate compensation for the bending stresses on the gantry (Valvez et al., 2022).

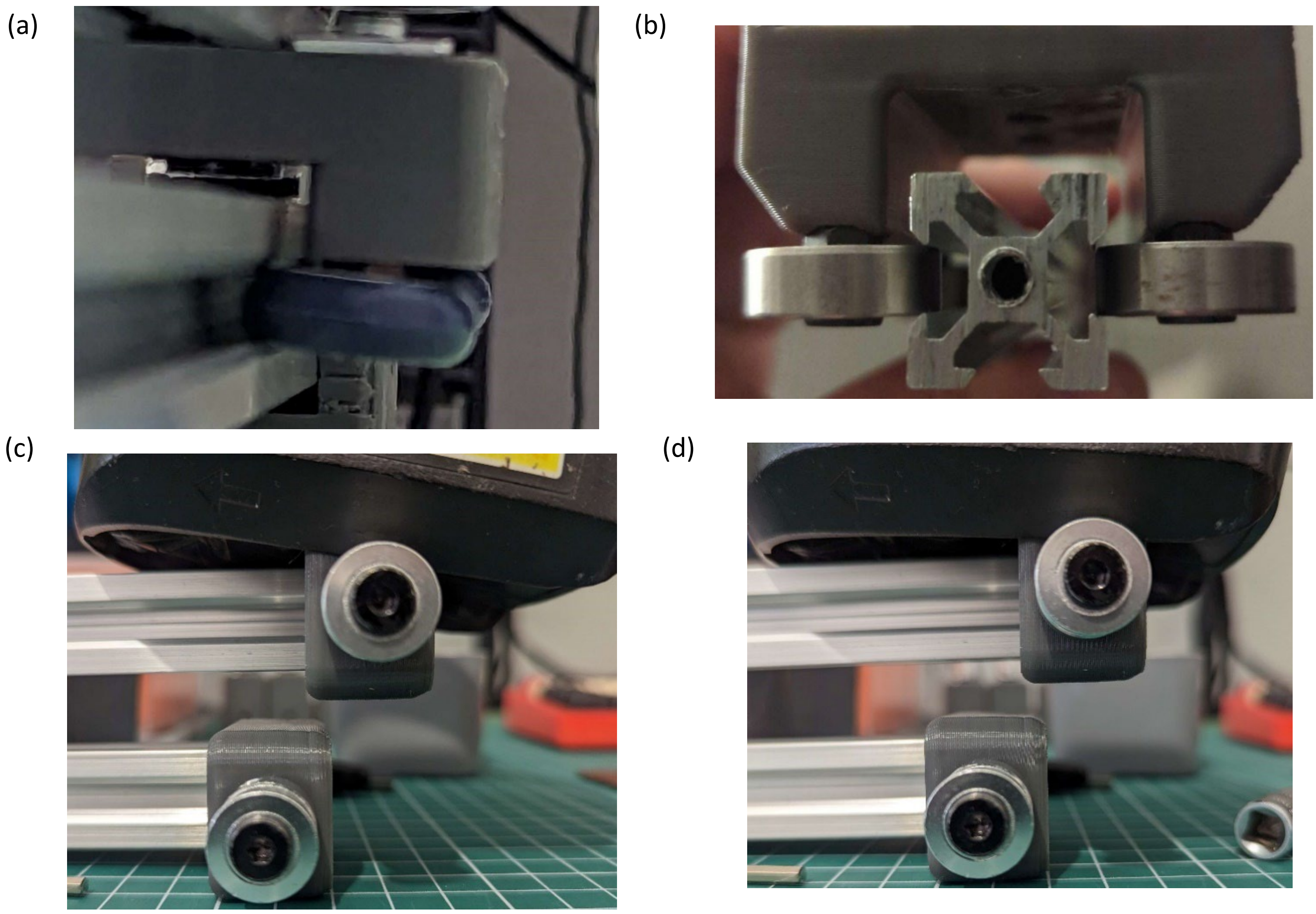


Figure 14 – (a) Wheel-based gantry. (b) Bearing-based gantry. (c) Wheel-based gantry deflection. (d) Bearing-based gantry deflection. Photos courtesy of Josh Wall.

Whilst these adjustments assisted in optimising operation, the lack of adequate torque in the chosen motor resulted in an inability to overcome extension beyond three rails, as shown below in Fig. 15(a). Several design adjustments were attempted to mitigate this, such as an addition of a larger 3D printed pulley on the motor, shown below in Fig. 15(b), but resulted in an excess of starting torque required to initiate motion. A bearing-based belt pretensioner was designed and implemented, shown in Fig. 15(c) & (d), which provided adequate tension to allow smooth operation but would not allow full extension.

The maximum extension achievable with the 3D printed toolhead was approximately 1000 *mm* across 3.5 X-rails, while the estimate of been 1200 *mm* across 4 X-rails was achievable with the MDF toolhead. This reduction in extension is due to the excess weight of the final toolhead, and hence the Warman device would have been limited to collection and deposition of only one vessel type, had further issues not arisen.

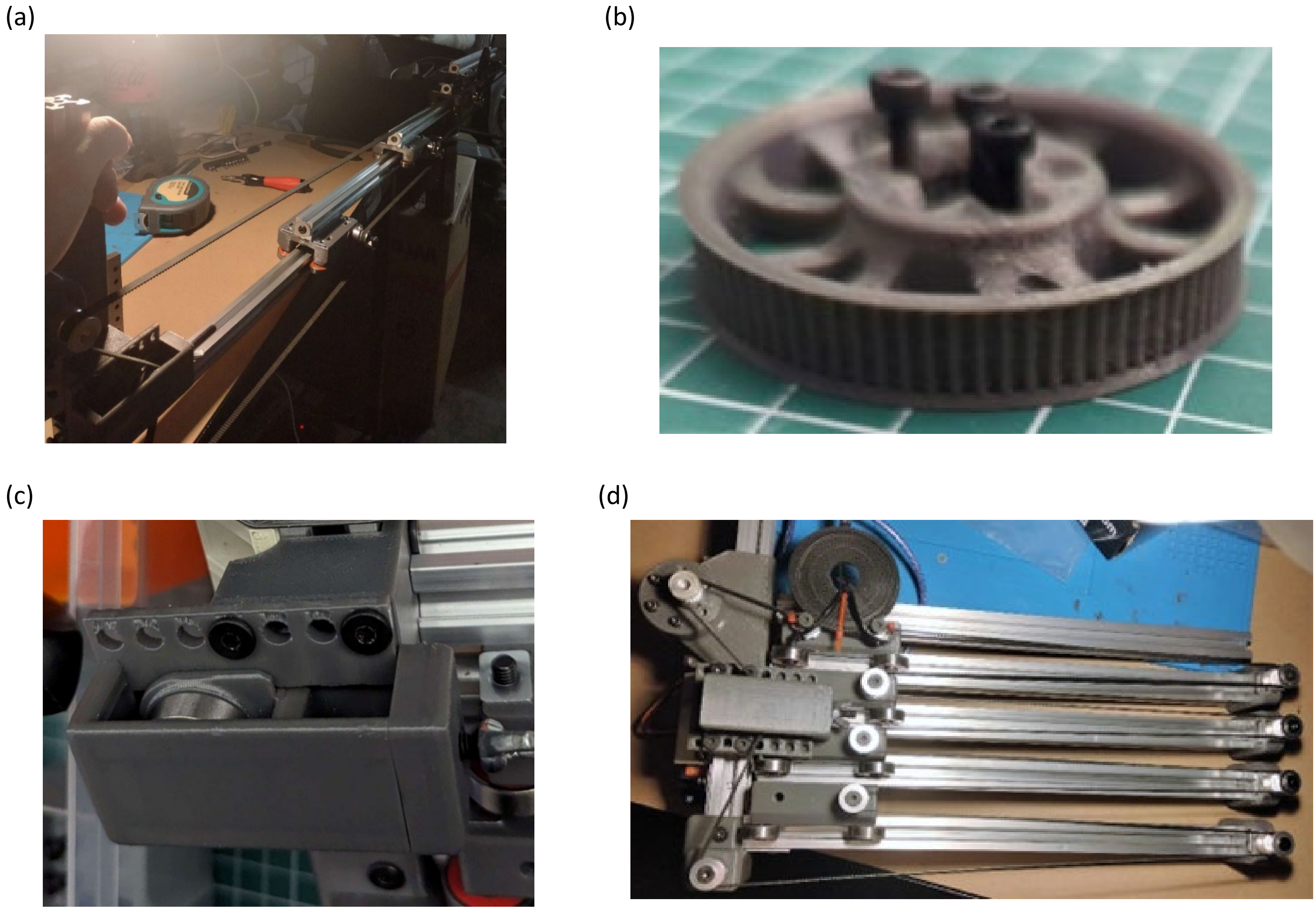


Figure 15 – (a) Linear arm at full-extension. Photos courtesy of Alec S. (b) 60 tooth belt pulley. Photos courtesy of Josh Wall. (c) Belt pretensioner. Photos courtesy of Josh Wall. (d) Belt pretensioner fitted to linear arm assembly. Photos courtesy of Josh Wall.

Toolhead

The conceptual design of the toolhead would have achieved it is required function in a novel fashion, but even at its inception it was noted that it would require significant investment into research and development for this to occur. As this did not happen, it was non-functional when required.

Several design issues, which had been noted early on, caused this. Issues such as the use of threaded rod preventing smooth movement of the MDF combs, shown below in Fig. 16 (left), the usage of warping MDF in a high-tolerance design, shown below in Fig. 16 (right), and the lack of adequate design calculations under the guise of iterative prototyping to achieve what was the then unknown "goldilocks zone" shown previously in Fig 7. Additionally, the vertical rotational servo chosen was under powered for use with the estimated weight of the original MDF toolhead but was kept under the guise of further design optimisation.

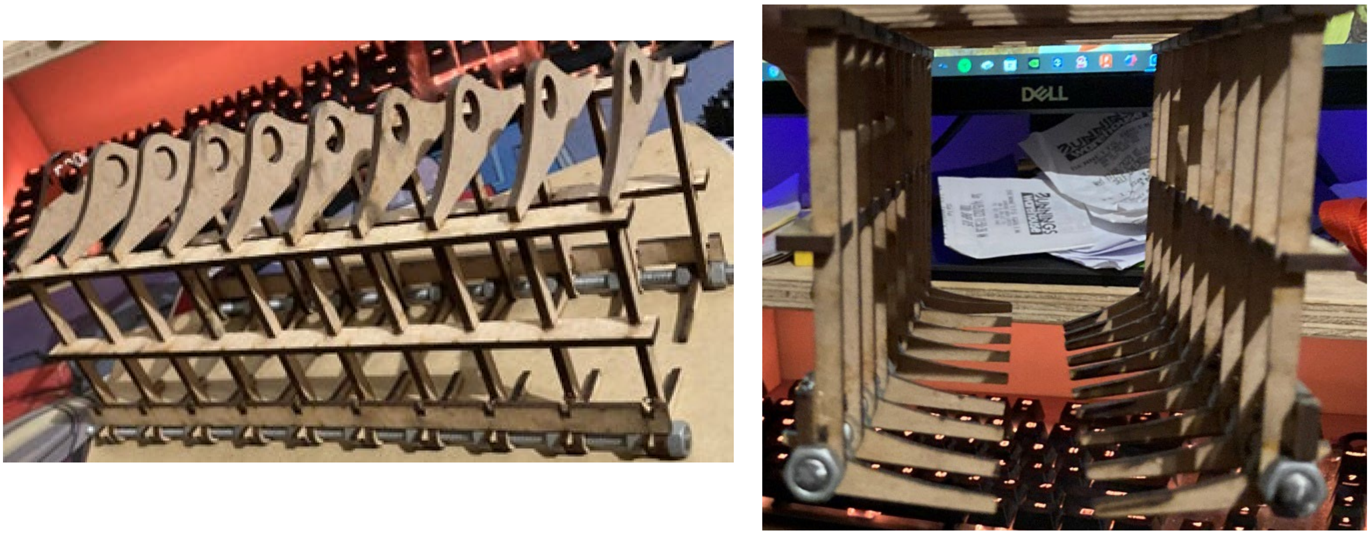


Figure 16 – Final assembly of MDF toolhead. Left: toolhead with visible threaded rods. Right: visible warping causing deviation between the left and right row of combs. Photos courtesy of James W.

As these oversights were not shared with the group in a timely manner, a 3D printed redesign, shown below in Fig 17, was attempted within the remaining time. Steps taken in the redesign consisted of calculation of the "goldilocks zone", usage of non-threaded rod, and overall design corrections. However, given the time limit several changes regarding manufacturing and design were unable to be implemented. Changes such as 3D printing on a glass bed V. PEI sheet to reduced friction between moving parts, adjusting the comb's design to allow adequate counterbalance, and overall weight reduction to reduce vertical rotational torque required.

Figure 17 – Redesigned & 3D printed toolhead. Photo courtesy of Callen N.

Vertical pivot mechanism

As shown previously in Fig. 11, the vertical pivot mechanism was a forward system, although two issues occurred during testing that were not able to be corrected in time. The MDF fixture, used to attach the vertical pivot motor to the steel tube, lacked the strength at the length required to stably position the linear arm at the rear of the build volume and allow optimal length of the linear arm. A steel plate would have been more suitable.

Due to the final weight of the linear arm, at full extension, the vertical pivot motor lacked the torque required to slowly lower or in some cases raise the arm at all. A passive design solution involving the utilisation of a moderate strength spring fixed between the linear arm and steel tube was proposed but the time and supplies were not available.

Crane base

Initially when assembled the Warman device was overweight and required reduction of materials in the crane base. As a result of this, the plywood base and steel tube had various manufacturing techniques used to reduce the weight. Subsequently, some teething issues occurred, such as the steel tube no longer fitting the crane base and resulting in a lean, shown below in Fig. 18. This was resolved by reprinting the rotational crane base insert with a taller edge along with a larger inner cube, shown previously in Fig. 11.

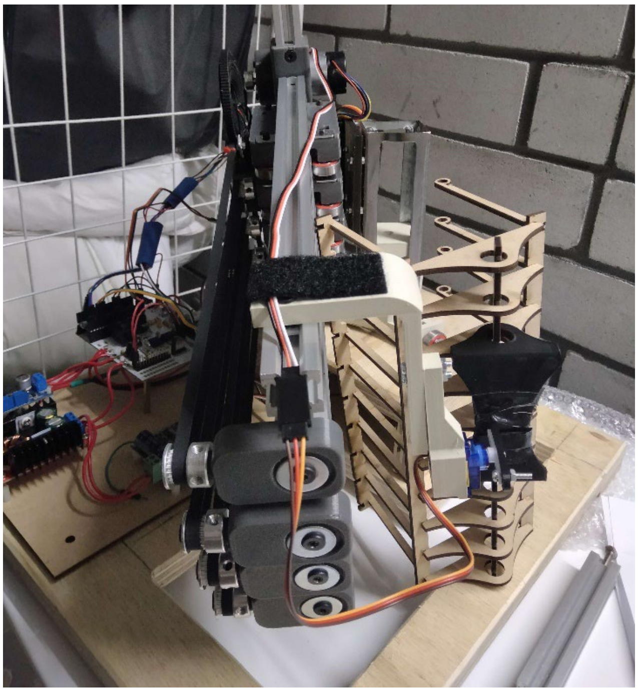


Figure 18 – Assembled Warman device with a lean. Photo courtesy of Alec S.

Final assembly

When finally assembled, an oversight during the weight reduction of the crane base resulted in a non-functional device mid-testing. When disassembling the crane base, shown previously in Fig. 9, the gearbox attached to the crane base rotational stepper motor, shown below in Fig. 19, was not correctly removed. Excessive force was used, instead of the loosening of grub screws, and in doing so the internal workings of the gearbox became incorrectly aligned. This misalignment slowly impaired the gearbox, until it finally seized and resulted in irreparable damaged the rotational stepper motor.

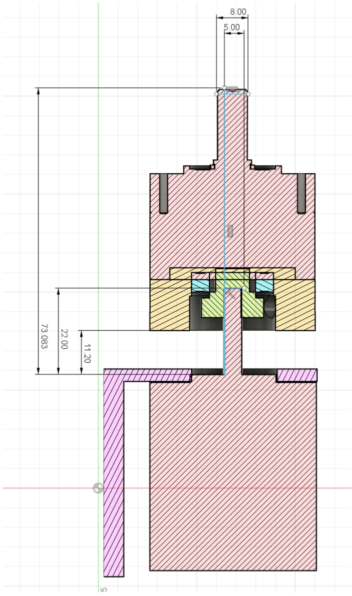


Figure 19 – Crane base rotational stepper motor (bottom) and gearbox (top). CAD image courtesy of Alec S.

With this setback, in addition to the non-functional toolhead, and reduced functionality of both the vertical pivot mechanism and linear arm we were unable to demonstrate a fully cohesive Warman device. Shown below in Fig. 20, demostration of the functional subsystems and proof-of-concept design for the underdeveloped or non-functional subsystems.

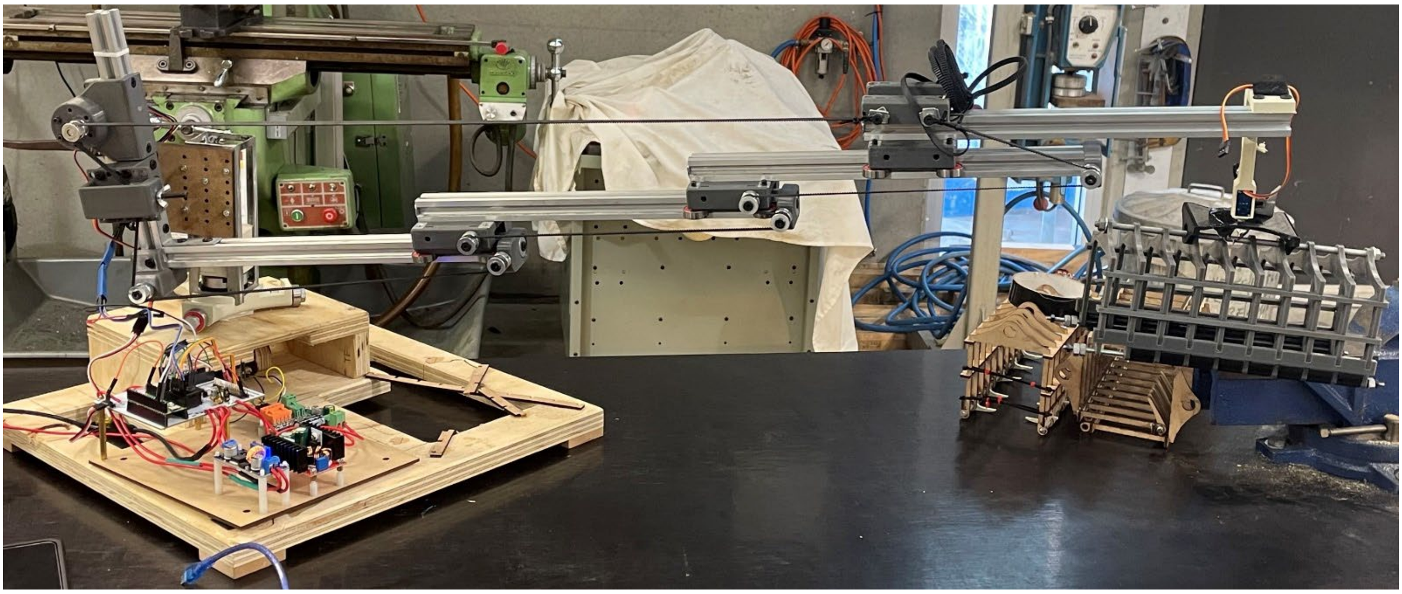


Figure 20 – Final Warman device extending outward, pitched upward, with the 3D printed toolhead. Photo courtesy of Callen N.

Self-reflection

Given additional time or if I were to compete again, I would opt to spend more time calculating more accurate estimates for the weight of subsystems and in-turn the requirements of motors & servos. A decision was made to work with a minimal budget, and if the above actions were taken, an argument could have been made to spend more as it would have been clearly required.

The other major areas in which improvement could be made is project management and inter-group communication. A team member could have been assigned reduced engineering-related capacity and given the sole role of project management. At a minimum, team member's accountability could have been adequately monitored and conversations around reduced capacity could have been had or potentially recognised. Hence, a more accurate project timeline could have been established and in turn, allowing a reasonable amount of time in which issues could be dealt with.

In doing so, issues that resulted in an inability to compete could have at least been brought to the team's attention before it was too late. A prioritisation of effort could have been made so at least some points could have been scored. These retrospective changes also assume that all team members are capable of an even share of the tasks and have sufficient capacity to evenly distribute all tasks required.

Conclusion

While a fully functional Warman device did not come to fruition within the given period, a series of subsystems that were solid proofs-of-concept or functional, or both, were able to be presented. Given additional time, a fully functional and competitive Warman device could be constructed by this team.

On the in-tangible side of achievements, there was a wealth of learning experiences because of this project.

One of which, is the benefit of multidisciplinary teams in developing an optimal solution. A trend occurred in which mechatronics-oriented designs aimed to be a universal solution and cover a variety of edge use-cases, which produced significant overcomplication. Whereas mechanical designs worked towards one specific, highly situational solution. For example, the toolhead used in the Warman device was a passive collection and deposition mechanism whereas, in the conceptual design report, many proposed mechatronics-oriented solutions involved a slew of electronics and sensors that were unnecessary.

Additionally, learning first-hand of the importance of project management and acknowledging that it will also reduce a contributor's capacity in engineering-related aspects. Projects will not happen without a project manager to schedule deliverables, assess them when due, and pivot when they are not up to standard, or on-time.

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Appendix A – Components & Hardware

	Part Name	Datasheet	Quantity	∑ Cost ($)
Hardware				
	ABEC-9 608 2RS bearings	**N/A**	**17**	0
	GT2 (2mm) Timing Belt (meters) - 5mm	**Datasheet**	**4**	0
	20-tooth GT2 Timing Pulley	**Datasheet**	**6**	0
	V-Slot 20 x 20mm - 500mm	**Datasheet**	**5**	7.45
	V-Slot 20 x 20mm – 1000mm	**Datasheet**	**1**	14.85
	10 SETS M3 * 10mm NYLON STANDOFF	**N/A**	**1**	2.4
	10 SETS M3 * 10 HEXAGONAL STANDOFFS MOUNTING KIT	**N/A**	**1**	4.2
∑ total cost ($)				28.90
Materials				
	PETG filament (1kg)	**N/A**	**1**	20
	MDF 900mmx600mmx3mm	**Datasheet**	**2**	5.2
	20mm thick plywood	**N/A**	**N/A**	0
∑ total cost ($)				25.20
Fasteners				
	M5 Nut - Pack of 10	**N/A**	**1**	2
	M6 washer (50 pack)	**N/A**	**1**	8.90
	Tee Nuts (25 Pack)	**N/A**	**1**	4.95
	M5 Low Profile Screws – various lengths	**N/A**	**~**	13.5
	50 x 50 mm 2mm gal tube (meters)	**N/A**	**5**	0
	16mm OD gal rod (meters)	**N/A**	**1**	0
∑ total cost ($)				29.35
Motors				
Cascading Linear Arm	30:1 Metal Gearmotor 37Dx68L mm 24V with 64 CPR Encoder (Helical Pinion)	**Datasheet**	**1**	63.56
Crane Base	Nema 17 Stepper Motor 560mN.m - Version B	**Datasheet**	**1**	0
Vessel Collector	9g micro servo (1.6kg)	**Datasheet**	**1**	6.95
Central Servo Motor	DS5180 Servo Motor High Torque 80Kg	**Datasheet**	**1**	43.13
Central Servo Motor	Planetary Gearbox Gear Ratio 10:1 for Nema 17 Stepper Motor	**Datasheet**	**1**	51.76
∑ total cost ($)				165.40
Electrical				
Cascading Linear Arm	150W DC-DC Boost Converter 10-32V to 12-35V 6A	**Datasheet**	**1**	9.85
Cascading Linear Arm	15A Single DC Motor Driver	**Datasheet**	**1**	32.95
Crane base	DRV8825 Stepper Driver	**Datasheet**	**1**	7.8
Micro Controller	Raspberry PI Pico H	**Datasheet**	**1**	13.0
Central Servo Motor	DC-DC ADJUSTABLE STEP-DOWN MODULE 5A 75W	**Datasheet**	**1**	4.8

PCB Fabrication	5x Printed Circuit Boards	**See Electrical Design**	**1**	36.09
PCB Fabrication	Voltage Regulator (12v)	**Datasheet**	**1**	0
PCB Fabrication	Voltage Regulator (5v)	**Datasheet**	**1**	1.55
PCB Fabrication	14.8V SOFT CASE LIPO BATTERY	**Datasheet**	**1**	34.49
PCB Fabrication	5A fuse	**Datasheet**	**1**	0.52
PCB Fabrication	30A Blade Fuse Holder	**N/A**	**1**	3.95
PCB Fabrication	10A Rocker Switch	**N/A**	**1**	1.91
PCB Fabrication	P-CHANNEL POWER MOSFET - TO-220 PACKAGE - 25A / 60V	**datasheet**	**1**	5.36
PCB Fabrication	20mA LED's	**N/A**	**1**	0
PCB Fabrication	12v zenner diode	**Datasheet**	**1**	0
PCB Fabrication	200k Resistor	**N/A**	**1**	0
PCB Fabrication	2k Resistor	**N/A**	**1**	0
PCB Fabrication	0.22uf Capacitor	**N/A**	**2**	1.00
PCB Fabrication	0.1uf capacitor	**N/A**	**2**	1.00
PCB Fabrication	Schottky Diode	**Datasheet**	**1**	0.49
Safety	Lipo-safe bag	**N/A**	**1**	5.95
∑ total cost ($)				160.71
∑ ∑ total cost ($)				409.56

Appendix B – Risk Assessment

Activity / Task / Location: Warman Demonstration	**Reviewed / Approved By: Josh Wall** **Signature and Date:**	
Risk Assessment Developed by: Alec S.		**Date: 24/05/2023**

Risk Matrix **Likelihood**

N.B. For more details regarding use of this matrix / definitions refer to final page of this document	Rare	Unlikely	Possible	Likely	Almost Certain
Severe ***Eg. Potential Fatality or Injury or Illness with permanent disability***	**MEDIUM**	**MEDIUM**	**HIGH**	**EXTREME**	**EXTREME**
Major ***Eg. Potential Lost Time Injury (but non-permanent disability)***	**LOW**	**MEDIUM**	**MEDIUM**	**HIGH**	**EXTREME**
Moderate ***Eg. Potential Medical Treatment injury or illness (but no lost time)***	**LOW**	**LOW**	**MEDIUM**	**MEDIUM**	**HIGH**
Minor ***Eg. Potential First Aid injury***	**LOW**	**LOW**	**LOW**	**MEDIUM**	**MEDIUM**
Minimal ***Eg. Hazard or near miss requiring reporting and follow up action***	**LOW**	**LOW**	**LOW**	**LOW**	**LOW**

Consequence

Actions required based on Risk Assessment

Extreme	An "extreme" risk requires immediate assessment and senior staff consideration is required; a detailed mitigation plan must be developed, and consideration should be given to ceasing the activity unless the risk can be reduced to a level of high or less; regular monitoring and reported on to the relevant management/steering committee; Target resolution should be within 1 month.
High	A "high" risk may also require immediate assessment and senior staff consideration; a mitigation plan must be developed; regular monitoring and reported on to the relevant management/steering committee. Target resolution (ideally reduction to medium or low level of risk) should be within 3 months.
Medium	A mitigation plan must be developed; existing controls need to be reviewed. Target resolution (ideally reduction to low level of risk) should be within 1 year.
Low	Risk is tolerable; manage by well established, routine processes/procedures and be mindful of changes to nature of risks.

Hazard Identification and initial Risk Rating			Control measures and Residual Risk Rating		Remaining Hazards	Actions required
What are the steps of the activity / items of equipment?	**What are the potential hazards?**	**Risk Rating based on Risk Matrix**	**What control methods or measures will be used to reduce the likelihood and/or the consequence of an illness or injury from those hazards?**	**Residual Risk Rating based on Risk Matrix**	**What hazard remains?**	**What additional actions are required (by who and in what timeframe) to raise the level of control?**
Setting Up the device	Pinch Crush Cuts Bruises	Minor	When setting up the Warman device all hands and tools will be accounted for during the placement and orientation of the device.	Minimal	N/A	N/A

Powering on the device	Burns Shock	Modera te	Lipo bag present during power on through to shut down. All cables sheathed. Fuse present.	Minor	Fire due to electrical fault	In event of a fire, ensure fire blanket or extinguisher is present.
Monitor the device	Struck by moving parts Fire Pinch Crush Cuts	Modera te	Delay between power-on and action implemented. All jigs, tools and parts accounted for during step 1. Staying clear of device once powered-on	Minor	Fire due to electrical fault	In event of a fire, ensure fire blanket or extinguisher is present.
Device halt/ shutdown	Struck by moving parts Pinch Crush Cuts Electrocution	Minor	Infinite halt implemented and LED light on device signals run is over. Power Switch present to ensure device is powered off. Keeping clear of device until it is confirmed to be powered off	Minimal		
Packing down the device	Pinch Crush Cuts Bruises	Minor	Like when setting up, all hands, tools and parts are accounted for when packing down the device from the Warman track	Minimal		

Charging the lithium polymer battery	Fire	Moderate	Whenever charging, the battery is placed within a Lipo fireproof safe bag and away from the project	Minimal	Fumes	Exiting the premises until fumes have dissipated
Error occurs	Fire Loss of project	Moderate	Should an error occur, battery will be placed away from the reach of the project, and a power switch exposed.	Minor	Fire due to electrical fault	In event of a fire, ensure fire blanket or extinguisher is present.

Summary of Requirements based on Risk Assessment		Review Period / Date
Personal Protective Equipment	Eye protection	
Other Equipment and Equipment Protection	Fire Extinguisher	
Training Requirements	N/A – if intervention is required only those familiar with the operation of the device should intervene	
Procedures, SOPs etc	N/A	
Relevant Legislation etc.	WHS Act 2011 (NSW) & Regulations / Codes of Practice	

Questions to ask in order to determine the hazards relating to the task:

A Could people be injured or made sick by things such as: • Noise • Light • Radiation • Toxicity • Infection • High or low temperatures • Electricity • Moving or falling things (or people) • Flammable or explosive materials • Things under tension or pressure (compressed gas or liquid; springs) • Any other energy sources or stresses • Biohazardous material • Laser	**D What could go wrong**? • What if equipment is misused? • What might people do that they shouldn't • How could someone be killed? • How could people be injured? • What may make people ill? • Are there any special emergency procedures required? **E Are procedures or organisational systems missing or not being followed**? • Standard Operating Procedures? • Risk Assessments? • Induction or training? • Management of change? • Safety Inspections? • Hazard reporting? • Contractor Management?
B Can workplace practices cause injury or sickness? • Are there heavy or awkward lifting jobs? • Can people work in a comfortable posture? • If the work is repetitive, can people take breaks? • Are people properly trained? • Do people follow correct work practices? • Are there adequate facilities for the work being performed? • Are universal safety precautions for biohazards followed? • Is there poor housekeeping? Look out for clutter • Torn or slippery flooring • Sharp objects sticking out • Obstacles **C Imagine that a child was to enter your work area?**	**F What kinds of injuries could possibly occur?** • Broken bones • Eye damage • Hearing problems • Strains or sprains • Cuts or abrasions • Bruises • Burns • Lung problems including inhalation injury/ infection • Skin contact • Poisoning • Needle-stick injury • Psychological illness or injury

• What would you warn them to be extra careful of? • What would do to reduce the harm to them?	

How to Assess Risk

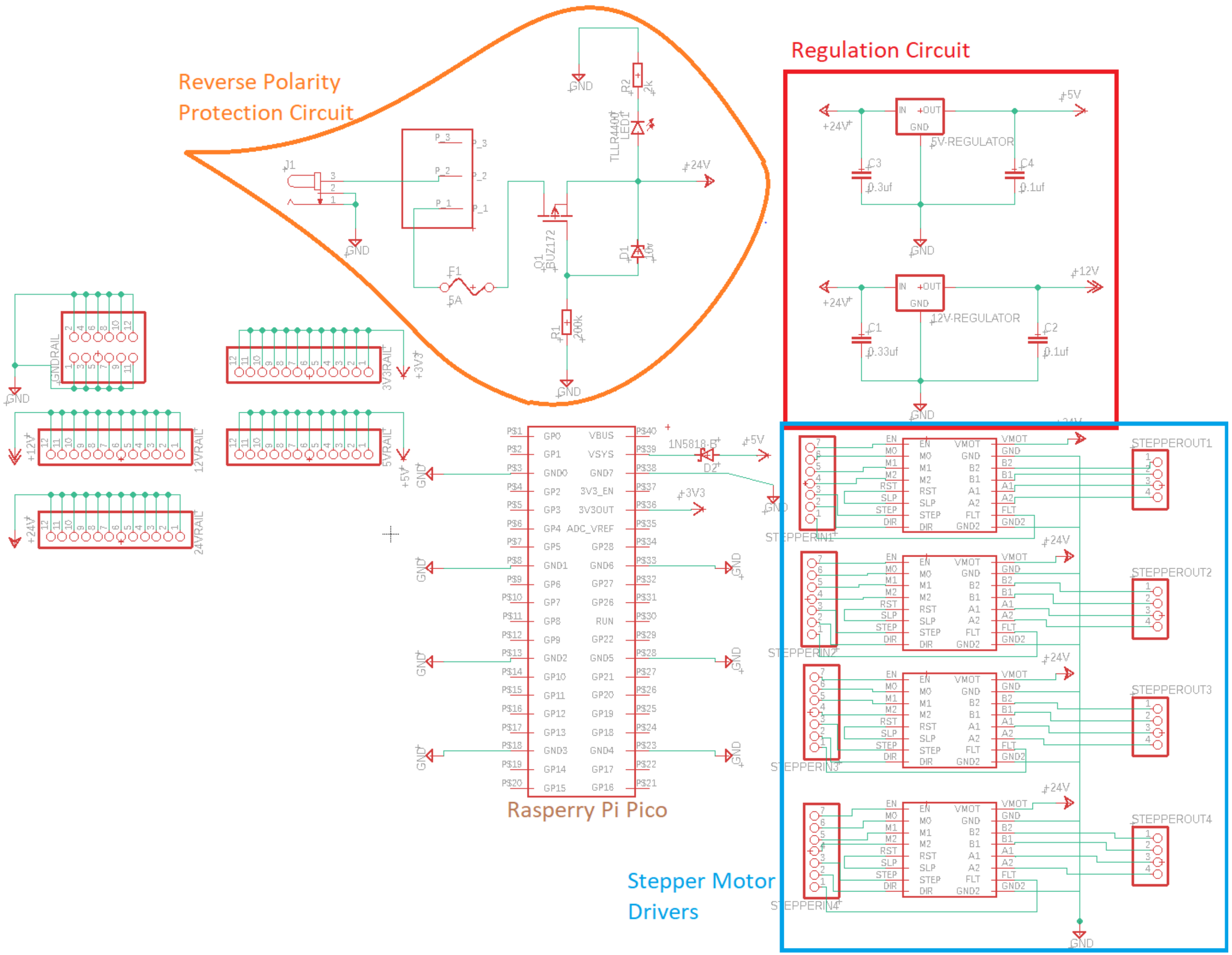
Step 1 – Consider the Consequences		*Step 2 – Consider the Likelihood*		Step 3 – Calculate the Risk Rating						
What are the potential consequences of an incident occurring? Consider what <u>could reasonably</u> happen as well as what may actually happen. Look at the descriptions and choose the most suitable Consequence.		**What is the likelihood of the consequence identified in step 1 happening? Consider this with the current controls in place.** Look at the descriptions and choose the most suitable Likelihood.		A. Take Step 1 rating and select the correct column. B. Take Step 2 Rating and select the correct line. C. The calculated risk rating is where the two ratings cross						
Consequence		**Likelihood**				**Rare**	**Unlikely**	**Possibly**	**Likely**	**Almost Certain**
Serious	Potential Fatality or Injury or Illness with permanent disability	**Almost Certain**	The event could be expected to occur in most circumstances: "This is a common problem here".	**CONSEQUENCE**	*Serious*	MEDIUM	MEDIUM	HIGH	EXTREME	EXTREME
Major	Potential Lost Time Injury requiring time off work (but non-permanent disability)	**Likely**	The event has a reasonable chance of occurring in usual conditions: "It has happened here before".		**Major**	LOW	MEDIUM	MEDIUM	HIGH	EXTREME
Moderate	Potential medical treatment Injury or Illness but no lost time	**Possible**	The event might occur occasionally, has occurred sometime: "Has infrequently happened here before".		**Moderate**	LOW	LOW	MEDIUM	MEDIUM	HIGH
Minor	Potential First Aid Injury	**Unlikely**	The event has a small chance of occurring. "It has not happened here but has occurred elsewhere".		**Minor**	LOW	LOW	LOW	MEDIUM	MEDIUM
Minimal	No injury but hazard exists or near miss occurred requiring reporting and follow up action	**Rare**	Very unlikely to occur. "It would be extremely rare for it to occur here".		**Minimal**	LOW	LOW	LOW	LOW	LOW

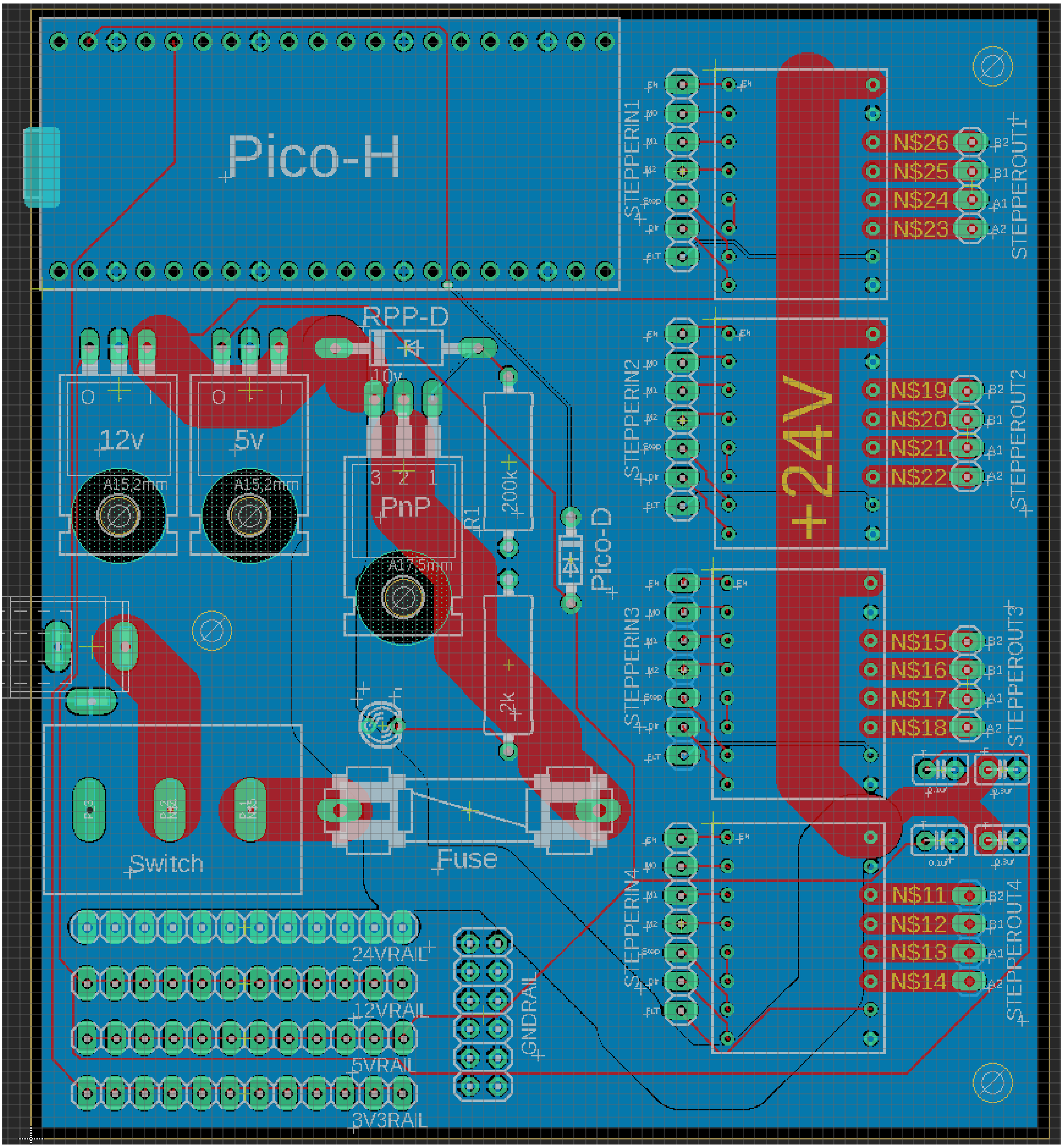
	Control Type	Example

Eliminate	Removing the hazard, e.g., taking a hazardous piece of equipment out of service.
Substitute	Replacing a hazardous substance or process with a less hazardous one, e.g., substituting a hazardous substance with a non-hazardous substance.
Engineering	Redesign a process or piece of equipment to make it less hazardous, Isolating the hazard from the person at risk, e.g., using a guard or barrier, or containing the hazard in an enclosure.
Administrative	Adopting safe work practices or providing appropriate training, instruction or information.
Personal Protective Equipment (PPE)	The use of personal protective equipment could include using gloves, glasses, earmuffs, aprons, safety footwear, dust masks. **NOTE: This is a last resort control and should be used in conjunction with higher level controls.**

Controlling the Risk: Risk control is a method of managing the risk with the primary emphasis on controlling the hazards at source. For a risk that is assessed as "extreme" or "high", steps should be taken immediately to minimize risk of injury. The method of ensuring that risks are controlled effectively is by using the "hierarchy of controls". The Hierarchy of Controls are:

Appendix C – Electrical Subsystem




Pico-H
RPP-D
10v
12v
5v
PnP
R1
200k
2k
Pico-D
Switch
Fuse
24VRAIL
12VRAIL
5VRAIL
3V3RAIL
GNDRAIL
+24V
STEPPERIN1
STEPPERIN2
STEPPERIN3
STEPPERIN4
STEPPEROUT1
STEPPEROUT2
STEPPEROUT3
STEPPEROUT4
N$26
N$25
N$24
N$23
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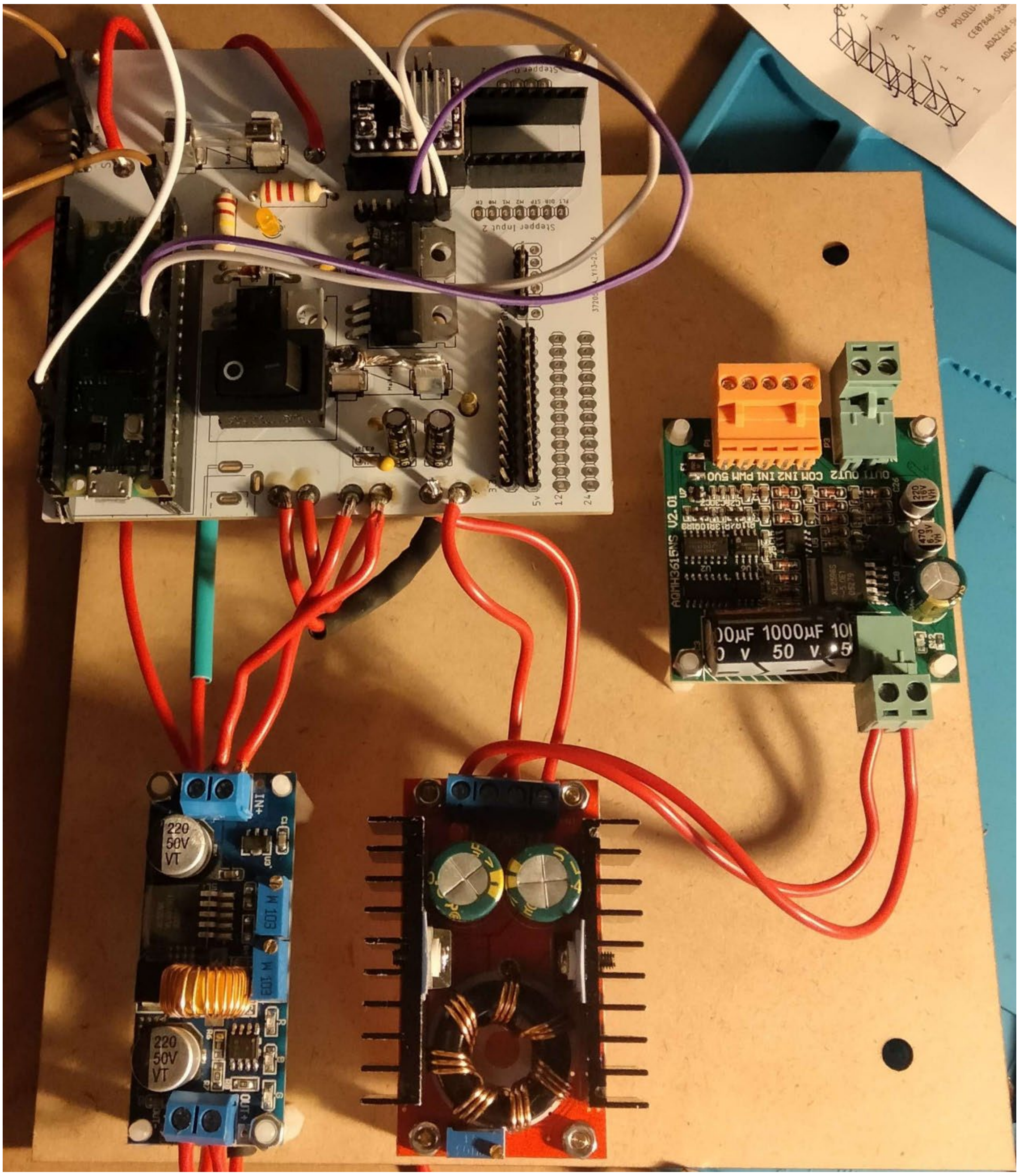
N$12
N$13
N$14



AQMH3615NS V2.01
5V0 PWM IN1 IN2 COM OUT2 OUT1
1000μF 50 V
220 50V VT