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1 Introduction

"The IMechE Design Challenge is an annual competition organised by the Institution of Mechanical Engineers (IMechE, 2026a).", providing competitors with the opportunity to design and manufacture an autonomous device within an engineering specification. The 2026 competition specifies an external pipe climber device capable of ascending and descending a vertical 22 mm diameter copper pipe in a controlled manner, whilst carrying a progressively increasing load in the form of a chain and executing a sequence of manoeuvres with precision within a three-minute window.

The competition emulates real applications and practices present in the emerging sector of autonomous vehicles, especially in the context of servicing of infrastructure in complex situations. Pipe and cable climbing robots are deployed for inspection and maintenance of infrastructure installed in environments where human access is hazardous, expensive, or impractical. Two systems present in industry highlight the scope. The SKY Wire rope climbing robot, developed by Inspection GC "performs autonomous testing on bridge suspension cables" (Inspection GC, 2024). The AFL SkyWrap "installs optical fibre on existing overhead lines" (AFL Global, 2024).

Both systems exhibit similar requirements to the competition, reliable, repeatable autonomous locomotion and manoeuvring along a cylindrical geometry whilst carrying a payload.

The team is competing in the Advanced Challenge Category, which permits programmable electronic devices, and requires a multi-movement sequence, including climbs, descents, position holds and a chain release. The device uses a single

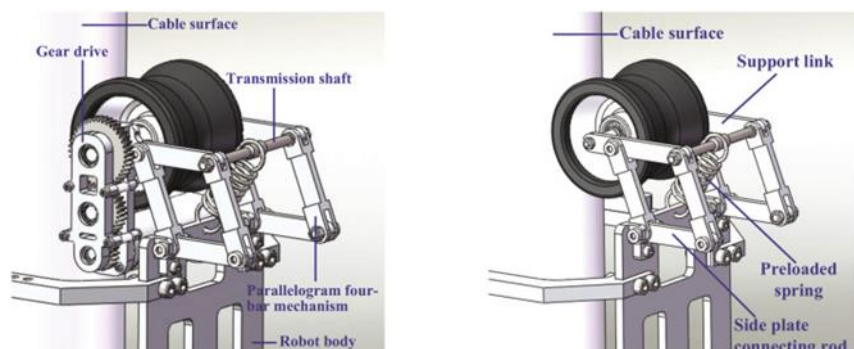


Figure 1, Parallelogram Tensioner, (Xu F. et al, 2021)

driven wheel powered by a NEMA 17 stepper motor through a 40:1 worm gear, opposed by two spring tensioned idle wheels on parallelogram four bar linkages. An Arduino microcontroller runs through the sequence using step counting, cross checked at checkpoints with data from an ultrasonic distance sensor, and a touch sensor at the top of the device for barrier detection.

The project saw significant setbacks due to the withdrawal of a team member, originally responsible for the mechanical design, leading to a complete redesign in a compressed timeline. This report documents the design process. Section 2 represents the work of the Team Lead, Section 3 represents work done by all team members, Section 4 and 5 represent the work of the Mechanical/Electrical Lead, and Section 6 represents the work of the Integration and Testing Lead.

The robot specifications proposed by this research utilize compression on the wheels, produced through a spring pulling on the wheel frame, to pull them tightly against the pipe. This allows the robot to climb up different pipe circumferences, as the spring will always pull on the frame

2 Project Management & Planning

2.1 Team Roles and Responsibilities

Table 1, Roles and Responsibilities

Role	Responsibility
Mechanical Design (Previously) "Callum"	• CAD Modelling of Climber Structure & Mechanisms • Model Slicing for 3D Printing
Project Lead "Ali"	• Meeting minutes • Documentation of climber design progress for reports & presentations • Scheduling • Handling Procurement
Mechanical/Electronics Design "Jon"	• Microcontroller Programming • Sensor Selection & Programming • Integration of power source • CAD Modelling of Climber Structure & Mechanism • Model Slicing for 3D Printing
Testing & Integration "Thab"	• Troubleshooting Climber • Prototyping • Ensuring climber is within specifications • Creating scenarios to test climber on key features (climbing ability, chain carrying, automated sequence & failsafe)

The project team is structured into various roles to facilitate the effective development of the climber system (Table 1). Every member has designated responsibilities within the project, enabling tasks to be accomplished efficiently while ensuring clear communication and collaboration during the development process.

Callum is in charge of the Mechanical Design position, which is concerned with climber's physical growth. To make sure the design satisfies practical requirements, this involves building intricate CAD models of the climber structure and its mechanisms. This position also entails slicing the models to prepare them for 3D printing, which enables the production of prototypes and parts for testing and assembly.

Recording meeting minutes, keeping track of the climber's design development for reports and presentations, and overseeing the project schedule to guarantee chores are finished on time are important duties lead by the project lead Ali. Managing procurement, which entails location and arranging the supplies and parts required for project is another aspect of this position.

The development of the climber's electrical and control system is the main emphasis of John's electronic design position. This involves programming the microcontrollers, choosing and configuring the right sensors, and incorporating the power source needed to run the system dependably.

Lastly, Thab handles the testing and integration, which guarantees that the system operates properly after the mechanical and electronic components are integrated. In order to assess important aspects including climbing ability, chain carrying, automated sequences, and failsafe mechanisms, this function entails identifying problems, producing prototypes, confirming that the climber satisfies necessary specification, and developing test scenarios.

To precisely outline each team member's role and participation in important project tasks, a RACI matrix (Table 2) was created. This ensures effective communication, accountability, and coordination throughout the climbing system's growth.

Task	Callum (Mechanical)	Ali (project lead)	Jon (Electronics)	Thab (Testing)
CAD modelling of climber	R	A	C	I
3D printing & prototyping	R	A	C	C
Microcontroller programming	I	A	R	C
Sensor selection & scheduling	I	A	R	C
Power system integration	C	A	R	C
Documentations & reports	C	R/A	I	I
Meeting minutes & scheduling	I	R/A	I	I
Procurement of components	C	R/A	C	I
System testing & troubleshooting	C	A	C	R
Performance validation	C	A	C	R

Table 2, RACI Matrix

R= Responsible A= Accountable C= Consulted I= Informed

2.2 Project Timeline

The project timeline outlines the climber system's development schedule, from basic design to final testing and validation. Establishing a defined timeline allows the team to better manage tasks, assign resources, and guarantee that project milestones are met on time.

The project has been compressed into multiple stages by the timeline, including design, development, prototyping, integration and testing. Before moving on to next step, certain tasks must be finished in each phase. The team can keep track on progress identify possible setbacks and keep team members updated.

By establishing due dates for important deliverables like CAD design completion, electronics integration, prototype assembly, and performance testing, the project timeline also facilitates efficient project management. The team can guarantee that the climber system is created methodically while fulfilling the project objectives and performance requirements by adhering to this timeline.

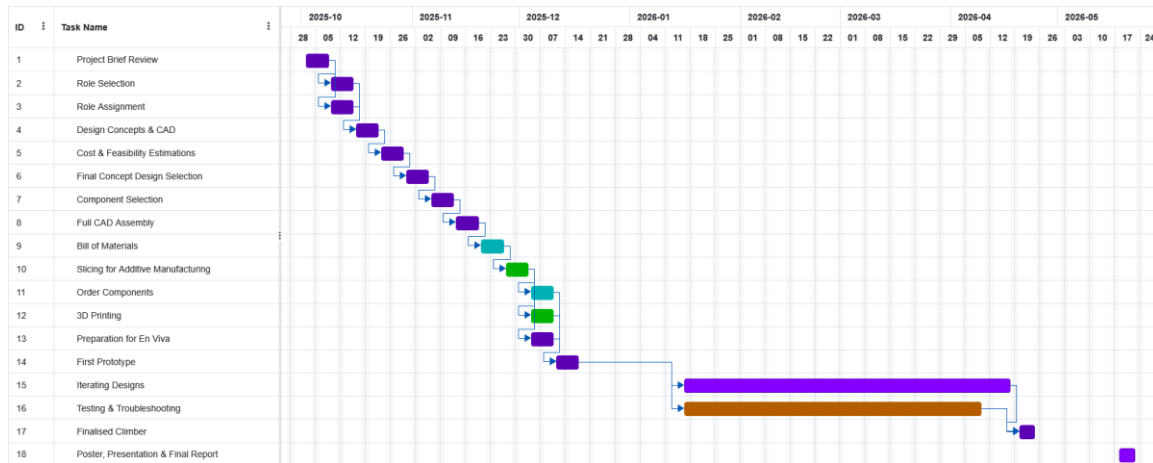


Figure 2, Gantt Chart

Purple: All group members involved

Green: Involve Electronic design

Orange: Involves Testing and integration

Key Milestones

- **M1:** Project planning completed
- **M2:** Mechanical design finalized
- **M3:** Electronics system integrated
- **M4:** Porotype assembled
- **M5:** Testing completed
- **M6:** Final system validation

2.3 Meeting Minutes & Documentation

To guarantee seamless cooperation throughout the climbing system's development, effective communication and documentation management were crucial. To assess project progress, talk about obstacles and plan future work, regular meetings were planned.

To assess the progress of the design, electronic development, and testing activities, the team met once a week to discuss updates and met in person after each deadline that been set for tasks to resolve possible problems, and make sure that every work was moving forward in accordance with the project.

To keep an accurate record of crucial technical and project management choices, decision tracking was put into place. Important choices made during meetings, such as design modifications, were recorded in the meeting minutes. Transparency was ensured by documenting these choices, which also made it possible for the group to review earlier conversation as needed. Additionally, by keeping team members accountable, this procedure made sure the projects goals stayed in line with the overall design specification.

CAD models and project documentation were managed using version control. To assure that the team always had access to the most recent information, each version of significant files was saved with an update version number and date. This method allowed the team to monitor the climber system's development history over the course of the project while reducing the possible of misunderstanding or date loss.

2.4 Procurement & Budget

The bill of materials and project budget were created to list all the parts needed for the climber system's design, production, and testing while making sure the project stayed under the allotted budget. To strike a balance between cost effectiveness and performance criteria, careful budget planning was required.

Three primary categories comprise the project's cost breakdown: prototype materials, mechanical components, and electronic components. Mounting brackets, fastening hardware needed for installation, and structural materials utilized to construct the climber frame are examples of mechanical components. These parts give the system the strength and stability it needs to function. The microcontroller, sensors, motors, and power supply components needed to regulate and automate the climber's operations are among the electronic components that account for a sizable amount of the budget to aid in the project's development and testing stages, prototyping supplies like 3D printing filament and extra tiny hardware were also added.

To guarantee that the necessary functionality could be attained without going over the project budget, component selection was carefully thought out. Essential parts that directly affect the system's performance, dependability, and safety were given priority.

A number of criteria, including pricing competitiveness, product dependability, component availability, and delivery time, were taken into consideration when choosing suppliers to guarantee that the parts matched quality requirements and were reasonably priced, reliable engineering and electronics sellers were selected. By using this strategy, the project team was able to satisfy the climber system's functional and technical objectives while maintaining a cost-effective solution.

3 Concept Development

3.1 Review of similar applications in industry

The concept of a device capable of climbing externally up a vertical pipe is well established, with multiple design principles present within engineering literature, and practices within industry.

In industrial inspection robotics, Li et al. (2020) provide an analytical review of inspection robots designs for overhead power transmission line applications. Three dominant strategies are identified, friction wheel, mechanical adhesion, and inchworm mechanisms. "Alhassan et al. (2020) provide an analytical review of inspection robot designs for overhead power transmission line applications, identifying friction wheel, mechanical adhesion, and inchworm mechanisms as the three dominant strategies."

The SKY Wire rope climbing robot (Inspection GC, 2024) uses motorised friction wheels with spring loaded clamping to maintain traction within a range of cable diameters. The SkyWrap system (AFL Global, 2024), on the other hand, travels upwards and in a spiral around cables. Both systems exceed the payload and scale requirements of the competition, allowing the team to make an informed decision towards this design strategy.

In academic literature, "Tavakoli et al. (2010) describe a three-wheel pipe inspection robot featuring spring-loaded arms maintaining normal forces, with contact points forming a triangular distribution that resists rotation across the pipe axis.". Viewed from above, the three contact points form a triangle across the pipes cross section. Their analysis shows this triangular distribution provides resistance to rotation across the axis aligned with the arrangement. Although the geometry of the chosen design differs, featuring a triangle along the vertical axis, the underlying principle is consistent. "Nayak and Pradhan (2014) compare clamping, belt and spring-tension mechanisms for small diameter pipe climbers, concluding that spring-tension passive wheel approaches offer simplicity and reliability whilst allowing adaptability to varying pipe diameters."

3.2 Concept Generation

Three mechanical concepts were generated and evaluated with five criteria in mind: grip reliability on a 22mm copper pipe, compliance with envelope of 400mm x 300mm, component cost within budget of £90, complexity of manufacture, and suitability for single-motor autonomous control.

Concept A is a dual drive symmetrically clamped design, with a motorised wheel on each side of the pipe, held in contact with a spring-loaded scissor mechanism. This offers high traction and balanced forces at the expense of two motors, two motor drivers, speed synchronisation and complex designs

to attach a worm gear to a movable wheel. The estimated costs of two stepper motors and drivers exceed budget allocation for the drive system alone.

Concept B is a three-wheel equilateral arrangement with three motorised wheels at 120-degree intervals around the pipe. Requiring three motors, it already exceeds the budget constraints. Beyond the budget issue, it also requires complex synchronisation of torque across three driven wheels to maintain stable locomotion, and packaging three drive assemblies within the 400mm x 300mm envelope poses challenges.

Concept C, the selected design, uses a driven wheel on one side of the pipe and two spring-loaded passive idler wheels stacked above and below on the other side. Viewed from the side, the three contact points form a triangle, this reduces the drive system to one motor and driver, allows for simpler design for the driven wheel, as it is static, and the vertical separation between the two idlers provides resistance to rotation across the pipe axis.

Table 3, Concept Evaluation Matrix

Criterion	Weight	A Score	A Weighted	B Score	B Weighted	C Score	C Weighted
Grip Reliability on 22mm copper pipe	3	4	12	5	15	3	9
Compliance with 400x300mm envelope	3	3	9	2	6	5	15
Component cost within £90 budget	2	2	4	1	2	5	10
Complexity of manufacture	2	2	4	1	2	5	10
Suitability for autonomous control	5	2	10	1	5	5	10
Weighted Total:			39		30		54

Table 3 above represents the weighted evaluation of the three concepts against five criteria. Each criterion is scored from 1 to 5, and then multiplied by the weight factor, relating to its relative importance.

3.3 Drive Mechanism

With concept C, the drive mechanism for the single driven wheel requires separate evaluation. The designs considered were direct drive, spur gear reduction, and worm gear reductions.

Direct drive was eliminated first, the NEMA 17 motor's holding torque of 32 N·cm gives a direct drive force at the contact point of 1.53 Newtons, far below the 18N requirement. "Output torque at the drive wheel is calculated using a worm gear efficiency of 35%, consistent with published values for 40:1 single-start worm gears (Norton, 2020)."

Spur gear reduction can provide the required force; however, the device must hold its position when unpowered, the gear ratio required to prevent back driving would present issues in terms of fitting within the envelope.

The selected worm gear, a single start 40:1 worm, has a lead angle of less than 6 degrees, preventing back-drive under normal loading (Norton, 2020)." Therefore, the device is able to hold position with zero motor current, fulfilling the scoring targets for the competition: 5 points for pre-start hold, 5 points for start target hold, 10 points for intermediate target hold, and 20 points for requiring no additional hardware or software. Further, a 40:1 worm gear unit is available off the shelf for a relatively low price and is easy to implement into the device design.

It is important to note the effect a concave wheel profile has on the rolling diameter. The diameter at the point of contact with the pipe is smaller than the outer diameter, still in contact with the pipe. With an outer diameter of 105mm and a concave profile cut to the pipe geometry, sitting just past the centreline of the pipe, approximately 12.1mm from the outer diameter. The contact point sits between outer diameter and the point of contact, giving the wheel an effective rolling diameter of 80.8mm. It is this figure that dictates climb speed and drive force. The idler wheels remain at 60mm in outer diameter for weight reduction and lowering part size. The full implications are discussed in Section 4.6.

3.4 Wheel Design

The device uses two different wheel sizes. The single drive wheel has an outer diameter of 105mm, whilst the two idler wheels are 60mm in outer diameter. The drive wheel diameter dictates the linear travel per revolution of the wheel, and the drive force applied to the pipe. As such, it directly impacts the estimated task completion time and the total weight carriable by the device. The idler wheels are passive, rolling freely under the spring pre-load, hence their diameter has no impact on performance.

The effective rolling diameter of the drive wheel is 80.8mm, based on a concave depth of 12.1mm from the 105mm outer rim. This figure is used for all speed and force calculations in Section 4.6. The idler wheels also have a concave profile matching the pipe, to ensure ideal grip force distribution.

The concave profile of the wheels provides a self-centring quality, resisting axial rotation, further, as the wheel matches the geometry of the pipe, the potential contact area touching the pipe is maximised, ensuring optimal grip and lower chances of marking the pipe during operation.

All three wheels are manufactured as composite components. The structural body of each wheel is printed in PLA, providing stiffness and allowing for accurate complex geometries. The concave contact zone plus a small surrounding margin is printed in TPU. TPU was selected for the contact surface due to its higher coefficient of friction compared to PLA and its ability to deform slightly under load. The slight deformation allows the TPU to conform to the pipe surface, improving contact area with the pipe surface. The PLA body transitions to the TPU insert near the contact zone, such

that the structural integrity of the wheel is carried by the PLA, whilst allowing interface with the pipe surface through the TPU inserts.

"For the friction calculations, a coefficient of friction of 0.5 is assumed for TPU on copper pipes, a conservative selection from published values for TPU on metal surfaces which typically range from 0.5 to 0.8 depending on surface finish and contact pressure (Bhushan, 2013)."

4 Mechanical Design

4.1 Design Requirements

"The mechanical design was governed by the competition constraints set out in the project specification (IMechE, 2026a)".

The mandatory constraints are:

- Max envelope of 400mm x 300mm diameter and length (excluding chain clip)
- Flat and even top surface, with absolutely no protrusions
- No contamination or surface damage to the pipe
- Single 50mm automatic clip as chain attachment

Performance requirements derived from estimates for scoring and task completion are:

- Grip force sufficient to climb against 18N of downwards force (From estimated 1.5kg device weight and 337 grams max chain weight)
- Drive torque sufficient to accelerate from rest and maintain speed under max load
- Traverse speed sufficient to complete the task within 3-minute timeframe
- Stable locomotion on pipe with little axial rotation, especially under max load

4.2 Structural Design

The main device chassis serves as the primary rigid connection body for device elements. One side houses the motor, the driven wheel, and the worm gear, the battery pack, microcontroller, sensors and other small components such as LEDs and Buzzers. The driven wheel is positioned at mid-height between the two idlers in a fixed position, featuring no active tensioning.

The opposite body provides attachment points for the parallelograms holding the idle wheels, and attachment holes for the tension springs. The tension springs on the idler wheels are responsible for the entire contact force the device exerts upon the pipe.

The bottom portion also houses the chain release system, and consequently the chain is carried on this side of the device. Both halves of the body are connected via protrusions on the sides of the bodies, which are fastened with pins.

4.3 CAD Modelling

The device was modelled entirely in SolidWorks, as a single assembly file (Figure 3), comprised of individual part files for each component. "All parts are individually numbered in accordance with the BoM part numbering scheme, as required by the general specification (IMechE, 2026b)." The CAD

model is the primary reference for all manufacturing dimensions and was used to verify envelope compliance and generate 3D slices for 3D printing software.

Most parts were designed for manufacture using facilities available to the team. 3D printing in PLA for structural components and 3D printing in TPU for wheel inserts. Others were purchased as off the shelf components such as shafts, motors, gear worms, sensors, microcontrollers, springs and bearings. No manufacturing was outsourced, in compliance with Section 4.5 (IMechE, 2025a) of the General Specification.

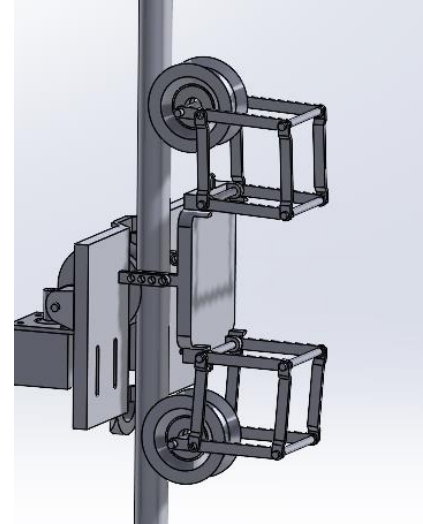


Figure 3, Prototype CAD Assembly

4.4 Idler Wheel Mounting

Each idler wheel is mounted on a parallelogram four bar linkage (Figure 4) with an effective area of 60MM X 60MM. The inner bar is fixed rigidly to the chassis. The outer bar carries the idler wheel axle. Stainless steel tension springs connect diagonally across the parallelogram interior, pulling the outer bar, and the wheel, toward the pipe surface.

The parallelogram geometry was chosen over a hinged arm design due to the change in angle of the wheel axis as the hinged arm deflects, causing an unwanted lateral force component. The parallelogram keeps the outer bar parallel to the inner bar at any point in the deflection state, maintaining optical contact with the pipe.

The top bar is 75mm rather than 60mm, the parallelogram itself closes at the 60mm mark, whilst the idler wheel axle attaches at the 75mm mark. The wheel therefore sits 15mm beyond the outer bar of the parallelogram, increasing spring pre-extension and therefore increasing the force applied to the pipe.

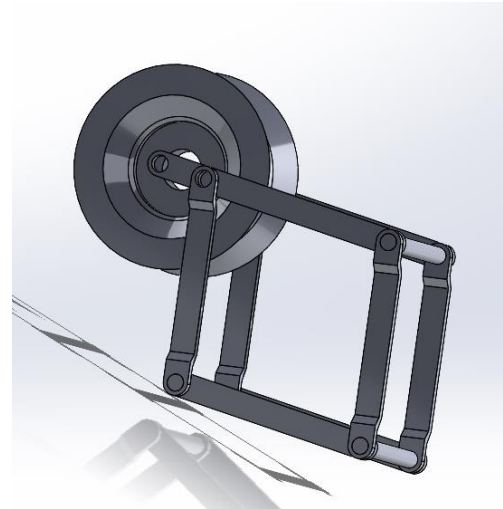


Figure 4, Parallelogram Tensioner

The springs are attached diagonally across the bars for two main reasons. The diagonal orientation resists shearing of the parallelogram frame, reducing its tendency to collapse into a rhombus under lateral load, and increases pre-extension due to the longer distance covered by the springs.

4.5 Spring Analysis & Force Calculations

The idler tension springs are 304 stainless, with an outer diameter of 4mm, a wire diameter of 0.6mm, and a free length of 50mm. "Spring stiffness was calculated using the standard helical spring formula (Norton, 2020):"

$$k = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n}$$

G = 69,000 N/mm² (shear modulus of 304 stainless steel)

d = 0.6mm (wire diameter)

D = 3.4mm (mean coil diameter)

N = 60 (number of coils)

Hence:

$$k = 0.474 \text{ N/mm}$$

The spring is installed across the diagonal of the 60mm x 60mm parallelogram:

$$x_{diagonal} = \sqrt{l^2 + l^2}$$

$$x_{diagonal} = 84.9 \text{ mm}$$

Pre-extension can be calculated by deducting the initial length from the stretched length, hence:

$$x_{pe} = x_{diagonal} - x_{initial}$$

$$x_{pe} = 34.9 \text{ mm}$$

The total force per spring can be calculated with the following equation:

$$F_{idler} = k \cdot x_{pe}$$

$$F_{idler} = 16.5 \text{ N}$$

To facilitate adhesion to the pipe, two springs per idler are considered.

The driven wheel is fixed rigidly to the body, hence its contact force against the pipe is a reactionary force to the idler spring loads. As such the force of the driven wheel is double the idlers:

$$F_{driven} = 66 \text{ N}$$

Total climbing load including device mass and maximal chain load:

$$W_{total} = (1.5 + (2.5 \cdot 0.145)) \cdot 9.81 = 18 \text{ N}$$

Friction force at the driven wheel must meet or exceed W_{total} , using a coefficient of friction of 0.5 for TPU on copper:

$$F_{friction} = \mu \cdot F_{driven} \cdot W_{total}$$

$$F_{friction} = 33N$$

Resulting in a safety factor of:

$$SF = \frac{33}{18}$$

$$SF = 1.83$$

A safety factor of 1.83 provides an adequate margin for variation in pipe surface finish and geometry. Adding a third spring per idler wheel raises the safety factor to 2.75 for minimal cost.

4.6 Torque & Drive Force Analysis

All speed and force calculations rely on the effective rolling diameter of 80.8mm. The profile of the wheels extends beyond the centerline of the pipe by 1.1mm, resulting in a concave depth of 12.1mm. Output torque at the drive wheel is calculated using a worm gear efficiency of 35%, consistent with published values for 40:1 single-start worm gears (Norton, 2020).

$$T_{motor} = 0.32N \cdot m$$

$$r_{gear} = 40:1$$

$$\eta = 0.35$$

$$T_{output} = T_{motor} \cdot Ratio \cdot \eta$$

$$T_{output} = 4.48N \cdot m$$

Drive force can be calculated by dividing output torque by the effective rolling radius:

$$F_{drive} = \frac{T_{output}}{r_{eff}}$$

$$F_{drive} = 110.9N$$

Giving a safety factor of:

$$SF = \frac{110.9}{18} = 6.16$$

The drive force safety factor of 6.16 confirms torque is not a limiting factor in operating performance.

Climb speed is estimated from the motor's operating speed. The NEMA 17 17HS4401 motor desynchronises at approximately 200 RPM when driven at 9V and under load. As stepper motors spin faster, a voltage is induced in the motor windings by their own rotation that oppose the current the driver is trying to drive through them. This is commonly referred to as back-EMF, and as back-EMF approaches and reaches the supply voltage the motor loses the ability to maintain torque and

inevitably loses synchronisation. A higher supply voltage increases the possible rotation speed the motor can reach before desynchronisation, at 12V this motor can reach 300-400 RPM, with a 40:1 gear reduction, it equates 7.5 to 10 RPM.

To calculate mission time, the total travel distance and planned hold durations must be established and summed. According to the competition specification, the advanced challenge mission (IMechE, 2025b, Section 6) comprises three travel legs:

- Leg 1: Climb from Start/End Target to Top of Barrier (1800mm)
- Leg 2: Descent from top barrier to Start/End target (1800mm)
- Leg 3: Climb from Start/End Target to Intermediate Target (900mm)

$$s_{total} = 4500mm$$

Further, three hold positions are required. Section 6.12 (IMechE 2025b) states that the net timed score excludes time spent at the top barrier and the Start/End Target. However, hold times impact bonus point accrual:

- 12 second hold at top barrier (10 bonus points between 10-15 seconds hold)
- 4 second hold at Start/End Target (5 bonus points between 3-5 seconds hold)

$$t_{target} = 12s + 4s = 16s$$

$$t_{max} = 15s + 5s + 5s = 25s$$

The task time constraint is verified against both the targeted and worst case hold duration to confirm the device performs within the time constraints. After the 40:1 gear reduction and using the effective rolling circumference of the wheel:

$$C = \pi \cdot d_{effective}$$

$$C = 253.84mm$$

At 9V, the motor is limited to around 200 RPM:

$$v = \frac{\frac{200}{40} \cdot 253.84}{60} = 21.2 \frac{mm}{s}$$

$$t_{target\ holds} = \frac{4500}{21.2} + 16 = 229s$$

$$t_{worst\ case\ holds} = \frac{4500}{21.2} + 25 = 237s$$

In both scenarios, the time constraint of 180s is not met, showing the inadequacy of running the motor at only 200 RPM.

Conversely, for a 12V motor running at 300 RPM:

$$v = \frac{\frac{300}{40} \cdot 253.84}{60} = \frac{31.7mm}{s}$$

$$t_{target\ holds} = \frac{4500}{31.7} + 16 = 158s$$

$$t_{worst\ case\ holds} = \frac{4500}{31.7} + 25 = 167s$$

At 300 RPM, the device has a 13 second margin in the worst-case scenario, as at 12V the motor can run at 300-400RPM without desynchronisation a higher RPM could be used to further increase the margin and score more points for a faster finish.

The system is powered by a single 6x AA battery pack as the sole energy source, as mandated by the General Specifications (IMechE Section 4.22, Section 4.22). A boost converter module steps the supply voltage from 9V to 12V for the motor driver's VMOT rail only. The Arduino and all sensors run off the source 9V supplied by the battery pack. A 100μF electrolytic capacitor running across the VMOT and GND pins of the stepper driver absorb back-EMF drives generated during deceleration and direction reversal in the motor, protecting the stepper driver. The stepper driver selection is discussed in Section 5.4.

4.7 Manufacturing and Building

The device structure is mostly comprised of components printed in PLA using FDM 3D printing. PLA was chosen due to its higher stiffness compared to other popular choices such as ABS, and ease of availability through faculty resources. Some parts were printed in TPU for better grip against the pipe, and a small selection of off the shelf components were selected to aid in fastening the device together.

The main body is split into two large parts. Due to inherent limitations within 3D printing regarding vertical extrusions, these parts were split into slices of a relatively similar thickness. Extrusions were fastened on to the main body using M3 screws, coupled with nuts or in some cases screwed directly into guide holes present in the body.

The driven wheel section includes guide holes for fastening the battery compartment, the microcontroller holder, the motor mount, and the bearings and axles running through the wheel. The driven wheel is attached to the axle through a Hex coupler, with set screws to maintain adequate

friction on the drive shaft. The driven wheel is comprised of two parts, which fasten together with M3 screws and possess an internal cavity matching with the hex coupler.

The idle wheel section includes holes for the attachment of the parallelograms holding the idle wheels, as well as the insertion holes for the springs attaching to the body and the parallelogram. The idle wheels attach to a bearing, through an adapter collar, which in turn attaches to the shaft connecting to the parallelogram. Further, towards the bottom a small housing for the chain is implemented and activated through a linear actuator.

During assembly of initial prototype prints, issues were encountered with part tolerances being too low in 3D printed parts, resulting in fixtures that were unable to be connected. Parts were re-designed to increase the size of internal cavities to allow for the plumb error.

Some misalignment issues have been encountered with shafts purchased online, dents on the metal bars prevent fixtures from sitting in their intended positions. In future iterations, purchasing bar stock and cutting to size should prevent misalignment issues.

5 Electronics Design

5.1 System Architecture

The electronics system centres around an Arduino Microcontroller. The Arduino executes the task program, reads sensor data and commands output devices, namely the motor driver, LEDs and a buzzer. A boost converter module steps the voltage up from 9V to 12V for the motor driver, enabling the motor to operate at 300-400 RPM. The Arduino runs directly off the 9V supplied by the battery pack, and sensors run either off the 9V line, or through the Arduino's 5V lines. The system is fully autonomous from start activation to the completion of the task, with no communication or code editing between runs.

5.2 Microcontroller Selection

The Arduino Nano R4 was selected as the microcontroller for this project. The Nano R4 is a 32-bit microcontroller with a Cortex-M4 processor running at 48 Mhz. The specifications provide ample headroom for running the sequence successfully. Although the board is one of the cheaper options available, it retains great functionality, with ample ports for input and output devices. Further, the small form factor reduces its footprint and weight. The board operates at 5V logic, fully compatible with the selected stepper driver and ultrasonic distance sensor without the need of extra components.

The Arduino platform was chosen due to the ease of use with external sensors and components, and the relatively simple sequence required, a stronger processor would gain no benefit over this selection whilst increasing costs and footprint.

5.3 Sensor Selection

Two sensors provide position information, operating as a pair. The primary position estimates are derived from stepper motor step counting. The NEMA 17 17HS4401 has a step angle of 1.8 degrees, meaning 200 steps to complete one full motor shaft revolution. After the 40:1 worm gear reduction, $200 \times 40 = 8,000$ steps to complete one revolution of the drive wheel. Each step therefore corresponds to a linear travel of:

$$d_{step} = \frac{C}{8000} = \frac{253.84}{8000} = 0.0317mm$$

This gives a theoretical resolution of 0.032mm per step, considering checkpoint target accuracy is within a 10mm section of the pipe, step counting provides accuracy well above what is required, further, the step count provides position estimates without the need of additional hardware. It is important to note the inherent weaknesses of step counters, there is no accounting for wheel slip, which could lead to errors in the position estimates. This is the failure mode the ultrasonic sensor is used to detect and prevent.

The HC-SR04 ultrasonic distance sensor provides an independent position measurement, immune to wheel slip. It emits a 40 kHz ultrasonic burst and measures the time taken for the echo to reach the sensor. Measurement ranges between 20mm-4000mm, covering all target positions for the competition. Limitations include susceptibility to mismeasurements due to a misaligned sensor and errors due to acoustic interference.

The touch sensor on the top surface detects physical contact with the top barrier and is a requirement as per the specifications. The touch sensor allows the Arduino to zero the step counter and detects signs of slippage in the run, as the top surface is a known height.

5.4 Circuit Design

The circuit connects the following components to the Arduino: TMC2209 Stepper Driver, HC-SR04 Ultrasonic Sensor, Touch Sensor, Green LED, Red LED, Buzzer, Chain Release Actuator.

The power system uses a single 6x AAA battery pack as the sole energy source. A single fuse is installed in series with the positive terminal of the battery pack, before any other components as per Section 4.25 (IMechE, 2025a). From the fused supply, the circuit splits into a 9V rail for the Arduino, and a boosted 12V rail for the stepper motor driver, produced by a XL6009 boost converter module. A 100 μ F electrolytic capacitor installed between the VMOT and GND pins of the stepper motor driver absorb back-EMF spikes, commonly generated during deceleration and direction reversal of the motor, protecting the driver.

The TMC2209 was selected over other commercial options such as the DVR8825 not only due to its ability to sustain operation at "300–400 RPM at 12V, and its StealthChop PWM current control technology which produces smoother motor motion compared to standard PWM control (Analog Devices, 2022)." Reducing vibration which could otherwise impact the accuracy of the readings from the ultrasonic sensor.

All exposed electrical joints are either insulated with heat shrink tubing or enclosed within the shell of the device to prevent finger contact (IMechE, 2025a, Section 4.26). Moving parts relating to the drive train are also enclosed within the shell to satisfy Section 4.27 (IMechE, 2025a). All cables are routed and fastened to prevent contact with moving parts (IMechE, 2025a, Section 4.28)

5.5 Programming & Control Logic

The Arduino microcontroller allows for programming to be stored on the device, ready to activate through a power button. Position tracking compares displacement readings from step-counting with measurements from the ultrasonic range sensor. If the ultrasonic reading is within a calibrated tolerance of the step count the step count readings are used for the final decision regarding the checkpoint. If the readings diverge, but the ultrasonic value is within the plausible range for the current phase of the sequence, the step counter readings are discounted, it is assumed the wheel has slipped, and the ultrasonic sensor is used for range finding for the final checkpoint approach.

If the ultrasonic sensor falls outside of the plausible range for the current phase of the sequence, its readings are disregarded, as it indicates there is either too much interference or the sensor has been jolted out of position during the run.

Part of the features available with the Arduino platform is the ability to split the task sequence into segments, each managed by a finite state machine (FSM). The system is only capable of applying one FSM state at a time, ensuring the sequence is followed properly. The seven FSM states are:

- IDLE. The device remains stationary at the start position, green LED lit, awaiting input from the start switch to progress.
- CLIMB_TO_TOP. Motor drives upwards, stopping once the touch sensor fires on contact with the barrier and progresses.
- HOLD_TOP. Motor de-energised, red LED and buzzer on for a 10 second timer then progresses.
- DESCENT_TO_START. Motor drives downward, step counter and ultrasonic sensor working in tandem, progressing once over START/END checkpoint 400mm from base.
- HOLD_START. Motor de-energised, red LED and buzzer on for a 4 second timer, then progresses.
- CLIMB_TO_MID. Motor drives upward, timer set for one second, after which chain releases. Progresses once at middle checkpoint 1300mm from base.
- HOLD_MID. Motor de-energised, red LED and buzzer on, hold until end.

5.6 Power System Integration

Six AA alkaline batteries in series provide a 9V supply with an approximate total capacity of 15,000mAh. The power system diverges into a 9V and 12V power rail, the former powering the Arduino and its components, and the latter, after being stepped up through a boost converter module, powers the stepper motor driver. The single main fuse is installed immediately after the positive terminal of the battery, ensuring protection for both power rails.

6 Testing & Integration

6.1 Compliance with Specifications

Non-conformances at the design stage were identified by comparing the design to all required competition regulations before physical testing. The review checklist in Appendix 5 of the General Specification was used as the benchmark for compliance assessment. Key elements and the design stage are as follows:

- Device envelope (400 mm x 300 mm): as verified in CAD. Parallelogram linkages are the largest components; at maximum spring extension, the idler wheels are contained inside a 400 mm diameter centred on the 22 mm pipe.
- No mention of wireless communication (section 4.16): compliant. The Arduino Nano R4 lacks wireless functionality. The HC-SR04 is an ultrasonic sensor, not a radio-frequency apparatus.
- Single battery pack (section 4.22): compliant. One holder containing six AA batteries.
- No lithium batteries (section 4.23): compliant. AA alkaline batteries utilised.
- Single main fuse (section 4.25): compliant by design.
- The upper surface is level and clean of any protrusions (section 4.3): confirmed in CAD.
- No pipe surface damage (section 4.5): the hollow geometry of the soft-material wheel effectively distributes the load.

6.2 Risk Assessment

A comprehensive risk assessment was conducted in accordance with General Specification section 4.20, approved by the academic supervisor, and provided in Appendix B. The following outlines key hazards and corresponding control measures:

- The rotating drive wheel and worm gear are inside the device chassis, so they can't be touched by fingers (section 4.27).
- Loading the springs during assembly: the springs are put in last, and the device is on a firm surface. Once the device is put together, the springs are completely inside the linkage frame.
- Device falling from pipe: During runs, all team members except the device controller stay outside the test area (section 4.61). Always wear the least amount of eye protection (Project Specification section 7.4).
- Electrical short circuit: there is just one main fuse in the positive supply line, and all connections are shielded.
- Handling batteries: AA alkaline cells that can't be changed by soldering or overcharging (section 4.24).

6.3 Prototyping Phases

Integration was planned to happen in four stages, with each stage checked before the next one starts. This way, problems might be found at the lowest level of assembly.

Stage 1:

The 3D printer: Print all the structural pieces, drill holes for the pivots, put together the parallelogram linkages with springs and then place them on a 22 mm test pipe to check the idler wheel contact and deflection range. Check that the gadget fits inside a 400 mm × 300 mm envelope with the wheels touching the pipe.

Stage 2:

Drive train: Attach the motor and worm gear to the body, then attach the drive wheel to the output shaft. Check that everything is lined up and rotates smoothly by hand. Check if the worm gear is self-locking by trying to turn the output shaft by hand.

Stage 3:

Putting together the electronics: Connect all wires to the Arduino, put in the fuse, and test each sub-circuit one at a time before connecting it to the main power. Use the serial monitor to check the step pulses from the Arduino. Before connecting the whole system, test the HC-SR04 and touch sensor separately.

Stage 4:

Full system integration: Put all the electronics in the body, run and secure the wires, and do the first powered run on the test pipe.

6.4 Performance Testing

A five-test program was designed to check performance from the sub-system level all the way up to the whole objective. At the time of the report's submission, no physical tests had been done because the physical prototype build was still going on. Before the tournament day, the program will be carried out.

Test 1:

Static grip: The device is on the pipe, and the motor is off. Check that the idler contact and worm gear can hold their own weight. Do it again with the whole 2.5 m chain. To pass, there must be no slip for 60 seconds with a full chain load.

Test 2:

Climb speed: Full 1,800 mm up and down, both with and without a load. Measure the real speed and compare it to the analytical estimate of 31.7–42.3 mm/s at 12V. Make sure the task is done in less than 180 seconds. Before the competition, the boost converter voltage or motor step frequency must be changed if the speed is less than 26.9 mm/s (ideal holds) or 29.0 mm/s (worst-case holds).

Test 3:

Checking the accuracy of the sensor's position and calibration: Set the steps-per-mm constant and the HC-SR04 tolerance window. Measure the stop position error at all three targets ten times each. All stops must be within +/-10 mm of the target to pass.

Test 4:

Chain release—trigger release at the calculated encoder location on ten runs. To pass, the release must be 100% successful.

Test 5:

Full task run: Three full Advanced Challenge sequences in a row. Keep track of the entire run time, the times you held the chain, the precision of the stops, and the conclusion of the chain release.

7 Discussion

7.1 Design Performance against Criteria

The analytical assessment indicates the device satisfies all theoretical performance requirements with a substantial safety factor of 1.83. This safety factor relates to the friction of the rubberized drive wheel, which used a conservative estimate of 0.5, common values range from 0.5 to 0.8. The pipe used in the competition is set up as purchased, including small imperfections and irregularities to the surface finish and geometry. The actual conditions of the pipe used within the competition is unknown, bench testing a static hold under a full chain load, or more, in a test rig mirroring test conditions would confirm whether the safety factor is sufficient, or if more springs are necessary on the parallelogram arms to increase the force applied to the pipe.

The drive force safety factor of 6.16 confirms the device is not limited by torque. Initial designs used a driven wheel identical to the idle wheels, with a diameter of 60mm, but the analysis in Section 4.6 identified issues with completing the tasks within the required timeframe using this design, prompting a redesign of the wheel and stepper motor setup. The drive wheel's outer diameter increased to 105mm, with a concave depth of 12.1mm giving an effective rolling diameter of 80.8mm. The motor supply voltage was increased from 9V to 12V to improve max RPM. Together, these give an estimated climb speed of at least 31.7mm/s, completing the sequence in 167 seconds at the most.

The boost converter adds minimal cost and complexity to the design, integrating easily into the stepper motor controller and the battery. Finally, the worm gear prevents the device from back driving whilst not under load, removing the need for mechanical breaks which in turn reduces device complexity, and awarding bonus points for holding position without using an additional control module.

7.2 Electronics & Control System Evaluation

The sensor redundancy aids in remedying glaring issues present within the step counter and the ultra-sonic sensor. Although the step counter is extremely accurate, it is susceptible to error from wheel slip and has no way to detect this. The ultrasonic sensor measures distance independently of wheel rotations, providing an unrelated measurement to compare it to, but it can struggle with acoustic interference introducing inaccuracies to measurements, which the stepper motor is impervious to, as it is not susceptible to acoustic interference. The touch sensor eliminates position uncertainty halfway through the sequence, allowing the sensors to be zeroed against a known height and potentially spot early signs of sensor data mismatch.

The TMC2209 stepper driver was selected due to its excellent performance in the 300-400 RPM operating range and its improved current control, decreasing jolts produced by the motors, which could reduce the accuracy of the ultrasonic sensor and increase the risk of wheel slippage.

The 100 μ F capacitor prevents back-EMF spikes harming the stepper driver. And the FSM architecture satisfies the no editing between runs requirements of section 4.17. All parts of the sequence as

stored on the device and critical variables such as hold times and distances to checkpoints are stored as variables within the code ahead of the runs.

7.3 Reflection on Project Management

The project planning approach was appropriate. Meetings took place in weekly intervals, and important decisions or information was noted down in meeting minutes. Gantt charts aided in time management and keeping on track. Two major weaknesses are identified in retrospect:

Firstly, the original team structure concentrated mechanical design on a single individual, with little involvement from other members. This created a single point of failure, and with the departure of said member from the group left the team at a standstill. Ideally, an approach with fallback team positions assigned would have prevented the stagnation that presented itself in this time, and a more transparent approach within the team to sharing findings and work done would help identify roles with too much workload assigned to them and improve the familiarity of the team with all aspects of the project.

Ideally, the team would have resumed developing the prototype that was then in design. However, the previous member was not forthcoming with CAD files for the parts designed during their occupancy of the Mechanical Lead role. In essence, the breakdown in communication between the team and the former member, and the avoidance of a difficult but necessary dialogue led to no prototype files being accessible after their departure, leaving the team with no choice but to start anew despite the challenging timeframe.

7.4 Impact of Team Member Withdrawal

The late withdrawal of the fourth team member significantly impacted development speed and key milestones. No prototype was built within the timeframe we established internally, which negated the possibility of real-life test data. However, the team quickly reformed the team structure and internal dialogue standards. The Mechanical Lead Role was consolidated with the Electrical Lead Role due to the synergies of both roles allowing for fast prototyping. Group files, including CAD designs, were amalgamated into a group folder to allow access to all members of the team, and both the Group Lead and the Integration & Testing Lead took up supporting sub-roles to alleviate the strain of a higher workload on the Mechanical/Electrical Lead.

The revised design is arguably more in touch with examples found in industrial applications relating to the competition. The parallelogram linkage, self-locking worm gear strategy, and sensor redundancy are deliberate and effective solutions to constraints within this competition.

The team acknowledges deficits being present in the report, namely the lack of test data or further refinement of a prototype. Although the calculations in theory show a good safety of margin, without rigorous testing the performance of the device is impossible to accurately depict. The planned test programme present within Section 6 aims to correlate real life data to estimates generated by the team, and identify any unforeseen weak points present in the design.

8 Conclusion

This report has presented the complete design of an external pipe climbing device for the Advanced Category of the iMechE Design Challenge 2026. The device uses a NEMA 17 stepper motor, coupled through a 40:1 worm gear reduction to drive a single 105mm concave wheel against a 22mm diameter vertical copper pipe, opposed by two spring-tensioned idler wheels on parallelogram four-bar linkages. The worm gear provides both the required torque for locomotion and self locking when the driven wheel is unpowered, enabling the device to hold position without additional hardware whilst unpowered. An Arduino microcontroller manages the sequence run using stepper step-counting, cross checked with ultrasonic distance sensor readings to estimate distance travelled, and a touch sensor to detect collision with the top barrier.

The design satisfies mandatory competition requirements as verified by the design compliance review. The device envelope, power source, fuse, lack of wireless communication, LED and buzzer integration are all inline with the specifications. The analytical assessment gives a lowest common denominator safety factor of 1.83, and a worst-case total sequence run time of 167 seconds, 13 seconds faster than the highest allowed time.

In short, the project successfully delivered a complete mechanical design with engineering analysis, a complete electrical system with justifications for component selection, a complete micro-controller and sensor selection with justifications, a bill of materials, plans for future testing of the device, and all in all a technically rigorous design on paper.

The project fell short on producing a physical prototype within a reasonable timeframe, and consequently failed to initiate tests on a physical prototype. These shortfalls are at least partly influenced by the departure of one of the team members from this project. The team's plan is to complete the physical build as soon as possible, to allow for the next stage of iterative design leading up to the competition.

9 Recommendations & Future Improvements

10 References

1. Al, A. (2026a) *RACI Matrix*.
2. Al, A. (2026a) *Roles and Responsibilities*.
3. AFL Global (2024) *SkyWrap Optic Fibre Cable Installation System*. Available at: <https://www.aflglobal.com> (Accessed: 22 March 2026).
4. Alhassan, A.B. *et al.* (2020b) ‘Power Transmission Line Inspection Robots: A review, trends and challenges for future research’, *International Journal of Electrical Power & Energy Systems*, 118, p. 105862. doi:10.1016/j.ijepes.2020.105862.
5. Da, J. (2026a) *Concept Evaluation Matrix*.
6. Da, J. (2026a) *Gantt Chart*.
7. Da, J. (2026a) *Prototype CAD Assembly*.
8. Da, J. (2026a) *Parallelogram Tensioner*.
9. *Datasheet*. Available at: https://www.analog.com/media/en/technical-documentation/data-sheets/TMC2209_datasheet_rev1.08.pdf (Accessed: 22 March 2026).
10. *Design Challenge 2026* (no date) *404 page not found*. Available at: <https://www.imeche.org/news/news-article/design-challenge-2026-rules-and-specification-released> (Accessed: 22 March 2026).
11. *Introduction to tribology, 2nd edition* (no date) *Wiley.com*. Available at: <https://www.wiley.com/en-gb/Introduction+to+Tribology%2C+2nd+Edition-p-9781119944539> (Accessed: 22 March 2026).
12. *Inspection visuelle et électromagnétique de câble d’acier* (no date) *Inspection visuelle et électromagnétique de câble d’acier | Inspection GC*. Available at: <https://www.inspectiongc.com/fr/inspection-visuelle-et-electromagnetique-de-cable-d-acier-1.html> (Accessed: 22 March 2026).
13. Nayak, A. and Pradhan, S.K. (2014) ‘Design of a new in-pipe inspection robot’, *Procedia Engineering*, 97, pp. 2081–2091. doi:10.1016/j.proeng.2014.12.451.
14. Norton, R.L. (2020) *Machine design: An integrated approach*. Hoboken, NJ: Pearson.
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11 Appendices

Project Kick-off Meeting Agenda

Meeting Name: Project Kick-off Meeting

Project Name: (IMechE project)

Date: 02/10/2025

Time: [12 pm]

Location: [IQ Building]

Attendees:

Ali

Thab

Jon

Callum

Agenda:

- Project Overview (15 mins): Provide an overview of the project, including its purpose and goals.
- Objectives and Scope (10 mins): Explain the project's objectives and scope by reading the project specifications and rules that been provided to ensure everyone understands the project guidelines.
- Roles and Responsibilities (10 mins): Discussing the roles and responsibilities of And how it can be divided between team members.

Aims for next meeting:

- Splitting roles depending on personal strengths.
- Decision about projects members roles and what they can provide regarding to their role.

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (09/10/2025)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Callum (Mechanical & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): Each team member provides a brief update on their roles depending on their strengths.

Project Lead: (Ali)

- Meeting minutes.
- Documentation of climber design progress for reports and presentations.
- Scheduling
- Handling procurement

Mechanical Design: (Callum)

- CAD modelling of climber structure & mechanisms
- Model Slicing for 3D printing

Electronics Design: (Jon)

- Microcontroller programming
- Sensor selection & programming

- Integration of power source

Testing & Integration: (Thab)

- Troubleshooting climber
- Prototyping
- Ensuring climber is within specifications
- Creating scenarios to test climber on key features (climbing ability, chain carrying, automated sequence & failsafes)

Team Achievements (5mins): Team roles discussion was taken and every member approved of their role towards the project and research provided.

Plans for the Upcoming Week (5 mins):

- Providing design sketches in the next 2 weeks
- Aims and objectives in the next 2 weeks
- Projects specs writing in the next 2 weeks
- Providing Research in the next 2 weeks

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (23/10/2025)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Callum (Mechanical & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): Each team member provides a brief update on

- Viewing sketches of climber designs
- Aims and objectives provided to define the purpose of the project and explains what project wants and breaks goals into achievable steps.
- Project specs were provided helps with setting clear requirements, guiding design and development and keeping project on track. All that done by referring to the IMech rules and regulations.

Team Achievements (5mins): sketches of designs as well as aims and specs were provided. Teams' decision was taking regarding to the design sketches and choosing design to develop.

Plans for the Upcoming Week (5 mins):

- Providing 3D drawing (3 weeks)
- Integration of power source (3 weeks)

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (13/11/2025)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Callum (Mechanical & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): integration of power source research been viewed and selecting power source we are using for the project.

Team Achievements (5mins): integration of power source, we are unsure of the miscommunication of Callum if he's up to date with the 3D drawing.

Plans for the Upcoming Week (5 mins):

- Providing 3D drawing (3 weeks)
- Sensor selection (3 weeks)

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (04/12/2025)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): Each team member provides a brief update on working tasks and what stage they on.

Electronics Design: (Jon)

- Sensor selection
- Integration of power source

Team Achievements (5mins): In this meeting Jon completed his tasks the sensor selection and integration of power source. As Callum didn't attend, we are planning on getting the 3D drawings completed by next week.

Plans for the Upcoming Week (5 mins):

- Providing 3D drawings 1 weeks
- Adding all information been gathered for approving with lecture 1 weeks
- Working on the presentation 1 week

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (11/12/2025)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): Each team member provides a brief update on viewing the information that been approved by the lecture and visualising the improvements we can make based on the lectures feedback.

Team Achievements (5mins): In this meeting Ali provided all the information notes after collecting and it's been approved with feedback for improvements. Presentation is completed to perform before Christmas half term. As Callum didn't attend this meeting as well, we are being forced to perform presentation without 3D drawing provided.

Plans for the Upcoming Week (5 mins):

- Providing 3D drawings 6 weeks
- Providing BOM 6 weeks

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (29/01/2026)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): Each team member provides a brief update on all tasks that have been completed up until first Viva.

Team Achievements (5mins): In this meeting all the tasks have been viewed and BOM has been provided by Jon. Discussing Callum's miscommunication and reporting to lecture as we will fall behind as we should be 3D printing parts by now.

Plans for the Upcoming Week (5 mins):

Waiting on Callum's update and advice from lecture on what we are doing until then.

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (05/02/2026)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): In the lectures meeting the update on Callum was that he is not in the teams anymore so we must do more team work to cover up all tasks that needed to be provided by him.

Team Achievements (5mins): in this meeting we will be working on Callum's delayed tasks to start working on to catch up

Plans for the Upcoming Week (5 mins):

- Producing 3D drawing to 3D print (1 week)
- collecting all work to organise the group again (1 week)
- ordering materials (1 week)

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (11/02/2026)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): This meeting was arranged to 3D printing parts.

Team Achievements (5mins): 3D printing not completed, materials delivery delayed.

Plans for the Upcoming Week (5 mins):

- completing 3D printing (2 weeks)
- collecting materials (2 weeks)

Weekly Team Meeting Agenda

Meeting Name: Weekly Team Meeting

Team Name: (IMechE project)

Date: (25/02/2026)

Time: [12pm]

Location: [IQ Building]

Attendees:

Ali (Project Lead)

Thab (Testing & integration)

Jon (Electronic & design)

Agenda:

Review of Previous Meeting Minutes (5 mins): Approve the minutes from last week's meeting.

Team roles Updates (20 mins): This meeting was arranged to 3D printing parts and collect materials.

Team Achievements (5mins): 3D printing completed, and all materials are collected.

Plans for the Upcoming Week (5 mins):

- prototype (2 weeks)
- testing climber (2 weeks)

BOM

Part name	Description	Qty	Unit cost (est.)
NEMA 17 17HS4401	Stepper motor, 32 N·cm, 1.8°, 5mm shaft	1	~£8
Worm gear unit	40:1 ratio, NEMA 17 compatible input	1	~£12
TMC2209 driver	Stepper driver module	1	~£5
Arduino Nano R4	Microcontroller, 48MHz, no wireless	1	~£18
XL6009 boost converter	9V→12V, up to 2A continuous	1	~£3
HC-SR04	Ultrasonic distance sensor	1	~£2
Touch sensor module	Top datum contact detection	1	~£1
Green LED	5mm, continuous run indicator	1	<£0.20
Red LED	5mm, hold state indicator	1	<£0.20
Buzzer	Active buzzer, 5V	1	~£1
AA battery holder	6× AA in series	1	~£2
AA alkaline batteries	6× AA	6	~£0.50 each
Fuse holder + fuse	Inline, rated [X]A	1	~£1
1000µF electrolytic capacitor	VMOT back-EMF protection	1	<£0.20
5mm automatic carabiner clip	Screwfix 334FE spec	1	~£2
PLA filament	Drive wheel body, parallelogram bars, main b	500g	£0.10/g
TPU filament	Drive wheel contact insert, idler contact inse	200g	£0.10/g
304 SS tension springs	OD 4mm, wire 0.6mm, L 50mm	4–6	~£1 each
Steel pivot pins	[M3/M4] for parallelogram joints	8	~£0.30 each
Steel axle bolts + nylon lock nuts	Idler and drive wheel axles	2	~£0.30 each
M3 screws + nuts	Motor mount, general assembly	10 to 20	~£0.10 each
Misc wire	Hook-up wire for circuit	2m	~£1
Resistors	Current limiting for LEDs	2	<£0.20
Transistor	Buzzer driver	1	<£0.20
Chain release actuator	Servo or solenoid — TBC	1	~£3–6

