Windmill Recycling Robot
Renewable Energy

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Contents

1 Introduction

1.1 Problem Identification

Renewable energy is vital for a sustainable future, yet maintaining infrastructure like wind turbines and solar panels presents challenges. As the global population grows and energy demands increase, there is a pressing need to transition away from fossil fuels and embrace cleaner alternatives. Renewable energy sources, such as wind, solar, and hydroelectric power, offer immense potential to meet our energy needs while reducing greenhouse gas emissions and mitigating climate change. However, the maintenance of renewable energy infrastructure, such as wind turbines and solar panels, as well as the waste they cause, often involves significant costs, logistical complexities, and safety risks for maintenance workers.

Robotic arms offer a promising solution, combining precision and autonomy to streamline maintenance tasks. By automating routine tasks and minimizing human intervention, robotic arms can streamline maintenance procedures, improve operational efficiency, and reduce costs. This report explores how integrating robotic arms into renewable energy maintenance can enhance efficiency and reduce costs, paving the way for a greener future. By designing, implementing, and testing a fully functional robotic arm, we can ensure significant advancements in the effectiveness and reliability of renewable energy maintenance and waste-management processes.

1.2 Literature Review

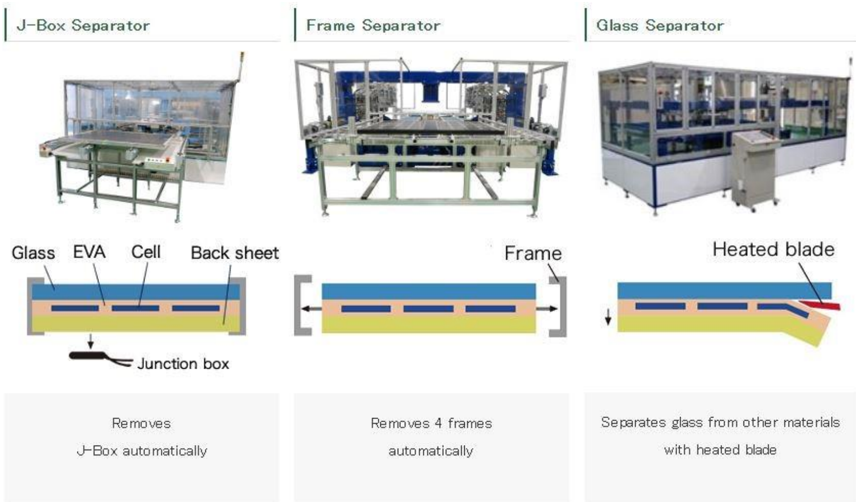
Most countries are using non-renewable energy as their mainstream energy source, but these sources have many drawbacks such as the gases and by-products produced due to the burning of fossil fuels have contributed to the degradation of the environment. Environmental concerns from these energy sources include air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances (Dincer, 2000). Therefore, it became essential to switch to another type of energy source, renewable energy sources, which are more environmentally friendly and are considered as an infinite energy source, unlike non-renewable energy sources. Even though renewable energy sources affect the environment less than their alternatives, they still produce waste byproducts which are disposed of in an inappropriate way causing damage to the ecosystem.

1.2.1 Solar Energy

The radiation and heat emitted from the sun are utilized through solar panels, also known as photovoltaic cells, in which through these cells the energy coming from the sun is converted into other forms of energy such as electricity. Solar energy is considered one of the least harmful methods used in the industry of power generation, but using this method has its drawbacks and challenges. A PV module manufacturer will produce a considerable amount of scrap metal during its operation, for example at the end of the PV module life cycle, they become unusable, and most manufacturers dispose of them without recycling or making use of them. Therefore, PV End-of-Life management became important. The materials that can be recovered from PV modules include the cover and substrate glass, silicon cells, and other metals in the c-Si modules. Throughout the past few decades, many approaches have been developed and implemented such as thermal, mechanical, and chemical approaches. The method we will discuss in this review is the disassembly of PV modules through robotics and automation (Heath, 2018). In Japan, companies have developed an automated solar panel disassembly line. It consists of three main components, the J-box separator, which removes the junction box from the PV panel, the frame separator, which removes the frames and finally the glass separator which extracts the glass from the other materials using a heated blade. A blade is heated up to 300 degrees Celsius and is used to separate the glass from other materials (NPC incorporated., n.d.). These extracted materials can then be used to reproduce more PV panels.

Automated Solar Panel Disassembly Line by NPC Incorporated:

Components



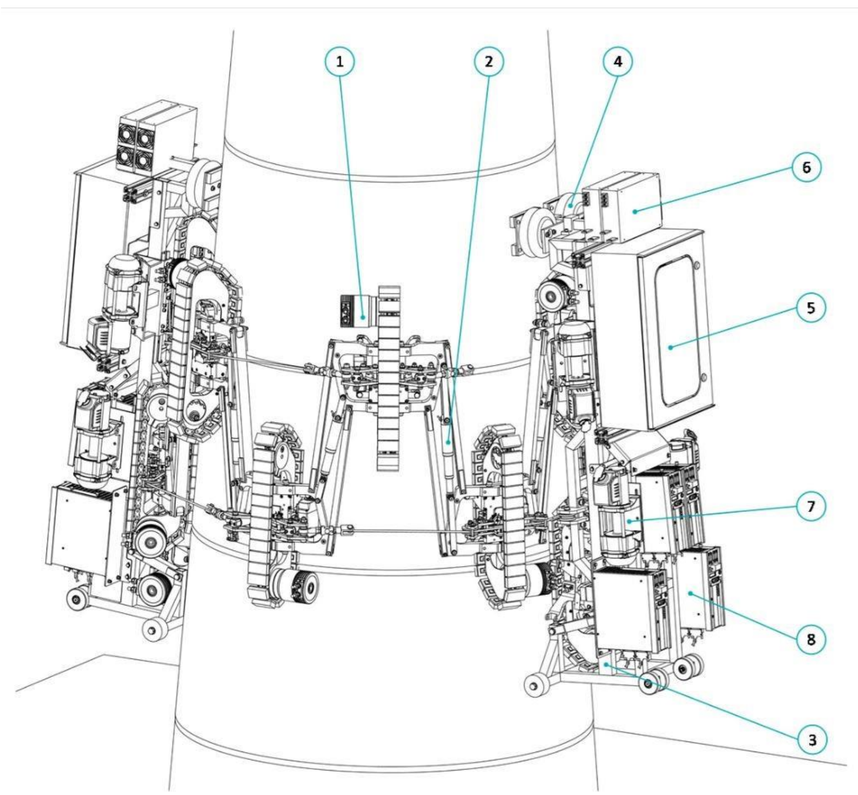
Specifications

Line size (W) x (H)	16.7 x 2.0 m
Applicable panel	Solar panel with back sheet
External dimension of panel	Min: 800 x 800 mm Max: 1,090 x 2,100 mm
Glass thickness	2.8 – 4.0 mm
Frame thickness	40 – 60 mm
J-Box position	Short side: center of a panel Long side: 40 – 150 mm from edge of a panel
Process time	Approx. 60 seconds (for 6 x 10 panels) *It may change depending on the panel conditions.
Interface	Touch screen (password, trouble/alarm management, counter functions)

1.2.2 Wind Energy

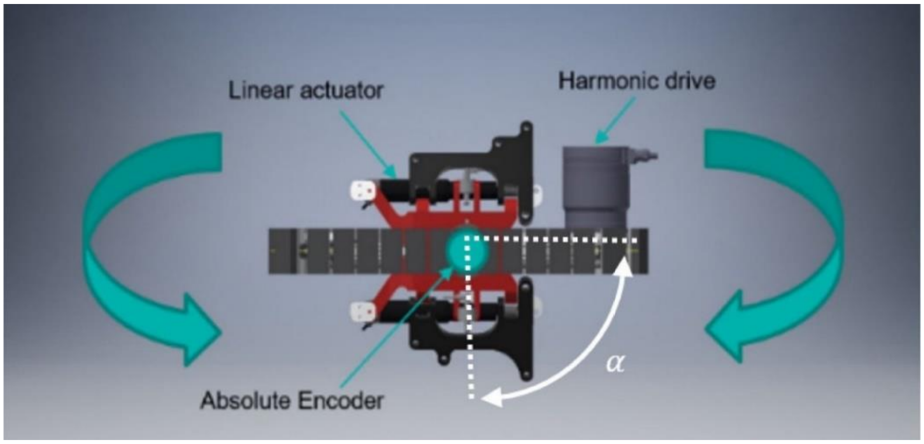
The sun provides another source of energy, wind energy, in which its uneven heating of the atmosphere, the earth's irregular surfaces, and the planet's revolution are all factors contributing to the generation of wind (Wind Energy Basics., n.d.-b). Wind turbines are used to convert energy from the wind to electricity and other forms of energy that can be utilized. Wind energy is also considered one of the cleanest energy sources, but it does have disadvantages. One of them is that the wind turbines are usually placed in locations with extreme environmental conditions therefore they require maintenance. Unless the turbines are maintained periodically, they will deteriorate and be reduced to waste, so, to extend their lifespan and conserve them, they require constant maintenance and supervision. Manual maintenance is a physically demanding task due to the enormous size of the wind turbines. Due to this job's dangerous nature, robots were developed to automate this task. One of the approaches was the multi-robot system and at its core is the CRR, climbing ring robot. It consists of three systems: locomotion, adhesion, and manipulation. This approach depends on a four-join gearing mechanism that connects the crawlers to climb the wind turbine and perform its function. There are tension straps that contract the climbing while applying radial forces from each crawler to the tower (Franko, 2020). Another application of robotics in maintenance is the blade-cleaning robot. It consists of a side brush frame, leading-edge brush frame, camera, water tank, water jet, wire rope holder, roller shock absorber, and brush. The blade-cleaning robot goes up the turbine and through sensors, it checks the condition, and whether there are any cracks or spots that need to be cleaned (Jeon, M., 2012).

Climbing Ring Robot:

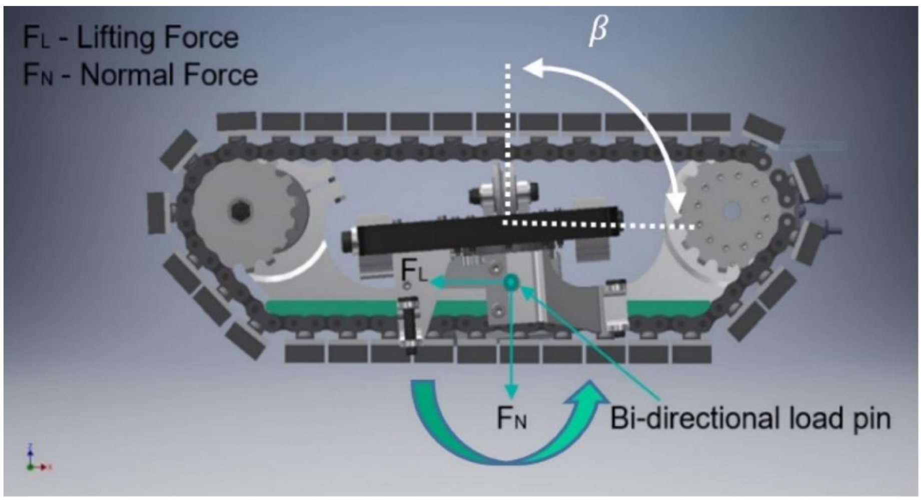


Degrees of Freedom:

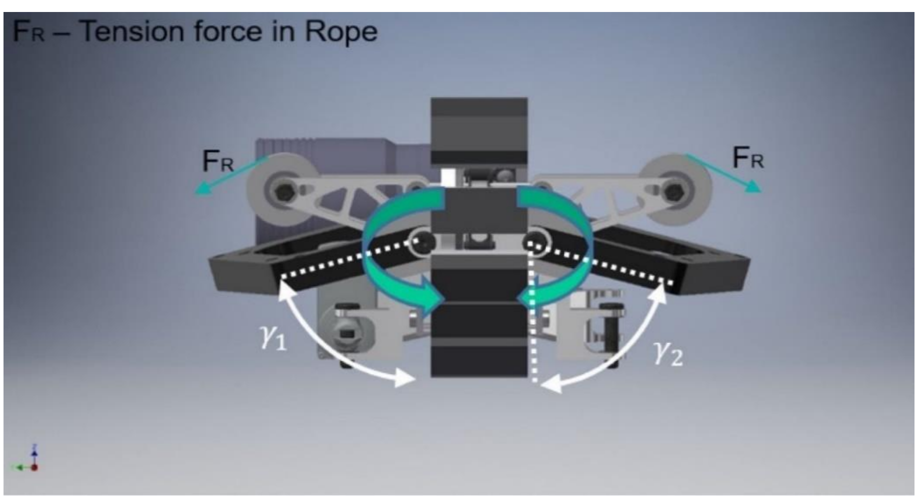
The first degree of freedom shown in the figure below is composed of two synchronized linear actuators pushing and pulling simultaneously and rotating the red part of the crawler frame vs. the black coupling towards the horizontal connection.



For conical-shaped wind turbine towers, the tilt motion β is enabled via a bolt bearing located beneath the steering mechanism. In every circumstance, the horizontal link is oriented vertically to the ground. Every crawler needs to line up with the surface.



The tensioning system's unequal contraction and expansion are turned off by the third DOF. As a result, the black connections to the horizontal connection can rotate along a vertical axis, but both angles γ are maintained by a gear mechanism. If not, every gripping angle would have a distinct alignment.



1.2.3 Hydropower

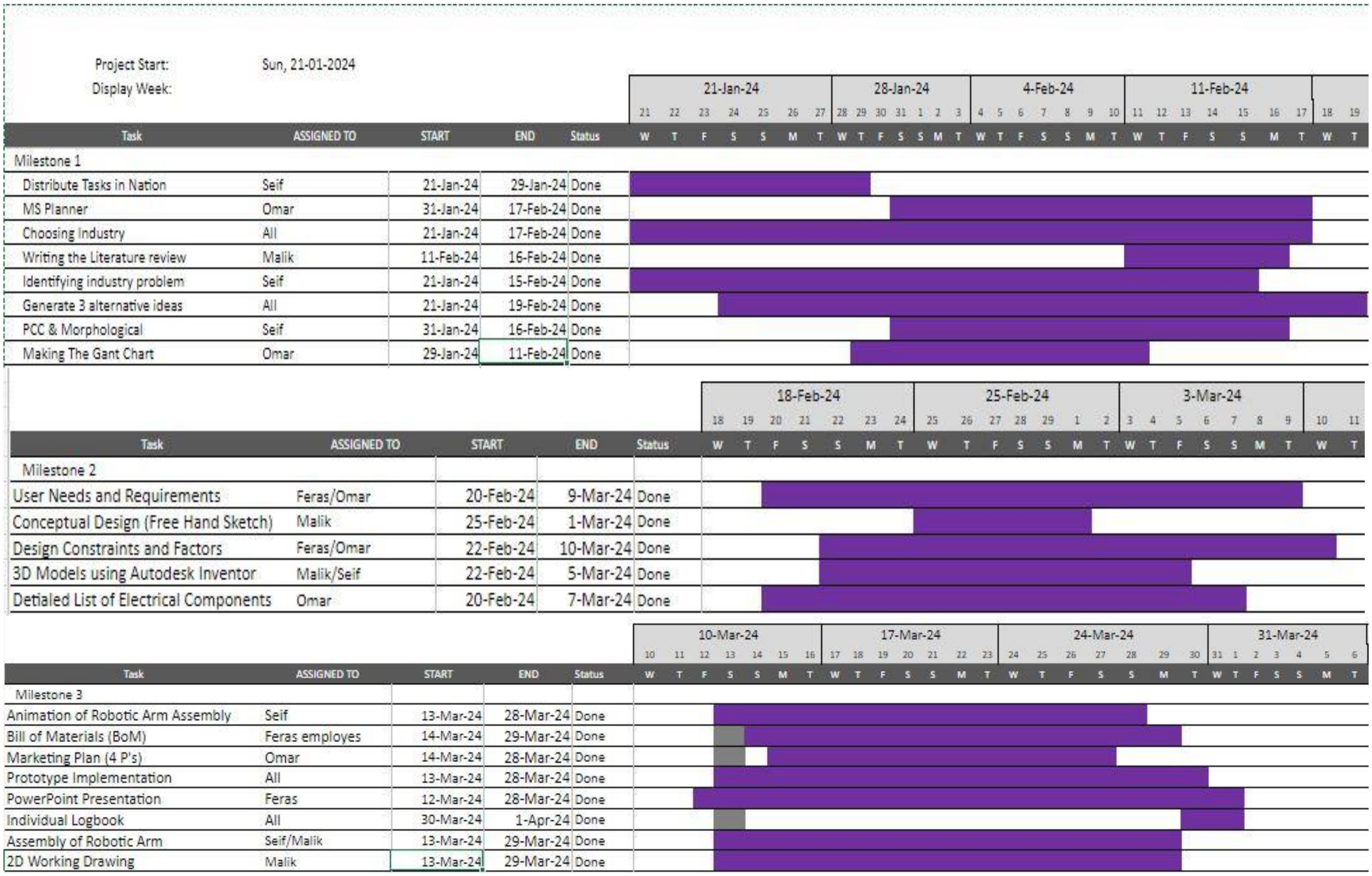
One of the earliest forms of renewable energy is hydroelectric power, which draws energy from the natural flow of moving water, such as rivers to generate electricity. This renewable energy source currently accounts for 28.7% of the total US renewable energy generation (*Hydropower Basics*, n.d.). Hydroelectric transmission is done through using the elevation difference such as dams. Usually, Field maintenance of hydroelectric machinery is performed manually due to the high complexity of the task. We will discuss one of the rarely used robots in hydroelectricity, the SCOMPI robot. SCOMPI is a multiprocessor and task-based robot. Throughout the last 15 years, SCOMPIs have been frequently deployed for a variety of applications such as repairing cavitation damage to turbines, which was the reason it was initially designed, to reinforce turbines and improve their performance in terms of efficiency. First, we will analyze cavitation erosion and what role the SCOMPI robot plays in solving it. Cavitation erosion occurs when tiny water vapor bubbles burst due to intense pressure, spraying micro water jets across the turbine's surface. To solve this problem, the SCOMPI robot was developed. It starts by removing all the spongy metal by gouging, then robots are deployed for wielding and grinding (Hazel, B., Côté, J., Laroche, Y., & Mongenot, P., 2011). Another application for robots is the fabrication and refurbishment/recycling of hydro equipment without dismantling them. They strengthen hydroelectric turbines and increase their performance. A real-world example is applied by the 'Genesis System,' a US-based company, which uses robots to weld wicket gates of hydroelectric plants resulting in significant improvements in the speed, quality and accuracy compared to the performance achieved through manual methods (Iqbal, J. 2019). Robots have also been used to detect corrosion on the piston rod of the hydraulic hoist of the hydropower station to prevent oil leakage and other severe consequences. The robot uses a detection system that gathers information through a laser camera to capture images. Once the images are analyzed, filters and operations like cascade filtering and morphological processing are applied. This helps extract important data such as gradient information from the images and depth data related to defects. (International Journal of Plant Engineering and Management., n.d.).

1.2.4 Conclusion

To sum up, the global shift towards renewable energy sources has become essential to avoid and prevent environmental damage. While solar, wind, and hydroelectric power offer cleaner alternatives, they have their drawbacks that need to be addressed. Many approaches have been developed such as robotic disassembly for solar panels and maintenance robots for wind and hydropower, show promise in minimizing environmental impact. These advancements will certainly prove to be important as they will allow us to achieve a sustainable energy future.

2 Planning

2.1 Gantt Chart



Project Start: Sun, 21-01-2024
Display Week:

Task	ASSIGNED TO	START	END	Status
Milestone 1				
Distribute Tasks in Nation	Seif	21-Jan-24	29-Jan-24	Done
MS Planner	Omar	31-Jan-24	17-Feb-24	Done
Choosing Industry	All	21-Jan-24	17-Feb-24	Done
Writing the Literature review	Malik	11-Feb-24	16-Feb-24	Done
Identifying industry problem	Seif	21-Jan-24	15-Feb-24	Done
Generate 3 alternative ideas	All	21-Jan-24	19-Feb-24	Done
PCC & Morphological	Seif	31-Jan-24	16-Feb-24	Done
Making The Gant Chart	Omar	29-Jan-24	11-Feb-24	Done

Task	ASSIGNED TO	START	END	Status
Milestone 2				
User Needs and Requirements	Feras/Omar	20-Feb-24	9-Mar-24	Done
Conceptual Design (Free Hand Sketch)	Malik	25-Feb-24	1-Mar-24	Done
Design Constraints and Factors	Feras/Omar	22-Feb-24	10-Mar-24	Done
3D Models using Autodesk Inventor	Malik/Seif	22-Feb-24	5-Mar-24	Done
Detialed List of Electrical Components	Omar	20-Feb-24	7-Mar-24	Done

Task	ASSIGNED TO	START	END	Status
Milestone 3				
Animation of Robotic Arm Assembly	Seif	13-Mar-24	28-Mar-24	Done
Bill of Materials (BoM)	Feras employes	14-Mar-24	29-Mar-24	Done
Marketing Plan (4 P's)	Omar	14-Mar-24	28-Mar-24	Done
Prototype Implementation	All	13-Mar-24	28-Mar-24	Done
PowerPoint Presentation	Feras	12-Mar-24	28-Mar-24	Done
Individual Logbook	All	30-Mar-24	1-Apr-24	Done
Assembly of Robotic Arm	Seif/Malik	13-Mar-24	29-Mar-24	Done
2D Working Drawing	Malik	13-Mar-24	29-Mar-24	Done

Excel File: Gantt Chart

2.2 Task Allocation

Title	Assignment	Start Date	Due Date	Bucket
Individual Logbook	OA MB SS FA		3/28/2024	Final Assignment
PowerPoint Presentation	OA MB SS FA		3/28/2024	Final Assignment
Prototype Implementation	OA MB SS FA		3/28/2024	Final Assignment
Marketing Plan (4 P's)	FA Feras A Abdelrahm		3/28/2024	Final Assignment
Bill of Materials (BoM)	OA Omar R Abdelhafe		3/28/2024	Final Assignment
Animation of Robotic Arm Assembly	MB SS		3/28/2024	Final Assignment
~~Choosing Industry~~	OA MB SS FA	1/21/2024	2/19/2024	Milestone 1
~~Writing the Literature review~~	MB Malik A Babiker	2/11/2024	2/16/2024	Milestone 1
~~Identifying industry problem~~	OA MB SS FA	1/21/2024	2/15/2024	Milestone 1
User Needs and Requirements	OA MB	2/20/2023	3/16/2024	Milestone 2
~~Distribute Tasks in Nation~~	SS Seif A Salama	1/29/2024	1/29/2024	Milestone 1
~~Generate 3 alternative ideas~~	FA Feras A Abdelrahm	1/31/2024	2/19/2024	Milestone 1
~~MS Planner~~	OA Omar R Abdelhafe	1/31/2024	2/19/2024	Milestone 1
~~PCC & Morphological~~	MB SS	1/31/2024	2/16/2024	Milestone 1
Design Constraints and Factors	FA Feras A Abdelrahm	2/20/2024	3/16/2024	Milestone 2
Conceptual Design (Free Hand Sketch)	SS Seif A Salama	2/20/2024	3/16/2024	Milestone 2
Conceptual Design (Free Hand Sketch)	SS Seif A Salama	6/13/2024	7/8/2024	Milestone 2
~~Making The Gant Chart~~	OA Omar R Abdelhafe	1/31/2024	2/11/2024	Milestone 1
3D Models using Autodesk Inventor	OA MB	2/20/2024	2/26/2024	Milestone 2
Detialed List of Electrical Components	SS FA	2/20/2023	3/16/2024	Milestone 2
Assembly of Robotic Arm	OA MB		3/28/2024	Final Assignmen
2D Working Drawing	SS FA		2/28/2024	Final Assignmen

3 Generating & Screening Designs

3.1 Ideation

3.1.1 Fly Cutter and Paint Brush

Theory of Operation:
Due to the need for stability for this robotic arm, two Bases on opposite sides will hold a stepper motor connected to a lead screw, which achieves vertical linear motion when rotated through the lead screw nut while being supported by a PVC pipe. A part attached to the lead screw nut contains a stepper motor that achieves horizontal motion by rotating a conveyer belt. Each end effector is attached to a separate conveyor belt. The paintbrush moves by a pan and tilt mechanism while the fly cutter moves by a shaft that is attached to two bevel gears moving through the rotation of a DC motor. An ultrasonic sensor is placed to measure the distance between the fly cutter and the metal being cut. The fly cutter cuts through wind turbine metals to recycle them, then the paintbrush coats the metal with a protective layer to avoid rusting.

Fly Cutter Advantages:
Fly cutters are highly precise, which enables smooth and accurate surface production on workpieces, and makes them suitable for windmill recycling. Additionally, its straightforward design and minimal maintenance requirements contribute to its cost-effectiveness and ease of manufacture.

Fly Cutter Disadvantages:
One limitation of the fly cutter is its access to only a single point of contact, which can result in slower cutting speeds compared to tools with multiple cutting edges. Another disadvantage is the need for enough stability. For that reason, two robot bases will be used instead of one.

Paint Brush Advantages:
The paintbrush provides fine detailing, which makes it suitable for such a precise application. The brush is also precise enough to avoid overcoating the metals, which can have several complications. It is also a cost-effective solution and is easy to manufacture.

Paint Brush Disadvantages:
Although the pain brush may be precise, it would need many sensors and motors to uniformly spread the coating and not miss a part of the metal. Although still possible, automating the paintbrush would come with difficulties.

3.1.2 Spray Nozzle and Plasma Cutter

Theory of Operation:
Similar to the first idea, this idea also requires stability. Two Bases on opposite sides will hold a stepper motor connected to a lead screw, which achieves vertical linear motion when rotated through the lead screw nut while being supported by a PVC pipe. A part attached to the lead screw nut contains a stepper motor that achieves horizontal motion by rotating a conveyer belt. Each end effector is attached to a separate conveyor belt. A plasma cutter ejects nitrogen through a small nozzle while ejecting a high electrical voltage, creating an electrical arc that melts and cuts windmill metals. The plasma cutter will use a pan and tilt mechanism to accurately cut edges. As for the second end effector, a spray nozzle would spray a special coating on the metal to avoid rusting. It would use a crank rocker mechanism to be able to spray the metal without accidentally going off the desired track.

Plasma Cutter Advantages:
The plasma cutter's high-temperature plasma enables precise cutting of various metals, including those used in windmill components. Additionally, the use of nitrogen as the cutting gas can result in cleaner cuts. Furthermore, the incorporation of a pan and tilt mechanism allows for accurate positioning and cutting of complex shapes and contours.

Plasma Cutter Disadvantages:
Requires high safety precautions due to its hot temperature. Produces high sounds. Produces more fumes than other metal-cutting methods, as well as hazardous waste, which is not environmentally friendly. Needs a gas supply and electrical infrastructure, which may result in higher initial setup costs and maintenance requirements.

Spray Nozzle Advantages:
The spray nozzle can equally spray a protective coating, which would prevent rust and corrosion. A crank rocker mechanism minimizes wastage and ensures efficiency. The spray nozzle would not require manual control, as its automation would be easy.

Spray Nozzle Disadvantages:
One potential drawback is the need for maintenance and cleaning to prevent clogging. Additionally, the spray nozzle system may be susceptible to environmental factors such as wind or temperature changes, which can affect the accuracy and consistency of the coating application.

3.1.3 Flame Sprayer and Wire Wheel

Theory of Operation:
For this idea, a classic robotic arm setup can be used. A base connected to several linkages would be used with a servo motor rotating those linkages. Two end effectors will be attached. A wire wheel would rotate using a shaft. The shaft is attached to bevel gears that rotate using a DC motor. As for the Flame sprayer, it will be connected through a shaft to a circular disc, which this disc is rotated using the slider-crank mechanism to convert rotary motion to linear motion to ensure that the flame spray is separated by an appropriate distance. The flame sprayer would melt the top layer of a metal while the wire wheel would enhance the top layer.

Flame Sprayer Advantages:
High temperatures generated by flame sprayers allow for efficient melting of the metal's top layer. The adjustable distance control provided by the slider-crank mechanism ensures precise and uniform treatment, enhancing process repeatability and quality.

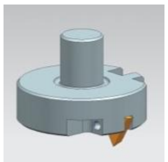
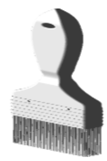
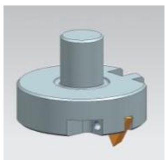
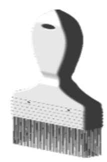
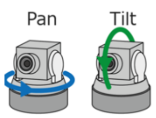
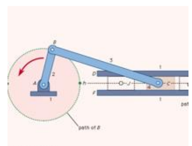
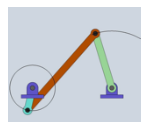
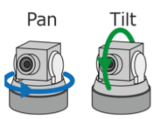
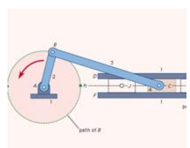
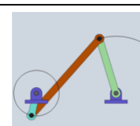
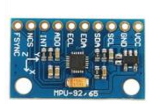
Flame Sprayer Disadvantages:
One potential drawback is the safety concerns associated with handling flammable gases and open flames, which may result in injury and safety concerns. High temperatures could also result in stress in metals. Moreover, the operational costs of fuel and maintenance for the flame sprayer system may be high compared to other surface treatment methods, potentially impacting the cost.

Wire Wheel Advantages:
Wire wheels can remove rust and paint while enhancing surface texture, resulting in a more durable metal. They are a cost-effective solution and are easy to manufacture as well.

Wire Wheel Disadvantages:
Although it removes rust, wire wheels may result in damage to thin surfaces, especially when too much pressure is applied. Another disadvantage is the fact that they may need maintenance as the wire wheel’s bristles may wear and tear over time.

3.2 Screening & Choice of Designs

3.2.1 Morphological Matrix

	Option #1	Option #2	Option #3	Option #4	Option #5	Option #6
End Effector #1	 Fly Cutter	 Paintbrush	 Spray Nozzle	 Plasma Cutter	 Flame Sprayer	 Wire Wheel
End Effector #2	 Fly Cutter	 Paintbrush	 Spray Nozzle	 Plasma Cutter	 Flame Sprayer	 Wire Wheel
Mechanism of End Effector #1	 Pan and Tilt	 Bevel Gear	 Crank Slider	 Crank Rocker		
Mechanism of End Effector #2	 Pan and Tilt	 Bevel Gear	 Crank Slider	 Crank Rocker		
Actuation Method for degrees of freedom	 Servo Motor	 DC Motor	 Stepper Motor			
Power Source	 Batteries	 Solar	 DC Supply			
Sensor	 Camera	 Ultrasonic	 IR	 IMU		

Combination 1: Fly Cutter and Paintbrush
End Effector #1: Fly Cutter
End Effector #2: Paintbrush
Mechanism #1: Bevel Gear
Mechanism #2: Pan and Tilt
Actuation Method for degrees of freedom: Stepper Motor
Power Source: Batteries
Sensor: Ultrasonic Sensor
Application: The fly cutter equipped with a bevel gear mechanism provides precise cutting, while the paintbrush with a pan and tilt mechanism offers flexible and accurate protective layer coating capabilities.

Combination 2: Spray Nozzle and Plasma Cutter
End Effector #1: Spray Nozzle
End Effector #2: Plasma Cutter
Mechanism #1: Pan and Tilt
Mechanism #2: Crank Rocker
Actuation Method for degrees of freedom: Stepper Motor
Power Source: DC Supply
Sensor: IMU
Application: This combination is suitable for industrial applications such as metal fabrication, where both spraying and cutting operations are required. The spray nozzle allows for efficient coating or cleaning processes, while the plasma cutter provides precise and high-speed cutting capabilities.

Combination 3: Wire Wheel and Flame Sprayer
End Effector #1: Wire Wheel
End Effector #2: Flame Sprayer
Mechanism #1: Bevel Gears
Mechanism #2: Crank Slider
Actuation Method for degrees of freedom: Servo Motor
Power Source: Solar
Sensor: Camera
Application: This combination could be used for surface preparation and finishing tasks in manufacturing or maintenance operations. The wire wheel allows for abrasive cleaning or polishing of surfaces, while the flame sprayer offers thermal treatment or coating application capabilities.

3.2.2 P.C.C. Analysis

	Precision	Reliability	Manufacturability	Cost	Total
Precision	….	1	1	1	3
Reliability	0	….	1	0	0
Manufacturability	0	0	….	0	1
Cost	0	1	1	….	2

The idea behind the robotic arm is to recycle windmills by cutting the top layer of metal and then applying a protective coating. For such an application, precision is the top priority, as an unprecise tool could result in an uneven surface, which would affect the aerodynamics of windmills. The application needs to be cost-effective to compete with similar robotic arms. The third most crucial factor has been decided to be reliability because a robotic arm in the renewable energy industry must be of clean energy, as well as require minimum maintenance. Although manufacturability is ranked as the least important, it is still important to choose a manufacturable design.

3.2.3 Selection

After analysis using the PCC method and morphological matrix, it has become apparent that our priority is precision, followed by cost, manufacturability, and reliability. The combination that meets the criteria is certainly the Fly Cutter and Paint Brush End Effectors, which cuts through windmills, measures the appropriate distance of the end effector through the ultrasonic sensor and maintains windmills by applying a special coating using its paint brush. This selection is best for precision as the fly cutter can precisely cut through windmills while the paint brush would evenly spread the special coating. As for the cost, the end effectors are not expensive. They are also easier to manufacture than other options such as a plasma cutter end effector. Finally, the end effectors are still reliable, as the fly cutter does not require maintenance as much as, for example, a spray nozzle.

4 User Needs and Requirements

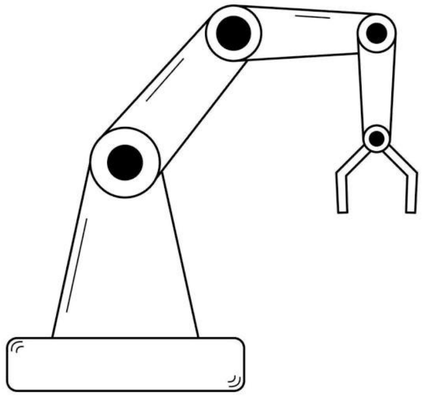
Requirement 1: Must have more than one **degree of freedom** (flexible)
Justification: as it increases the arm will have more flexibility, speed, and more applications the user will be able to do without modifying the robot's design to do other tasks (EVS, 2023).
Relevance: For the end-effectors (Brush and Fly Cutter) to finish cutting the metals and de-rust them more quickly, this will enable them to move more quickly. The end effectors can move in five degrees of freedom upwards, downwards, left, and right also the end effectors themselves rotate and tilt (the fly cutter rotates, and the brush rotates and tilts).

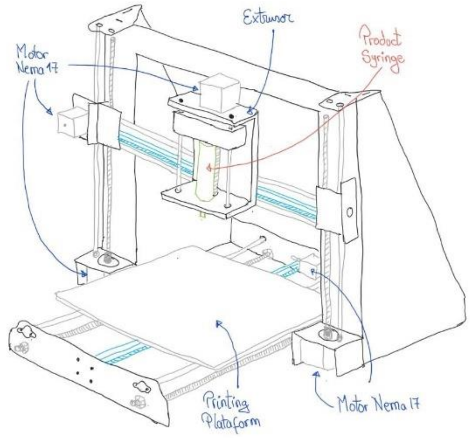
Requirement 2: Quality Control (Ensuring each piece of metal has the same dimensions, thickness, and shape)
Justification: it can help to lessen the potential for human error. When done manually, many tasks and processes related to quality control and assurance are repetitive and invite the opportunity to introduce errors (Foster, 2023).
Relevance: To maintain consistency in the application of tasks such as de-rusting and cutting to each metal piece handled by the robotic arm, thereby promoting quality control, an ultrasonic sensor is incorporated into the fly cutter. This sensor measures the distance between the cutter and the metal surface. Ensuring that this requirement is met, guarantees uniform treatment for every piece of metal, eliminating discrepancies and enhancing overall quality assurance.

Requirement 3: Safe to use (Stability and Protection from dangerous applications)
Justification: help maintain worker safety by doing jobs that pose an elevated risk of harm to people more precisely and working in hazardous areas.
Relevance: The Robotic Arm will include cutting metals using a fly cutter so workers supervising the process must be protected. This is a dangerous application as the cutter rotates with a high-speed cutting of the metals so an ultrasonic sensor will detect if someone is approaching the robot by detecting a sudden change in distance, which will shut down. This process is done by programming this command on Arduino Uno. Also, the lead screw is supported by a rod so it can withstand the load in the middle part of the project. This ensures that the robotic arm will be stable enough to withstand heavy-duty applications.

Requirement 4: User-Friendly (remotely controlled no need for human intervention)
Justification: Simplifying the operation and maintenance of the robotic arm enhances usability and reduces the need for specialized training. Intuitive controls and clear instructions streamline tasks for operators, minimizing errors and maximizing productivity.
Relevance: The robotic arm boasts user-friendly features, eliminating the necessity for manual intervention as most movements are managed through a mobile application. This convenience is achieved through the utilization of a pre-programmed Arduino UNO board, which houses all the requisite instructions for user interaction. By pre-programming the board with expected user commands, the arm's operation is simplified, enhancing usability.

5 Design Constraints and Factors





Constraint 1: Rigidity
Explanation: One of the primary issues with the initial concept pertains to the insufficient strength of the robotic arm to endure the intended applications, namely Cutting and Paint Brush operations. This inadequacy stems from the arm's composition of numerous linkages interconnected with a base, which lacks the requisite durability to withstand the stresses induced by metallic materials. Moreover, the rotational speed of the fly cutter exceeds the tolerances of the linkages, rendering them incapable of enduring such velocities. Consequently, as a collective decision, our group opted to transition to the configuration depicted wherein the end effectors are affixed to a horizontally positioned rod centrally located. This rod is supported by a lead screw and an additional rod to bolster its structural integrity.

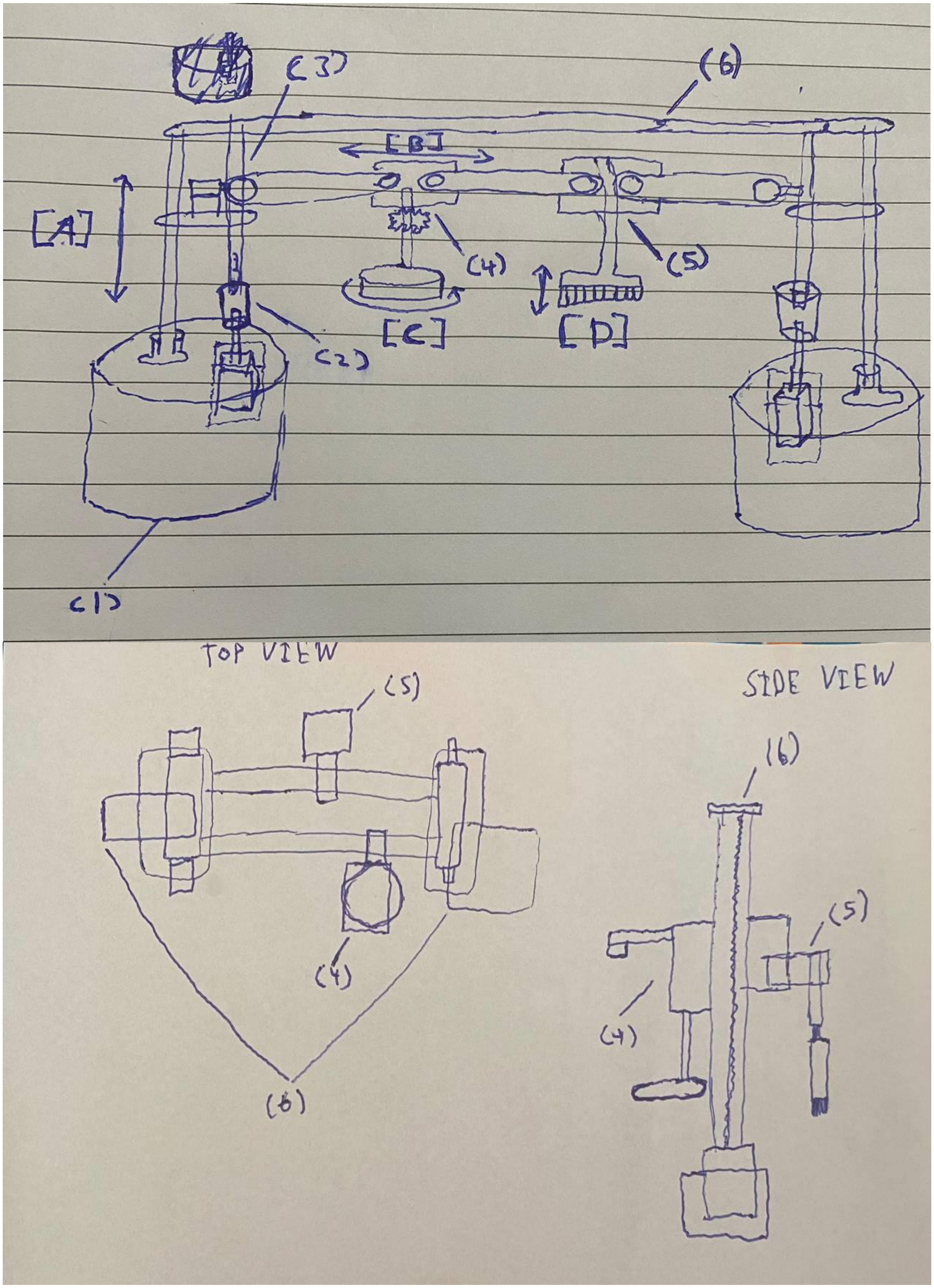
Constraint 2: Flexibility
Explanation: End-effectors need to move freely in different directions to cover the entire surface of the metal efficiently and complete tasks quickly. While the first idea lacked this flexibility, the alternative design provides five degrees of freedom. This means that the end effectors can move up, down, left, and right, as well as rotate and tilt individually. For example, the fly cutter and paintbrush can both rotate and tilt as needed. The fly cutter's movement is controlled by a rod connected to two synchronized bevel gears, powered by a DC motor. An ultrasonic sensor is also included to measure the distance between the cutter and the metal, ensuring accurate cutting. On the other hand, the paintbrush's movement is achieved through a pan and tilt mechanism, with a servo motor controlling its rotation. These features allow for precise and versatile operation, making the robotic arm suitable for a variety of tasks in the renewable energy industry.

Constraint 3: Assembly Considerations
Explanation: During the assembly process, a modification was made to one of the end effectors, specifically the spray nozzle, due to the complexity involved in its mechanism. Consequently, it was substituted with a paintbrush, which offers a simpler application method and is expected to provide greater coverage of the metal surface.

Constraint 4: Cost
Explanation: On an industrial level the project is expected to cost around (10000 egp), but due to the different materials used and the project being made as a prototype may cost around (4000 egp). During the project's design phase, we analyzed the cost by calculating the weight of each component. It was discovered that the projected cost exceeded initial expectations. Consequently, deliberations were held regarding potential design modifications, particularly focusing on reducing costs associated with the base, such as removing unnecessary parts to reduce its mass.

Constraint 5: Vibrations
Explanation: The first idea was abandoned because the linkages were weak and could not handle the demands of working with metal. This weakness led to vibrations and the possibility of the linkages getting detached. Additionally, the noise generated by this setup would make it difficult for workers to supervise. So, we switched to the design which uses lead screws and PVC. In this innovative design, the main potential source of vibration is the lead screw, which might rust over time. This could cause the bolt to move slowly up and down, creating noise. However, we can reduce this issue by placing the robotic arm in favorable weather conditions, preferably sheltered from wind and rain. This way, rusting and noise disturbances will be minimized.

6 Conceptual Design (Free Hand Sketch)



This is a 2D hand sketch showing our prototype's main components after they are assembled. Our robot has 5 degrees of freedom.

(1) shows the base of the robotic arm, it consists of two identical bases at each end. The base has a hole in it designed depending on the dimensions of the stepper motor. The stepper motor’s main function is to provide a degree of freedom allowing the end effectors to move linearly along its height [A].

(2) illustrates the connection between the stepper motor and the lead screw in which they are attached through a coupler in addition to the rod attached alongside the lead screw for additional support and stability. As the stepper motor causes the lead screw to rotate, the end effectors connected to it are forced to move in a linear motion along the robot’s height.

(3) shows the main connection between the lead screw and the conveyer belt, which carries the end effectors. This part consists of a nut that keeps it fixed to the lead screw and consists of a servo motor which is responsible for turning the groove pulley and in turn, rotates the V-belt causing the end effectors to move along its length [B], this movement is another degree of freedom. The conveyor belt's main function is to allow the robot to switch between the two end effectors.

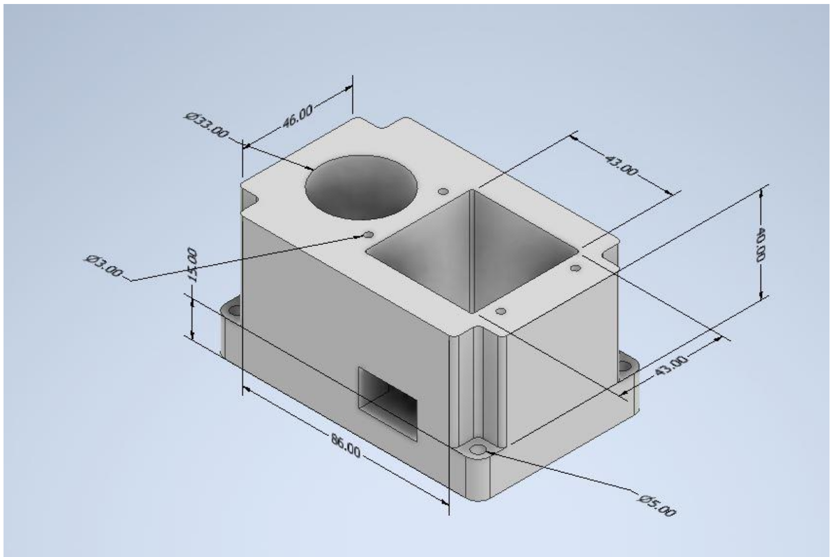
(4) shows the belt clamps, which create the connection between the v-belt and the end effectors. (4) specifies the design of the fly cutter end effector, which will be used to remove the rust from the surface of scrap metals. Attached to the belt clamp shown by (4) is a box consisting of servo motor ultrasonic sensors and bevel gears, leading us to the third degree of freedom [C]. Through the shafts and bevel gears, the rotary motion produced by the servo motor is transmitted to the fly cutter allowing it to rotate at high speeds.

In addition, (5) is the second end effector, a paintbrush used to apply a protective coating to the metals to be prepared for future use. The paintbrush is connected to the second belt clamp through an attachment. This end effector has an additional degree of freedom provided by the pan and tilt mechanism, [D], connected to the paintbrush adding a movement mechanism. Finally, (6) shows the top plate connected to the other side of the supporting rod and lead screw and its only purpose is to add stability and support to the prototype.

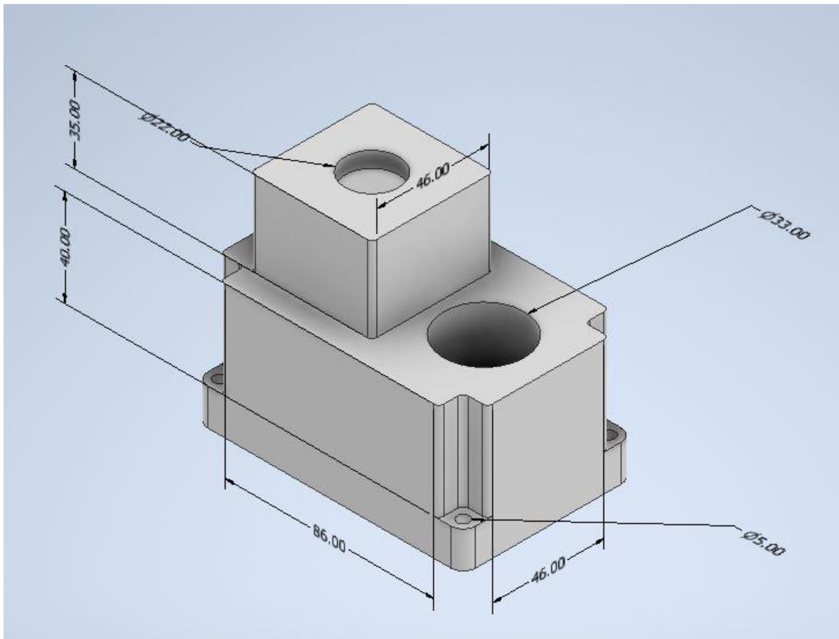
7 3D Models using Autodesk Inventor

The following are all 3D Models designed using Inventor and used in the final assembly (refer to appendix E):

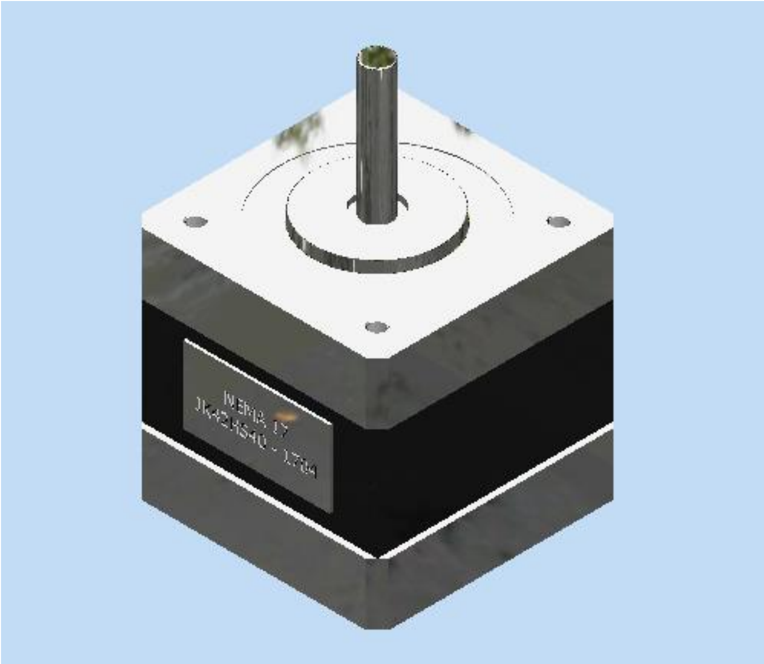
Project Base



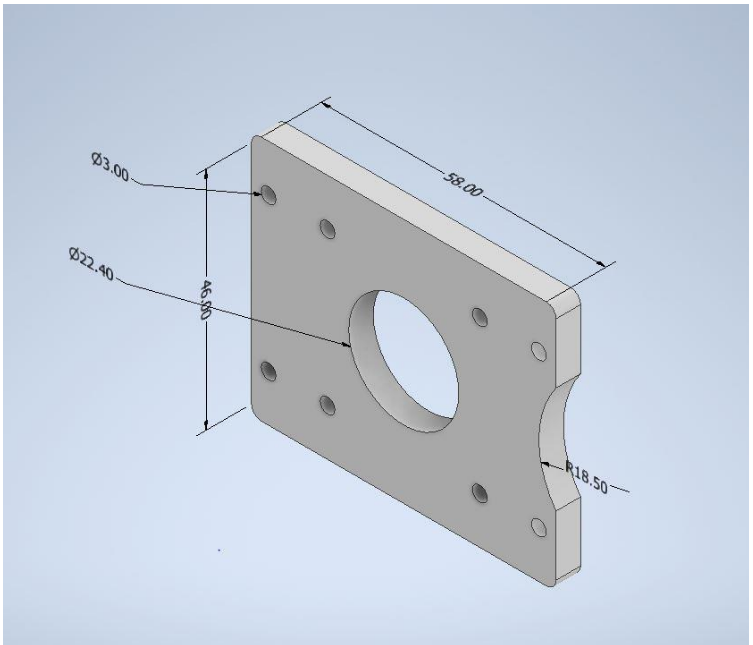
Project Base Right



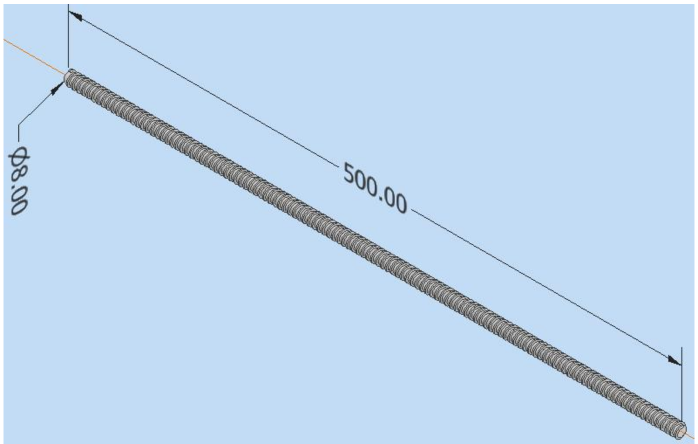
NEMA17 Stepper Motor



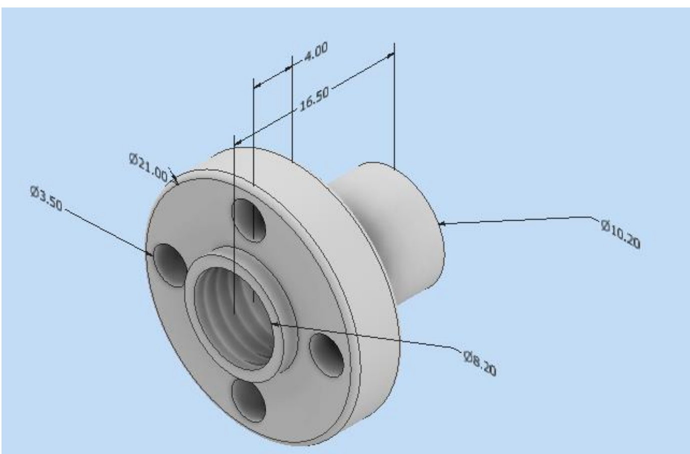
Motor Cover



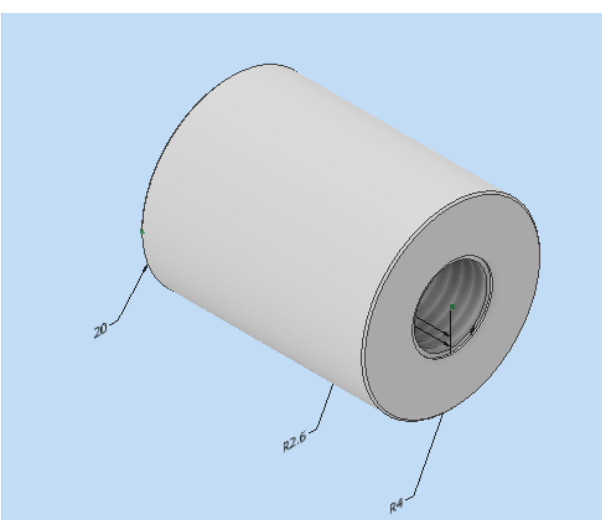
Lead Screw



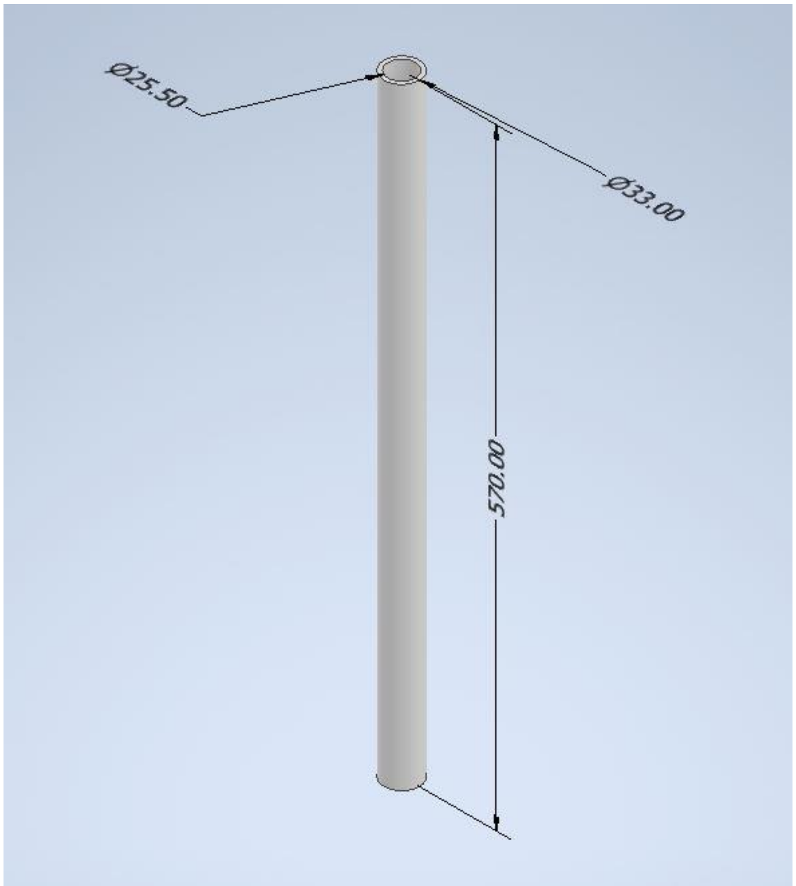
Lead Nut



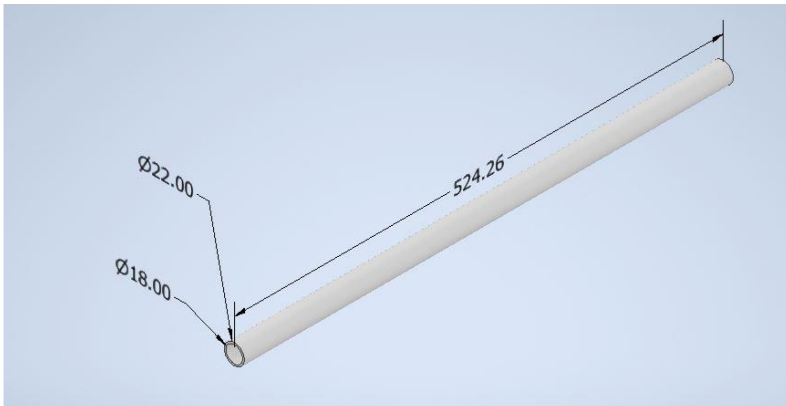
Coupler



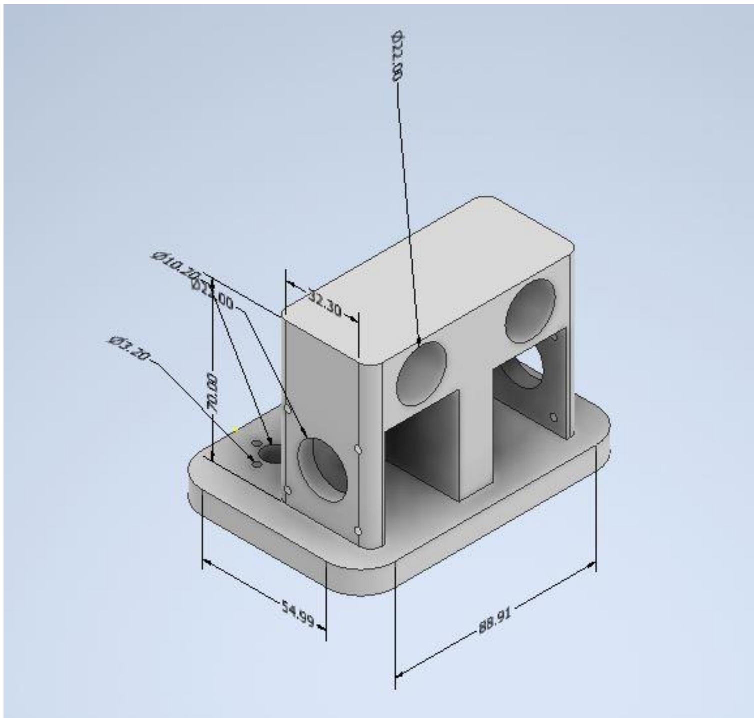
PVC Pipe Base



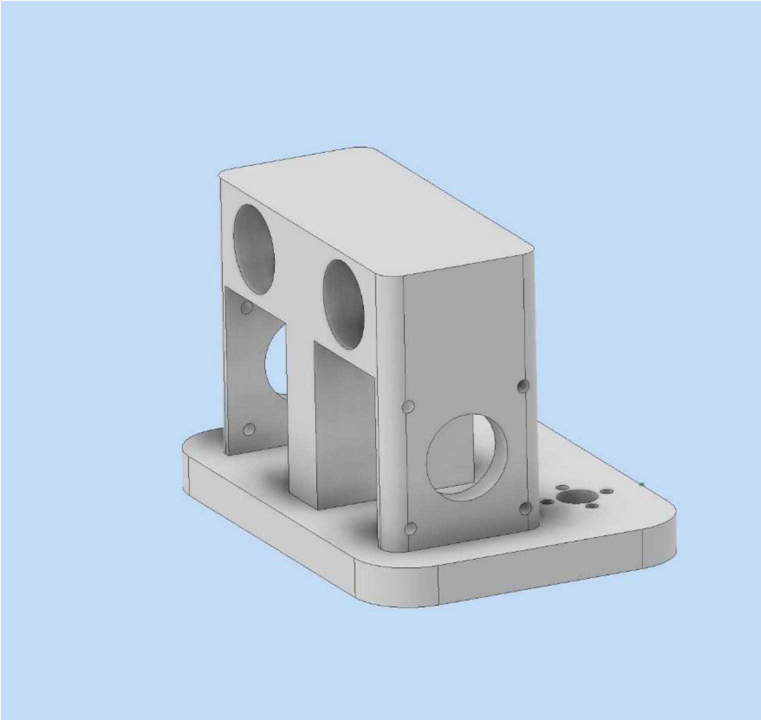
PVC Pipe Middle



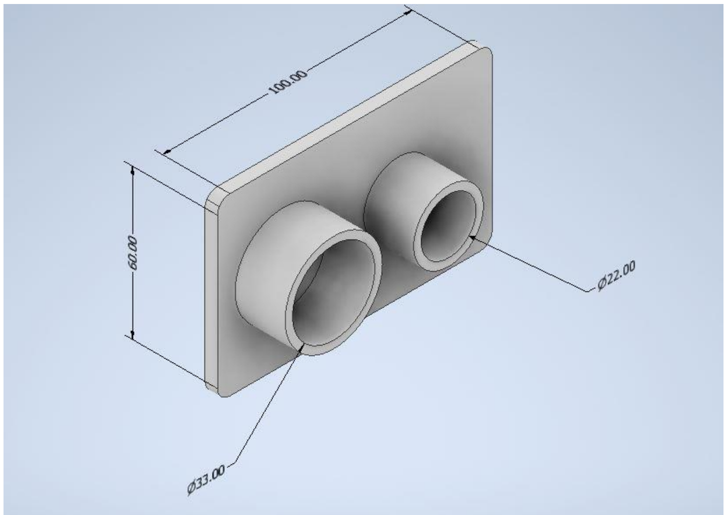
Middle Part



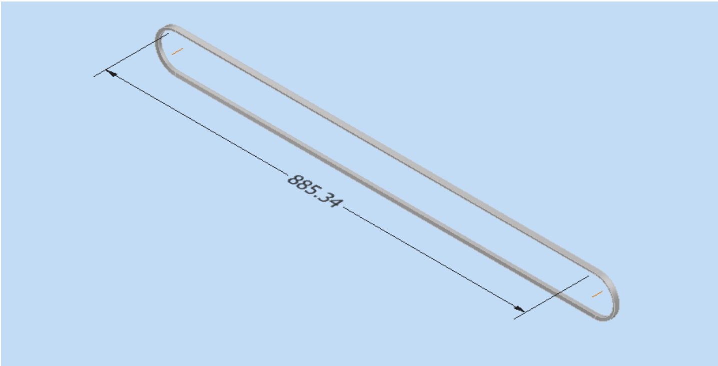
Middle Part Right



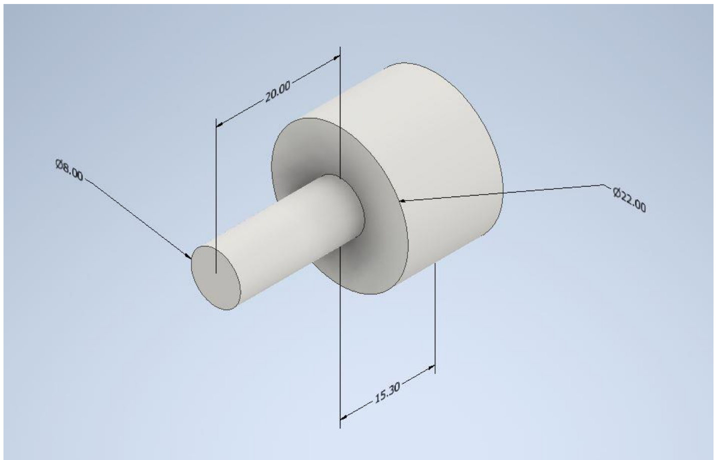
Top Part



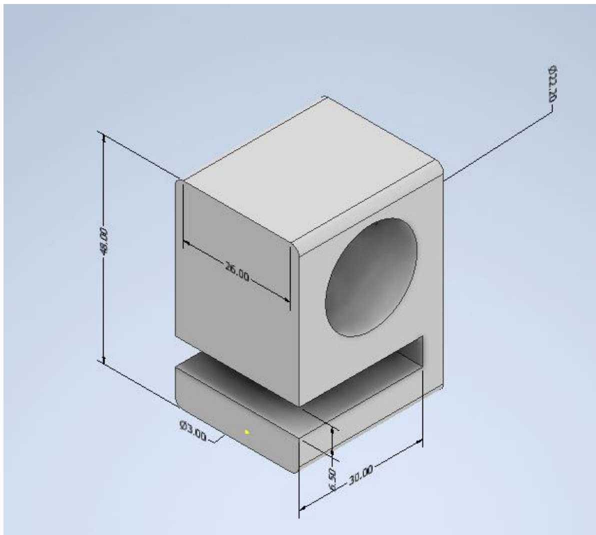
V-Belt

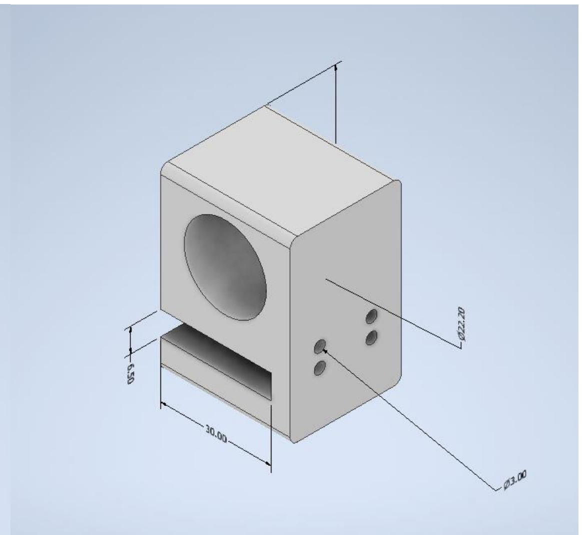


Flat Pulley

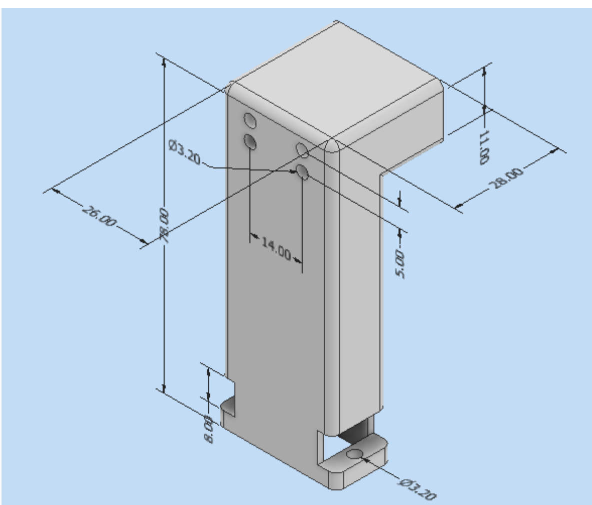


Belt Clamp

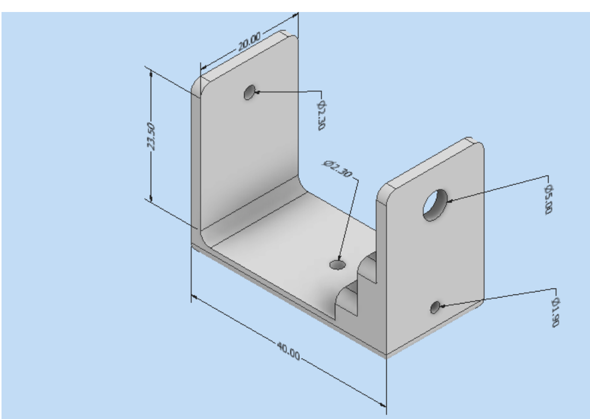




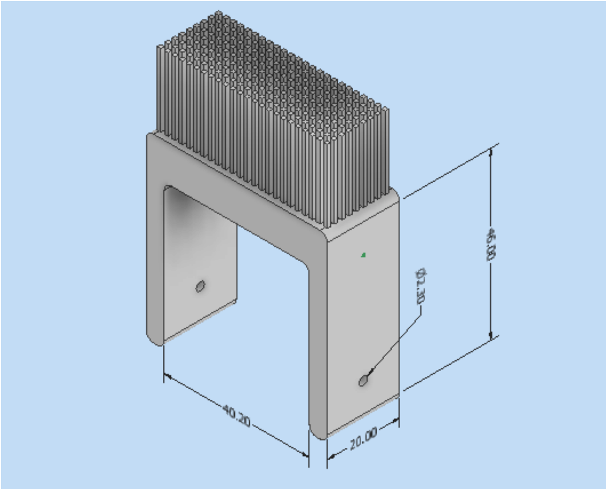
Attachment of Brush



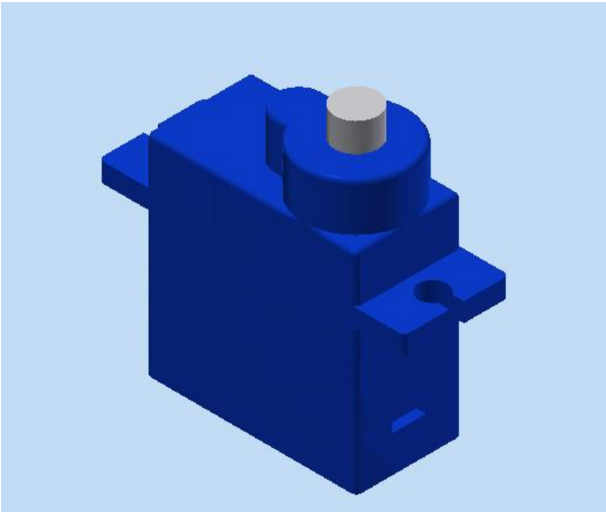
Pan and Tilt Brush



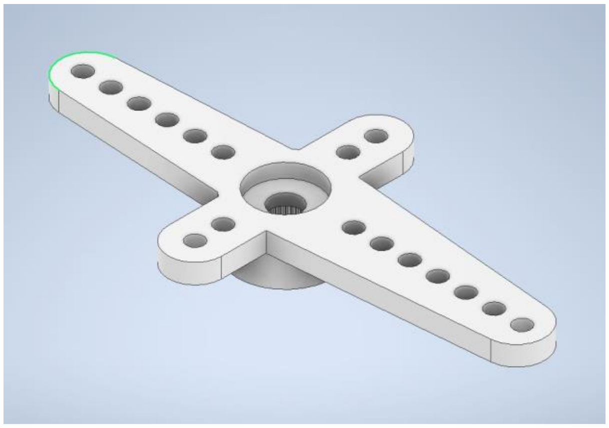
Brush



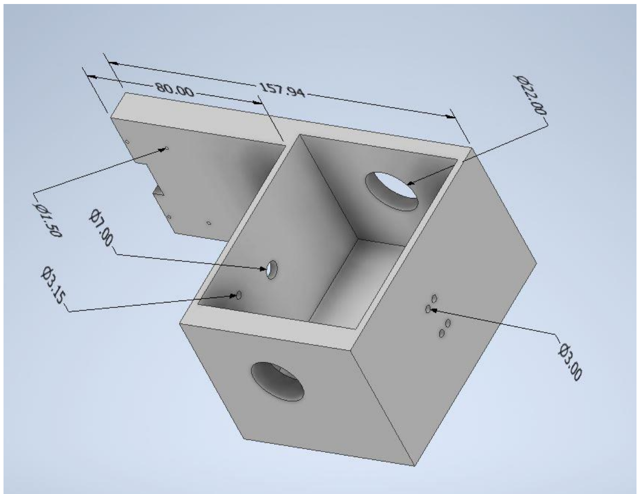
Servo Motor



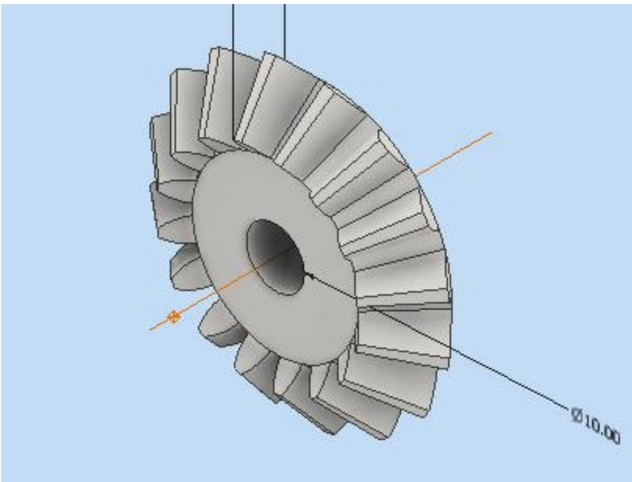
Servo Motor Attachment



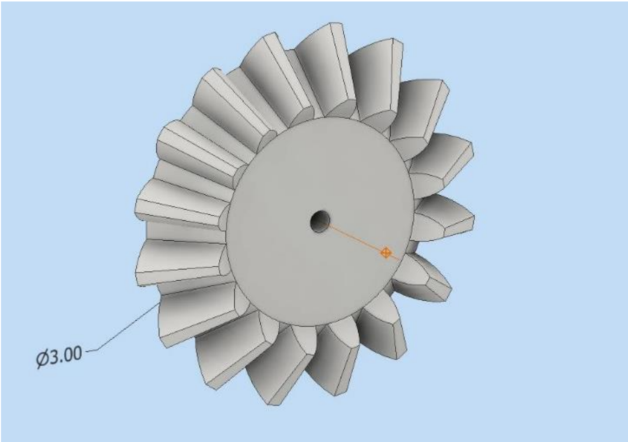
Gearbox



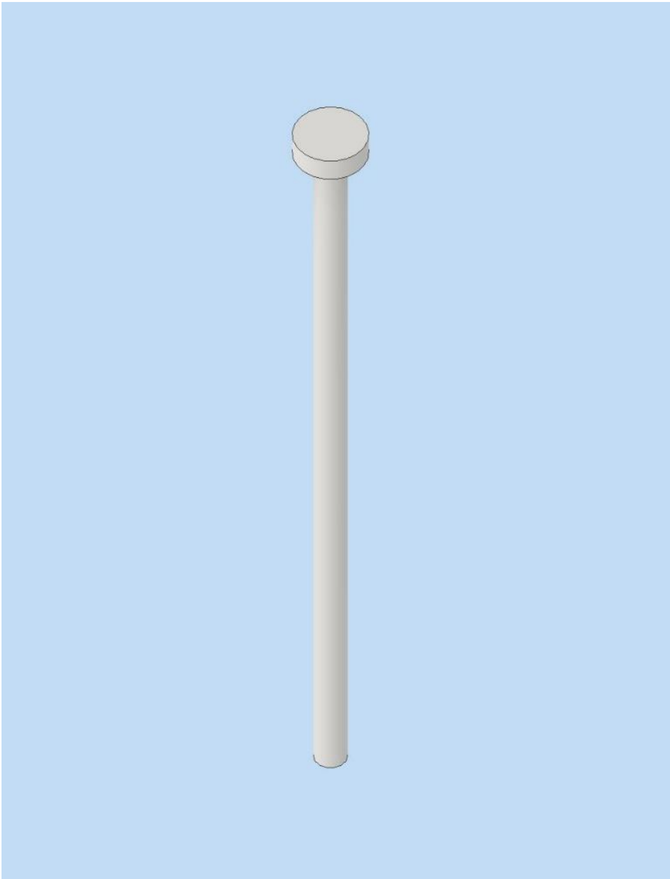
Bevel Gear 1



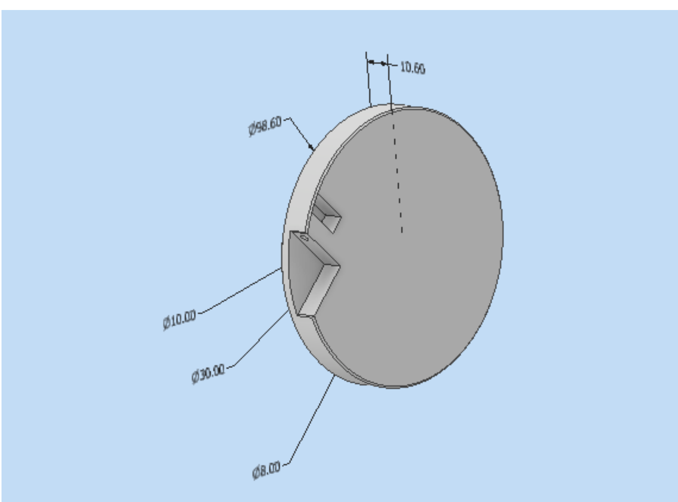
Bevel Gear 2



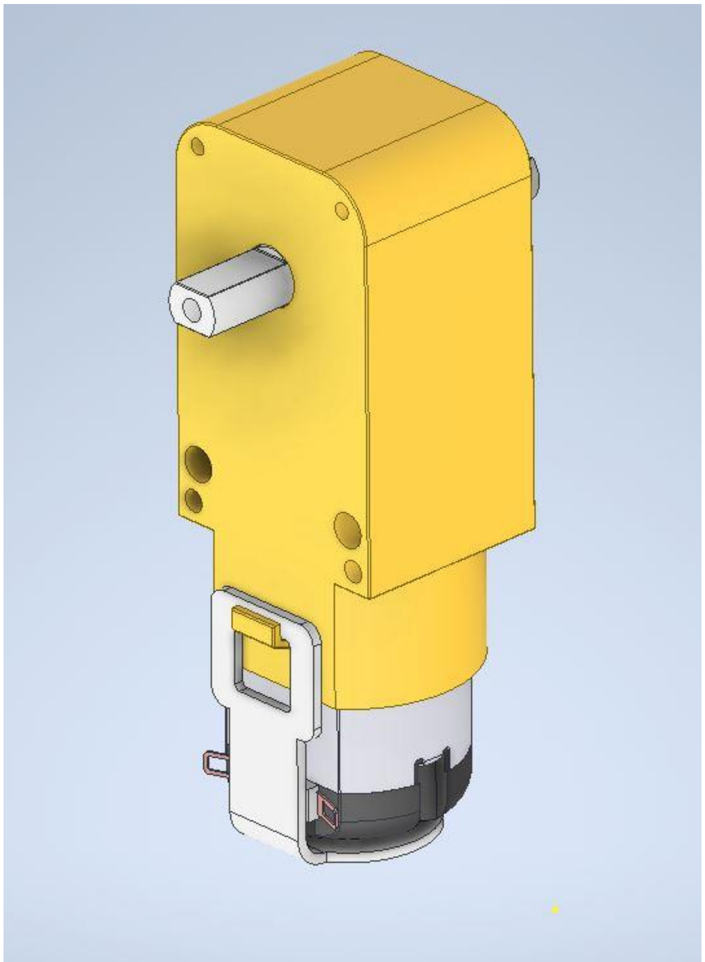
Rod



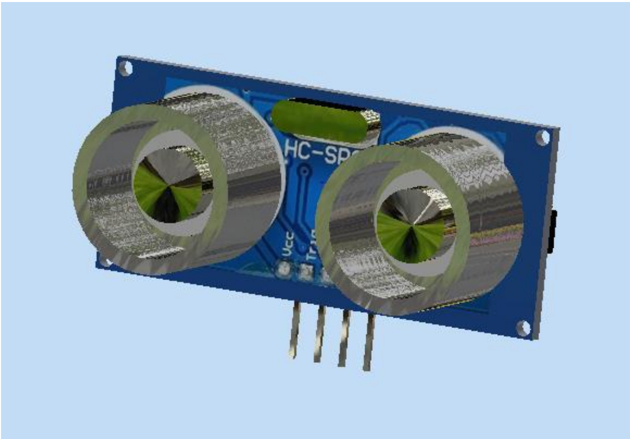
Fly Cutter



Geared DC Motor

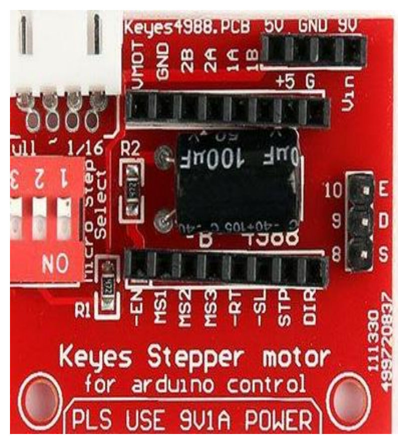


Ultrasonic Sensor (HC-SR04)

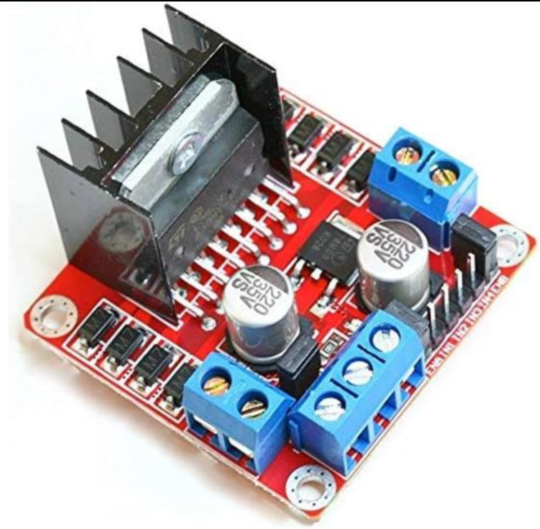


8 Detailed List of Electrical Components

Component Name	Description	Relevance	Price	Figure
Ultrasonic Sensor (HC-SR04)	The ultrasonic sensor is an electronic device that uses ultrasonic waves to measure the distance between the sensor and a target object. It consists of a transmitter that emits ultrasonic waves and a receiver that detects the reflected waves. The time taken for the waves to travel to the object and back is used to calculate the distance.	The ultrasonic sensor is used at the end of the robotic arm to measure the distance between the fly cutter and the surface below the cutter. This information is crucial for controlling the depth of the cut and ensuring precision during the cutting process.	48.50 EGP	
Stepper Motors (NEMA 17)	A stepper motor is a type of electric motor that moves in discrete steps. It consists of a rotor with permanent magnets and a station with electromagnets. By energizing the electromagnets in a specific sequence, the rotor can be rotated in precise increments.	Two stepper motors are used for the lead screw mechanism, which is responsible for the vertical control of the robotic arm. These motors provide precise positioning and control of the arm's movement along the vertical axis. Additionally, one stepper motor is used to move the pulley, which controls the surface on the horizontal axis.	850 EGP	

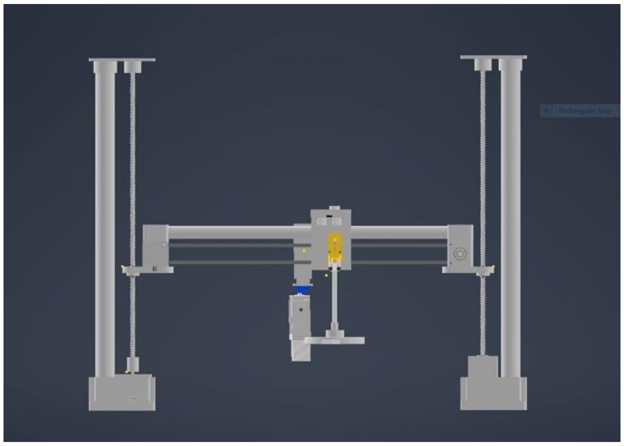
Power Source Battery (3.7V Li-ion)	A lithium-ion battery is a type of rechargeable battery that uses lithium ions as the active material. It provides a high energy density and a long lifespan, making it suitable for powering portable devices.	The batteries are used to supply constant power to the robotic arm and the pulley. They ensure that the system has a reliable and uninterrupted power supply, allowing for continuous operation.	95 EGP	
Stepper Motor Driver Board (A4988 – DRV8825)	A stepper motor driver board is an electronic circuit that controls the operation of a stepper motor. It provides the necessary electrical signals to energize the motor's electromagnets in the correct sequence, enabling the motor to rotate in precise steps.	The stepper motor driver board is used to control the speed and angle of movement of the stepper motors. It ensures that the motors operate smoothly and accurately, allowing for precise control of the robotic arm's movements	85 EGP	

Arduino Uno	The Arduino Uno is a microcontroller board based on the ATmega328P microcontroller. It has digital and analog input/output pins, allowing it to interface with various sensors and actuators. It can be programmed using the Arduino programming language or other compatible software.	The Arduino Uno can be integrated into the mechatronics system to automate the robotic arm's operation. It can be programmed to receive data from the ultrasonic sensor, control the stepper motors based on the sensor data, and perform other automated tasks.	455 E GP	
Geared DC Motor	A geared DC motor is a type of electric motor that combines a DC motor with a gear train. The gear train reduces the motor's speed and increases its torque, making it suitable for applications that require high torque at low speeds.	The geared DC motor rotates the gears responsible for rotating the fly cutter. It provides the necessary torque to move the surface smoothly and accurately.	35 EGP	

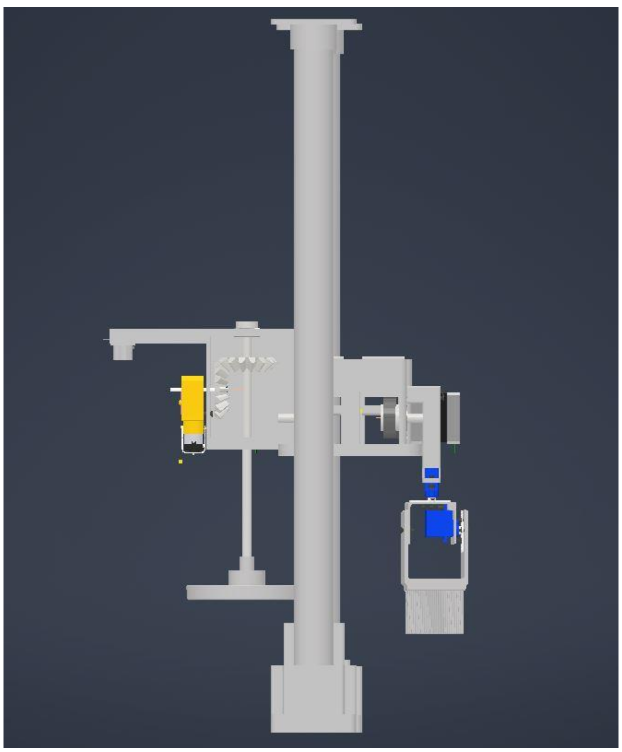
L298H DC Motor Driver	The L298H DC motor driver is an integrated circuit that can control the speed and direction of two DC motors. It allows for independent control of each motor, making it suitable for applications that require precise control of multiple motors.	The L298H DC motor driver is used to control the geared DC motor that drives the pulley. It ensures that the motor operates smoothly and accurately, allowing for precise control of the surface movement.	85 EGP	
SG90 Servo Motor	The SG90 servo motor is a small, lightweight servo motor that is commonly used in robotics and automation projects. It can rotate through a specific angle range and can be controlled using a pulse width modulation (PWM) signal.	The SG90 servo motor is used to control the paint brush that applies the protective coating to the steel surface. It allows for precise control of the paint brush's position and orientation, ensuring uniform application of the coating.	85 EGP	

9 Assembly of Robotic Arm

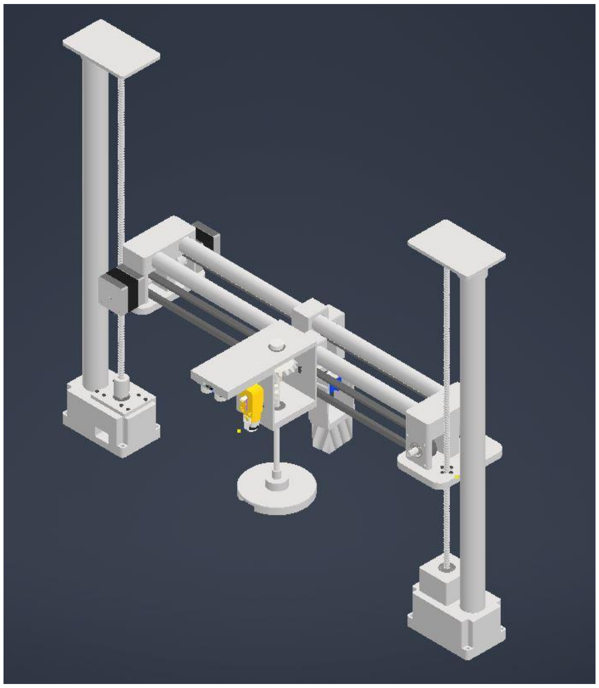
The following figures illustrate our robotic arm design after it has been assembled on inventor from multiple views (refer to Appendix E):



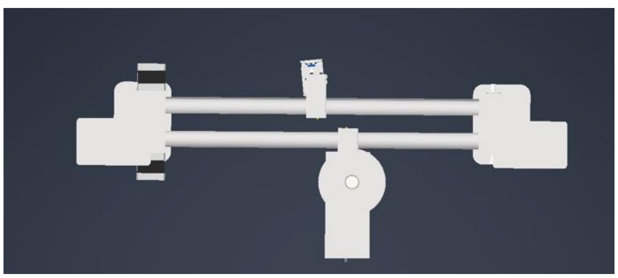
Front View



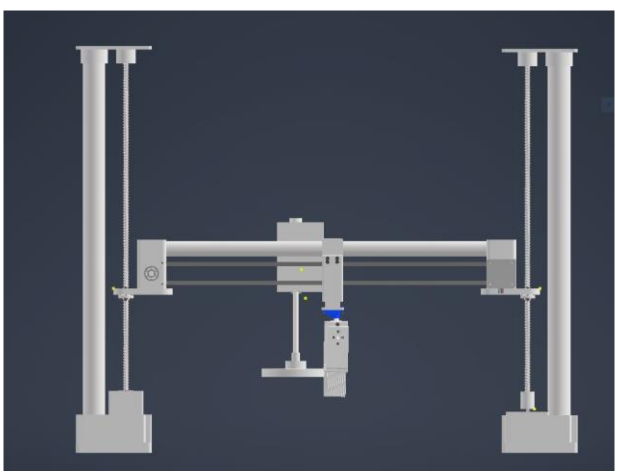
Side View



Top-right Corner View



Top View



Back View

10 Animation of Robotic Arm Assembly

In this section of the report, we showcase the mechanisms of our robotic arm and the way it functions and moves to achieve its purpose. The link below allows you access to our animation where we display how each part of the prototype is connected, methods of movement, degrees of freedom and how each mechanism works and contributes to the functionality of our project.

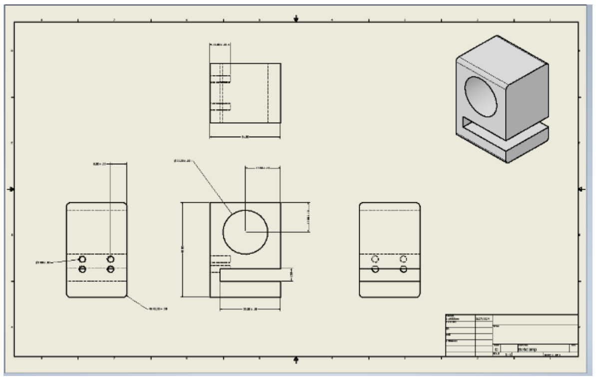
Animation Link

11 2D Working Drawings

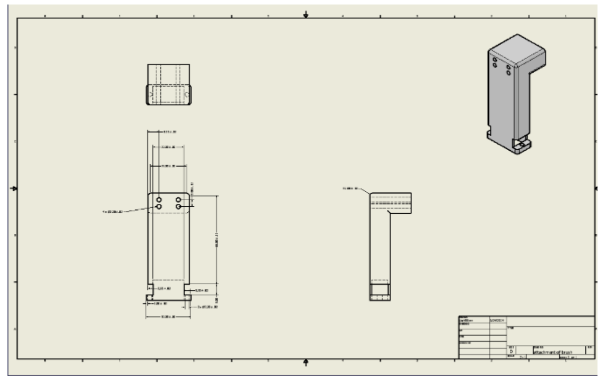
11.1 Parts

The following are 2D Working Drawings, designed using Inventor (refer to Appendix E), which can be used in the manufacturing phase:

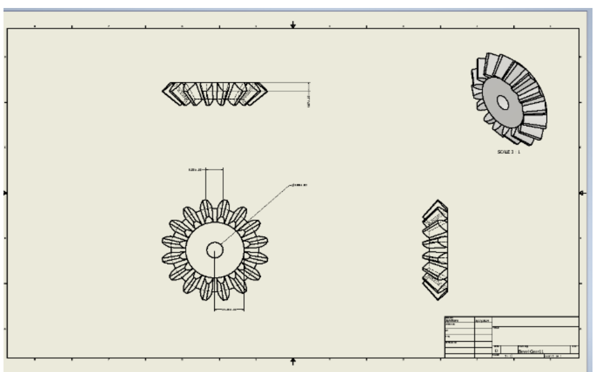
Belt Clamp

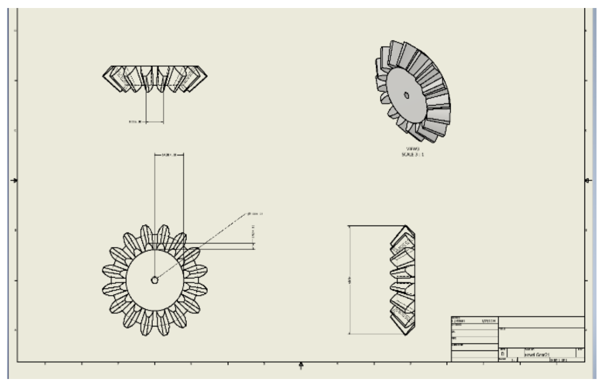


Brush Attachment

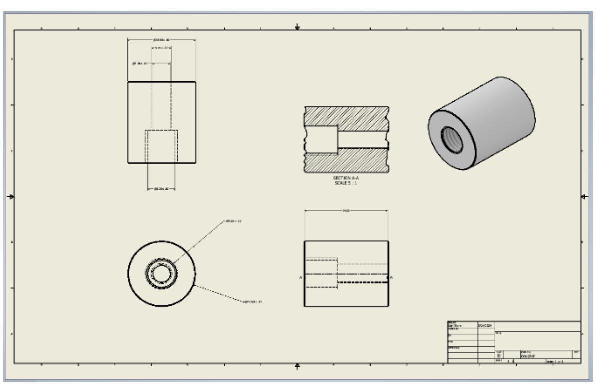


Bevel Gears

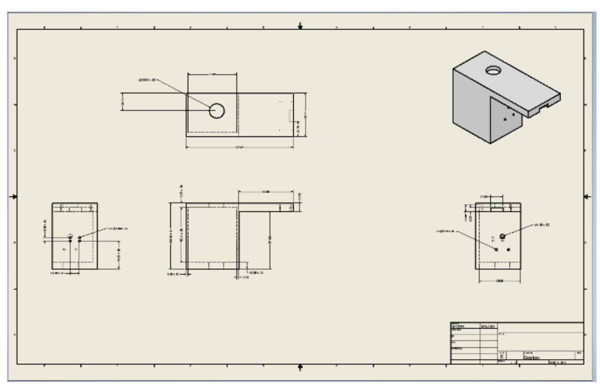




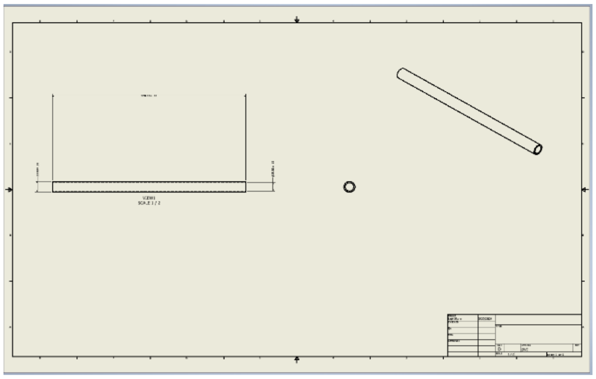
Coupler



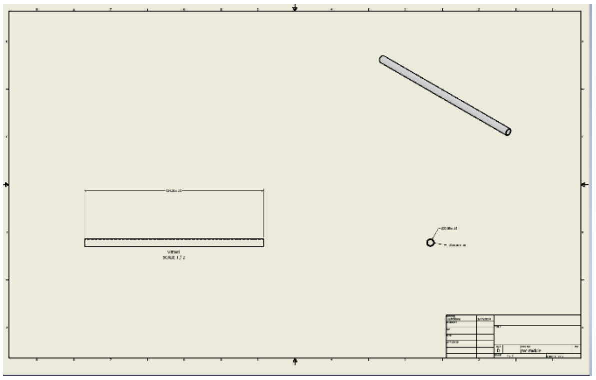
Gearbox



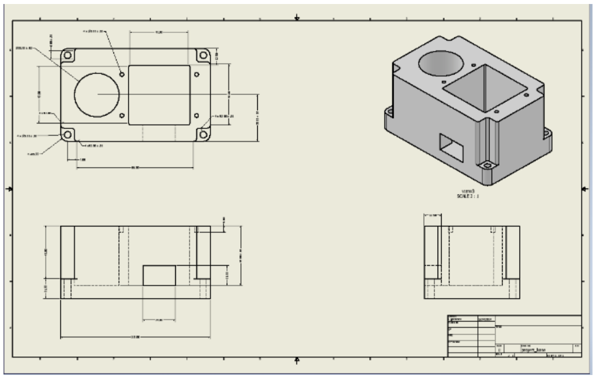
PVC



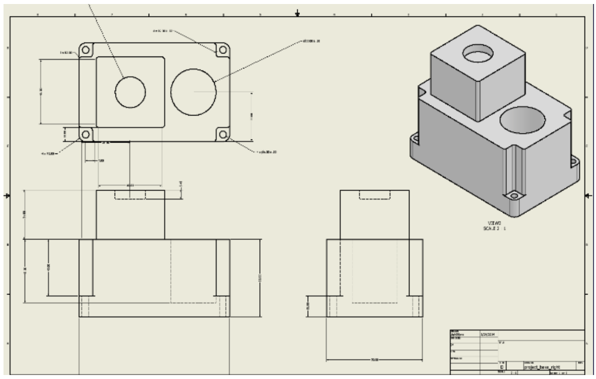
PVC Middle



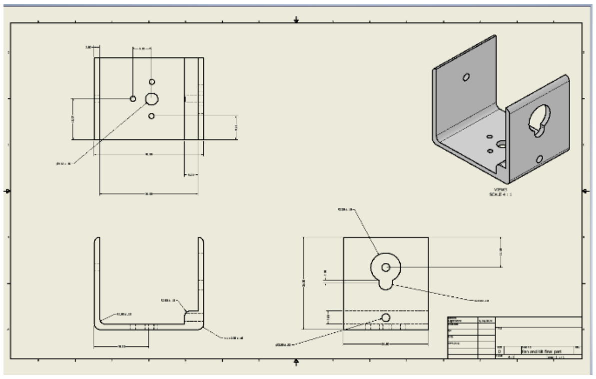
Project Base



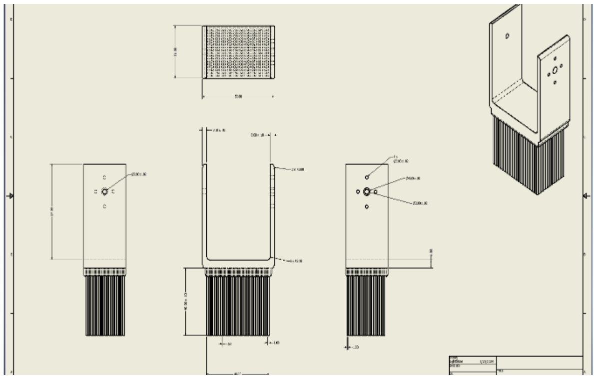
Project Base (Right Side)



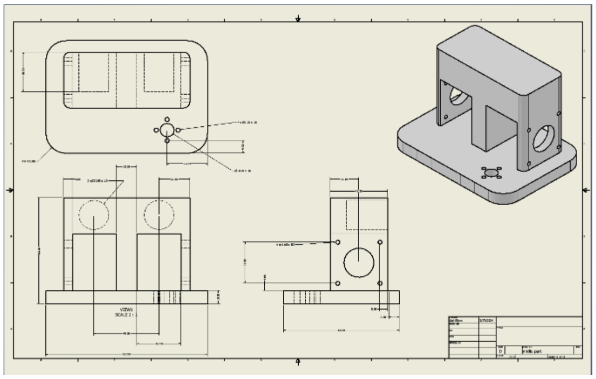
Pan and tilt



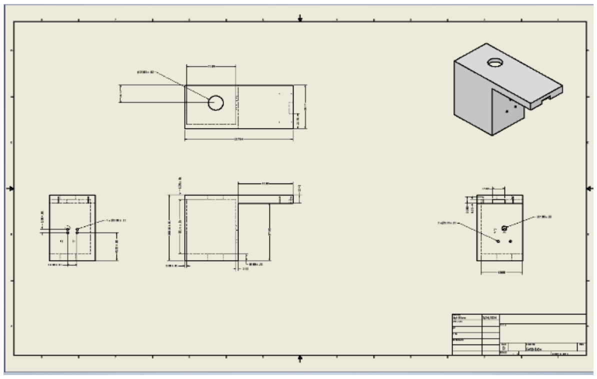
Final Brush



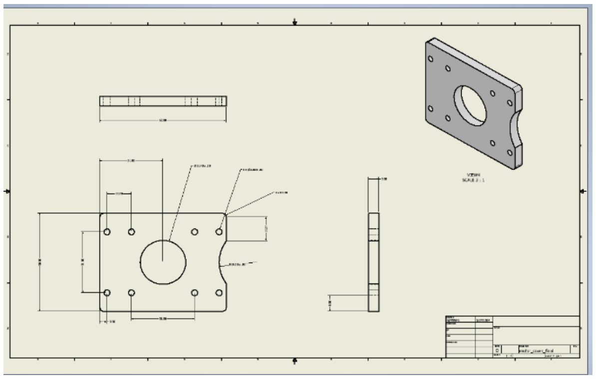
Middle Part



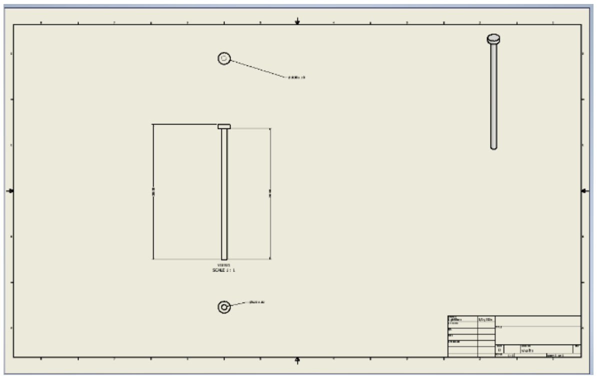
Gear Box



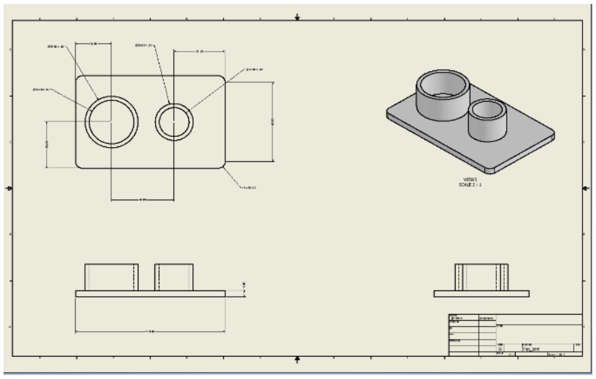
Motor Cover



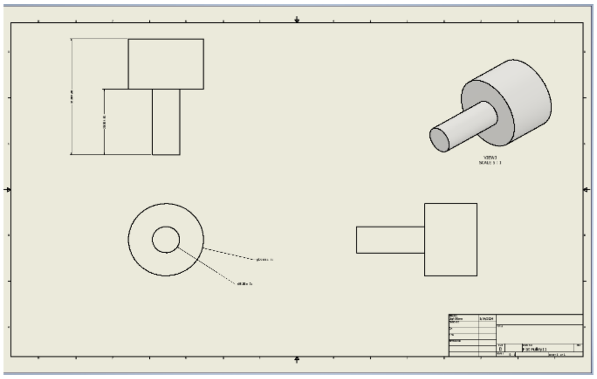
Fly Cutter Shaft



Top Plate

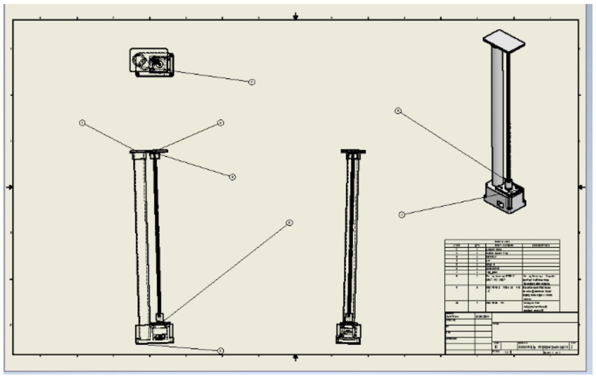


Flat Pulley

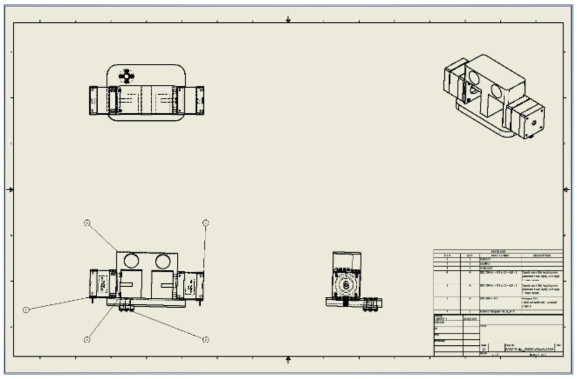


11.2 Subassemblies

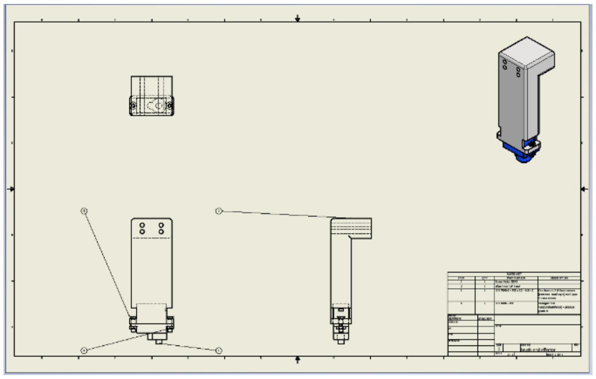
Left Side Assembly



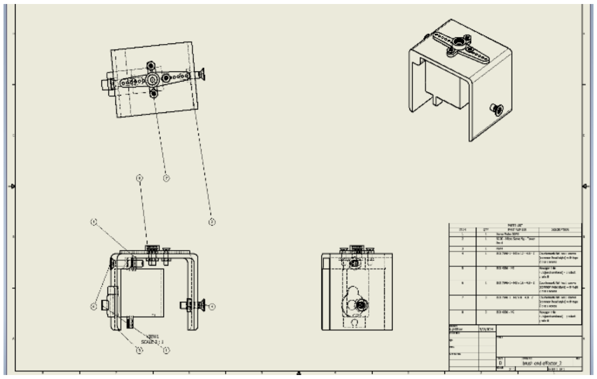
Middle Part Assembly



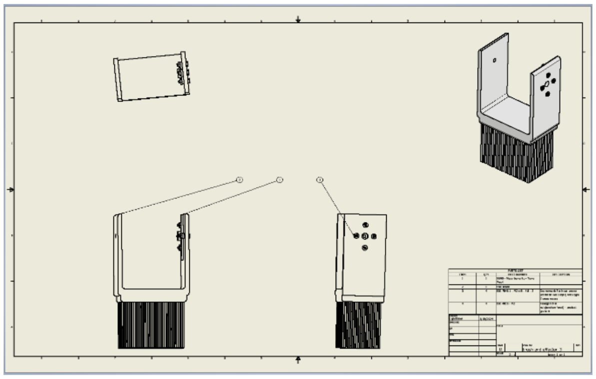
Brush End Effector 1



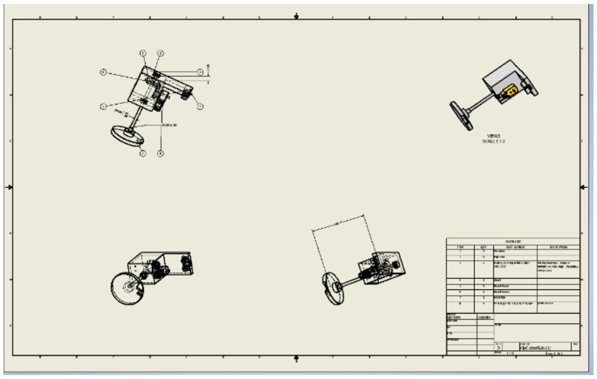
Brush End Effector 2



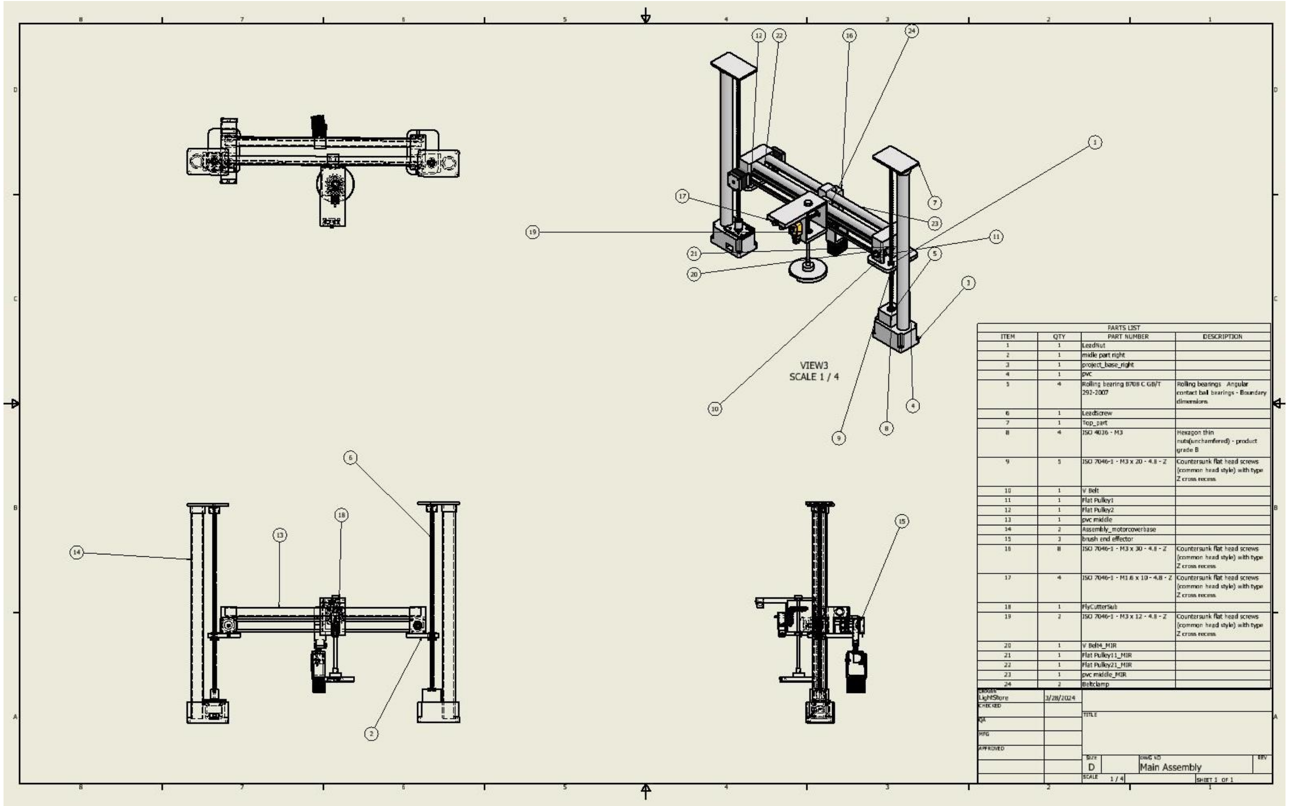
Brush End Effector 3



Fly Cutter Sub Assembly



11.3 Main Assembly



12 Bill of Materials (BoM)

Bill of Materials							
Assembly Name	Robotic Arm						
Total Piece	74						
Total Cost	5815						
Comments	The Total Pieces and cost do not include the body of the project						
Component Name	**Final Output (Position)**	**Product Code**	**Unit of Measurement (UoM)**	**Dimensions**	**Total Quantity**	**Unit Cost**	**Total Cost**
Aluminum Alloy 5000 Series	Body of The Project	S5000	Tons (T)	-	-	Variable	Variable
M1 Screw	Across the whole project	M110	Millimeters (mm)	10	4	Variable	Variable
M2 Screw	Across the whole project	M28	Millimeters (mm)	8	7	Variable	Variable
M3 Screw	Across the whole project	M316	Millimeters (mm)	16	13	Variable	Variable
M3 Screw	Across the whole project	M330	Millimeters (mm)	30	8	Variable	Variable
M3 Screw	Across the whole project	M312	Millimeters (mm)	12	5	Variable	Variable
M3 Screw	Across the whole project	M320	Millimeters (mm)	20	9	Variable	Variable
Electric Cables	The Electrical Circuit	-	Centimeters (cm) or Meters (M)	-	undefined	-	
A4988 DRV8825 Extension Dual Driver Board	The Electrical Circuit (For Stepper Motor NEMA17)	DRV8825	Pieces	-	1	75	75
Arduino UNO R3	The Electrical Circuit	ABX00042	Pieces	-	1	500	500

L298 Dual H-Bridge Motor Driver (DC and Stepper Motors)	The Electrical Circuit	L298	Pieces	-	1	100	100
18650 Rechargeable 3.7V Battery	The Electrical Circuit	B18650	Voltage (V)	3.7	6	70	420
4 Cell Li-on Battery Holder 4×18650	The Electrical Circuit	B74600	Voltage (V)	(3.7x4) = (14.8)	1	35	35
2 Cell Li-on Battery Holder 2×18650	The Electrical Circuit	B74600	Voltage (V)	(3.7x4) = (7.4)	1	20	20
Bearing	Base	B822	Millimeters (mm)	(8 inner - 22 outer)	6	55	330
Lead Screw with Nut	Base	LN8500	Millimeters (mm) and Pitch (mm)	(8 x 500) / 2	2	200	400
Flexible Coupler	Base	C510	Millimeters (mm)	(5 to 10)	1	90	90
PVC Pipe	Base	PVC331	Millimeters (mm) (Length) and Inches (inch) (inner diameter)	33 / 1	1	Variable	Variable
PVC Pipe	Base	PVC33.5	Millimeters (mm) (Length) and Inches (inch) (inner diameter)	33 / 0.5	1	Variable	Variable
Stepper Motor (NEMA 17 - 3.6 Kg.cm)	Base	-	Pieces	-	1	520	520
Stepper Motor (NEMA 17 - 3.6 Kg.cm)	Middle Part (Belt)	-	Pieces	-	2	520	1040
Timing Pulley GT2	Middle Part (Belt)	TP36	Millimeters (mm) and Teeth	(5 Inner Diameter / 6 Width) and (36)	2	160	320

GT2 Timing Belt black	Middle Part	B2	Meters (M)	2	2	85	170
Micro Servo Motor	End-Effector (Paint Brush)	SG90	Pieces	-	2	85	170
DC Geared Motor Dual Shaft BO Motor-Straight	End-Effector (Fly Cutter)	-	Pieces	-	1	35	35
Bevel Gear	End-Effector (Fly Cutter)	BG2012	Pascals (PA) and Diameter Pitch (DP)	20 / 12	1	Variable	Variable
Bevel Gear	End-Effector (Fly Cutter)	BG2016	Pascals (PA) and Diameter Pitch (DP)	20 / 16	1	Variable	Variable
Ultrasonic Sensor Module	End-Effector (Fly Cutter)	-	Pieces	-	1	45	45

For justification of the choice of material (Aluminum Alloy 5000), refer to Appendix B.

13 Marketing Plan (4 P's)

13.1 Product

13.1.1 Robotic Arm

The robotic arm is a revolutionary solution designed to transform the recycling and reuse of steel from wind turbines, embodying the principles of the 3Rs (Reduce, Reuse, Recycle). Its primary function is to remove rusted surfaces and apply a protective coating to prevent further corrosion, enabling long-term storage and distribution of the steel. By focusing on steel, the robotic arm eliminates the need for dedicated machinery to recycle other materials found in wind turbines, such as fiberglass, resin, plastic, iron, cast iron, copper, and aluminum, which would be costly and exceed the budget, in comparison to the value these dedicated machinery provide, the cost is exceeds the value provided by the machines.

Product Features:

- Rust removal and protective coating application: The robotic arm employs advanced technology to efficiently remove rusted surfaces and apply a protective coating, ensuring the longevity and quality of the recycled steel.
- Extended storage and distribution capabilities: The protective coating applied by the robotic arm extends the storage life of the recycled steel, allowing for long-term storage and distribution without the risk of degradation.
- Reduced waste generation: By effectively recycling steel from wind turbines, the robotic arm significantly reduces waste generation, contributing to environmental sustainability.
- Elimination of dedicated machinery for other materials: The robotic arm eliminates the need for dedicated machinery to recycle other materials found in wind turbines, reducing costs, and simplifying the recycling process.

13.1.2 S235 & S355 Steel

According to an article from Elsevier,
“By 2050, global annual blade waste will reach 2.9 Mt, with 43 Mt of cumulative blade waste” since the wind turbines steel waste is rapidly increasing, the two types of steel S235 & S355 will be considered as our main product, since they can be deployed in a lot of fields, it can make our target market bigger, since the steel market are always in demand of more steel, these products will never find an issue to sell, here is an assessment of their applicability.

S235 Steel:

- S235 steel is a mild steel with a yield strength of 235 MPa. It is commonly used in general construction applications where strength and hardness are not critical factors.
- For the construction of reinforcing bars, structural beams, and roofing sheets, S235 steel may be sufficient if the load-bearing requirements are not too demanding.
- In the automotive industry, S235 steel can be used for non-structural components such as body panels and interior parts.
- For shipbuilding, S235 steel may be suitable for non-load-bearing structures and internal components.
- In renewable energy applications, S235 steel can be used for support structures that do not require high strength.

S355 Steel:

- S355 steel is a higher-strength steel with a yield strength of 355 MPa. It offers improved strength and durability compared to S235 steel.
- For construction applications involving heavier loads or more demanding structural requirements, S355 steel is a better choice than S235 steel.
- In the automotive industry, S355 steel can be used for structural components that require higher strength, such as chassis frames and suspension systems.
- For shipbuilding, S355 steel is suitable for load-bearing structures, decks, and hulls.
- In renewable energy applications, S355 steel can be used for wind turbine towers, solar panel frames, and other components that require high strength and durability.

Additional Applications:

Beyond the applications mentioned above, S235 and S355 steel can also be used in various other industries and applications, including:

- Machinery and equipment manufacturing
- Agricultural implements
- Railway construction
- Oil and gas pipelines
- Storage tanks and vessels
- Bridges and civil infrastructure
- Furniture and household appliances

13.2 Price

The cost of the robotic arm is justified by the savings it can generate through reduced waste and the ability to reuse steel for various purposes. The robotic arm eliminates the need for dedicated machinery to recycle other materials found in wind turbines, such as fiberglass, resin, plastic, iron, cast iron, copper, and aluminum, which would be expensive and exceed the budget.

13.3 Place

The robotic arm is designed to be used in industrial settings, particularly recycling facilities and factories that process steel from wind turbines. It can be integrated into existing production lines or installed as a standalone system. The robotic arm's compact size and flexibility allow it to be easily maneuvered and positioned within the workspace.
Promotion

13.4 Promotion

To promote the robotic arm and its benefits, various marketing strategies can be employed. These include:

- Creating a website and online presence to showcase the robotic arm's capabilities and advantages.

- Participating in industry trade shows and exhibitions to demonstrate the robotic arm and network with potential customers.
- Developing case studies and success stories from early adopters of the robotic arm to highlight its real-world impact.
- Collaborating with industry publications and media outlets to generate publicity and awareness about the robotic arm.

13.5 The 4 R's

As this project focuses on sustainability, we would further adapt product section by adding the 4's (Reduce, Reuse, Recycle, Redesign)

13.5.1 Reduce

According to a report from the National Renewable Energy Laboratory, "wind turbines are predominantly made of steel (66-79% of total turbine mass)." Reducing waste involves minimizing the amount of waste generated by optimizing the manufacturing process and reducing material consumption. While there are other materials present in wind turbines, such as fiberglass, resin, plastic, iron, cast iron, copper, and aluminum, creating dedicated machines to recycle these materials would exceed the budget and be impractical considering the end product. For instance, most wind turbines consist of only 11% to 16% resin or plastic, 17% iron or cast iron at most, 1% copper at most, and 0.2% copper at most (111). Therefore, the robotic arm focuses on reducing waste by removing the rusted surface and coating it with a protective coating to protect the material from rust. This allows for long-term storage and distribution of the steel without accumulating rust.

13.5.2 Reuses

Reusing the recycled steel from wind turbines involves finding new applications for the material. The robotic arm enables the reuse of steel by removing the rusted surface and applying a protective coating, making it suitable for various purposes. This reduces the demand for newly produced steel and promotes a circular economy.

13.5.3 Recycle

Recycling the steel from wind turbines involves breaking down the material and reprocessing it to create new products. The robotic arm facilitates the recycling process by removing the rusted surface and applying a protective coating, making the steel easier to process and reuse. This reduces the environmental impact associated with steel production and contributes to a sustainable future.

13.5.4 Redesign

Redesigning wind turbines to minimize waste and facilitate recycling is an important aspect of sustainability. By incorporating the principles of the 3Rs (Reduce, Reuse, Recycle) into the design phase, manufacturers can create wind turbines that generate less waste and are easier to recycle at the end of their lifespan. This contributes to a more sustainable wind energy industry.

14 Prototype Implementation

Our first step after finishing the assembly file was calculating the total cost of the standard parts, we needed to implement our prototype, such as the screws, bearings, motors and so on. After calculating these costs, we calculated the weight of the parts we designed, how much filament we needed and how much would it cost. After comparing several types of filaments into account, we chose to use PLA+ filament for the 3d printed parts due to its high quality and low cost, but even then, we had exceeded our expected budget therefore we had to edit the 3d parts to use less filament. Also, to reduce costs even further, we decided to implement only one conveyor belt and attach both end effectors to the same belt, which allowed us to save funds on additional motors, belts, and pulleys. After many adjustments, we compiled a list of the parts we needed to implement the prototype and so we started browsing several electronics stores and purchased the required components.

The following is a table showing the components and parts we purchased in the prototype:

Component	Properties	Quantity	Unit Cost	Total Cost
18650 Lithium Battery	3.7 V Dual Slot	6	70 EGP	420 EGP
Ultrasonic Sensor	Distance: 2 – 400 cm	1	65 EGP	65 EGP
Mini Geared DC Motor	90 +- 10 rpm	1	35 EGP	35 EGP
Arduino Uno	Programmable Microcontroller	1	500 EGP	500 EGP
Coupler	5 mm to 10 mm	1	90 EGP	90 EGP
Lead Screw with nut	8 mm x 500 mm	2	240 EGP	480 EGP
Timing Pulley GT2	36 teeth – 8mm inner diameter	2	160 EGP	320 EGP
GT2 Timing Belt	2 m	1	170 EGP	170 EGP
M3 Screws	30-20-16-12 mm	35	1.5 EGP	52.5 EGP
M2 Screws	8 mm	7	1.5 EGP	10.5 EGP
M1 Screws	10 mm	4	1.5 EGP	6 EGP

PLA Filament	3D Printing	2	1200 EGP/kg	2400 EGP
PVC Pipes	33 mm/ 1 inch 22 mm / 0.5 inch	3	45 EGP	135 EGP
Radial Bearing	22 mm outer 8 mm inner	6	55 EGP	330 EGP
Battery holders	2-battery holder 4-battery holder	2	20 EGP	40 EGP
Used Stepper Motor	NEMA 17	2	100 EGP	200 EGP
Servo Motor	SG90	2	85 EGP	170 EGP
L298N Motor Driver	DC Motor Driver	1	85 EGP	85 EGP
Stepper Motor Driver	Dual	1	80 EGP	80 EGP

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15 Individual Logbook

Individual Contributions Logbook				
Name	Seif Ayman Salama			
ID	202200639			
Milestone 1				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
Problem Identification	Introduced and Identified the Problem	29/01/2024	29/01/2024	1 day
Morphological Matrix	Made the Morphological Matrix and three combinations	30/01/2024	01/02/2024	3 days
PCC Analysis	Made PCC and justified choices	30/01/2024	01/02/2024	3 days
Selection	Selected the most suitable idea based on PCC and Morphological	30/01/2024	01/02/2024	3 days
Milestone 2				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
Inventor 3D Parts	Designed: Base Parts, Middle Parts, Top Part, PVC, belt clamp, and all three parts for brush end effector	20/02/2024	24/02/2024	5 days
Milestone 3				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
Inventor Assembly	Assembled Brush end effector and left side of the robotic arm as well as the Belt Clamp	22/03/2024	26/03/2024	5 days
Animation	Did the full animation on Inventor	29/03/2024	30/03/2024	2 days
Ideation (Final Version)	Redid the Ideation section from scratch to improve quality	30/03/2024	30/03/2024	1 day
Prototype Implementation	Responsible for Programming DC Motor and Stepper Motor as well as overseeing the 3D Printing Process	25/03/2024	01/04/2024	8 days

Individual Contributions Logbook				
Name	Feras Adel Abdelrahman			
ID	202201619			
Milestone 1				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
Ideation	Helping in gathering ideas for the project and alternatives / specifying theory of operations, advantages, and disadvantages of each idea	21 Jan 2024	15 Feb 2024	20 Days
Milestone 2				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
User needs and Requirements	Determining user needs by research and observing important factor that a robotic arm user would consider	20 Feb 2024	9 March 2024	19 Days
Design Constraints	Presenting important factors that we considered during the design process and obstacles we faced during the process using figures as demonstration	22 Feb 2024	5 March 2024	13 Days
Milestone 3				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
Bill of Material	Stating Each component used in the prototype or industrial version of the project. Research regarding which store offers better price for the component / the component's unit price / total price / quantity / position in the project /	14 March 2024	29 March 2024	16 Days
Presentation	A presentation documenting our process throughout the past milestones	12 March 2024	28 March 2024	17 Days

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Individual Contributions Logbook

Name	Malik Anas Bedawi Babiker
ID	202301110

Milestone 1

Tasks	Detailed Contribution	Start Date	End Date	Total Time
Literature Review	I researched the history of robotics in the renewable energy industry and have written the literature review.	30/01/2024	02/02/2024	4 days
Ideation	Assisted in brainstorming ideas	31/01/2024	31/01/2024	1 day

Milestone 2

Tasks	Detailed Contribution	Start Date	End Date	Total Time
Conceptual Free Hand Sketch	Sketched 2d drawings of our robotic arm concept and explained them.	18/02/2024	19/02/2024	2 days
3D Models	I worked and designed on the 3D parts required in order to assemble our robot.	20/02/2024	24/02/2024	5 days

Milestone 3

Tasks	Detailed Contribution	Start Date	End Date	Total Time
Robotic Arm Assembly	I have worked on assembling the robotic arm and ensured that all parts fit together and edited the 3d parts when necessary	22/03/2024	26/03/2024	5 days
2D Working Drawings	I created 2d working drawings of each of the parts, sub-assemblies, and main assembly.	29/03/2024	30/03/2024	2 days
Prototype implementation	I purchased the components from multiple electronic stores and described our implementation process in the report.	30/03/2024	31/03/2024	2 days
Report Conclusion	I wrote the conclusion where I summarized the main ideas of the report and made a comparison between our target requirements and our actual parameters.	31/03/2024	31/03/2024	1 day

Individual Contributions Logbook

Name	Omar Reda Mohamed Abdelsamad			
ID	202201648			
Milestone 1				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
MS Planner	I created the whole MS planner and assigned the tasks with deadlines for all three milestones	31-jan-24	17-feb-24	17 Days
Gant Chart	I created the whole gantt chart with the start and end dates and constantly edited the assigned dates and tasks when needed	29-jan-24	11-feb-24	13 days
Generate 3 Alternatives	I contributed to generated the ideas, mainly to one of them, the rest was done by my colleagues	21-jan-24	19-feb-24	3 weeks
Choosing Industry	I helped by choosing the main industry and my colleagues did the writing in made it possible	21-jan-24	17-feb-24	3 weeks
Milestone 2				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
User Needs and Requirements	After the person the task was assigned to wrote it, I fixed the rest according to the feedback of the doctor	20-feb-24	9-mar-24	3 weeks
Design Constraints and Factors	After the person the task was assigned to wrote it, I fixed the rest according to the feedback of the doctor	20-feb-24	10-mar-24	3 weeks
Detailed List of Electrical Components	I made the list from start to finish, seif helped me add a few parts since he was more involved with the assembly	20-feb-24	7-mar-24	3 weeks
Milestone 3				
Tasks	Detailed Contribution	Start Date	End Date	Total Time
Marketing Plan (4 P's)	I did the marketing plan from start to finish, under the guidance of the doctors and the positive feedback from my colleagues	14-mar-24	28-mar-24	2 weeks
Prototype Implementation	I helped a little in implementing the prototype, even though my contribution to this task was the least, I helped a little with getting the components and the 3d filament	13-mar-24	28-mar-24	3 weeks
Individual Logbook	This was not a task, the individual logbook is done by all the students in the project	30-mar-24	1-apr-24	2 days

16 Conclusion

In conclusion, our robotic arm has met the goals and requirements stated in the original problem statement. The robotic arm has provided an alternative means of refurbishing and utilizing waste metals without human intervention. Therefore, it has succeeded in automating this task and we predict that it will benefit the renewable energy industry greatly. The use of this robotic arm will save a lot of time, labor, and costs in the long term. The refurbishment of the wind blades will also reduce the waste produced from the generation of wind energy. Furthermore, not only can the robotic arm itself be mass produced and sold as a business product, but also the refurbished metal parts resulting from the process of refurbishment can be utilized in many business opportunities, such as reshaping the refurbished metal scraps to be utilized for different purposes including reusing in construction, manufacturing new appliances and so on.

After brainstorming multiple ideas, we used the PCC and the morphological chart methods in order to choose the most suitable idea that can meet our requirements, so through this selection process, we chose a dual robotic arm with a paint brush and a fly cutter as its end effectors in addition to the mechanisms that will drive each of the end effectors and the mechanisms that will provide multiple degrees of freedom to our robotic arm. The next step was drawing conceptual hand sketches to apply in the Autodesk Inventor software. After drafting the design, we started drawing the 3D parts and assembling them. Finally, after the robotic arm assembly was done, we proceeded to create an actual prototype of our design through 3D printing and woodwork. Throughout the implementation process, we drafted a BoM (Bill of Materials) table, and we continuously updated the table until we completed the implementation process. Creating a prototype of the design was necessary to test our product and how it would work in real-life circumstances. The last step was creating a marketing plan utilizing the four Ps to make sure that the product would produce net profit.

In the beginning of the design process, we set some target specifications that we aimed to commit to as much as possible, but as the process went on, many factors came into consideration, and we had to adjust accordingly. The following table lists the specified requirements against the actual values used in this project.

Specifications	Target	Actual
Total cost	3000 EGP or less	About 4700 EGP
Automation	Automated	Remote controlled
Degrees of freedom	At least 4	5
Power Source	Solar Energy	Lithium Batteries
Fly Cutter Speed	1440 rpm	100 rpm
Integrated Sensors	Ultrasonic sensor	Ultrasonic sensor
Max height	1 meter	60 cm
Coating End - Effector	Spray Nozzle	Paint Brush
Modularity	Yes	N/A
Precision	High	Moderate
Robotic Arm Type	Articulated	Cartesian

16.1 Future Improvements

- Replacing the paint brush end effector with a spray nozzle as it is more efficient, effective and provides more precision than the paint brush.

- Adding a conveyer belt at the robot's base to provide an additional degree of freedom along the robot's width.

- Replacing the DC geared motor with higher quality motors such as stepper motors to increase speed and precision.

- To make the robotic arm more environmentally friendly, replace the lithium batteries with a renewable energy source such as solar or wind energy sources.

- Program the microcontroller connected to the robotic arm and add more sensors to make the robotic arm automated, so it will not need human intervention.

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18 Appendices

Appendix A

Learning Outcomes:

1. Investigate and define a problem to identify constraints and criteria:

   Thorough research was conducted to understand challenges in the renewable energy industry, leading to the identification of the need for efficient waste metal refurbishment. Constraints such as sustainability, health and safety, commercial viability, and industry standards were carefully considered to frame the problem effectively.

2. Understand stakeholders' requirements with a focus on product/process life-cycle:

   By researching the market needs and similar robots, we were able to determine what the customer is willing to buy. Through this, we enhanced the product to suit the market's needs and demands.

3. Apply a systems approach to solve problems with innovative solutions:

   Adopting methodologies like PCC analysis and morphological matrix helped us select the most ideal and innovative approach. The resulting robotic arm solution featured two precise end effectors (fly cutter and paint brush), and mechanisms, integrating a full mechatronics system.

4. Ensure fitness for purpose for all aspects of the solution:

   By writing a BOM and implementing the prototype, we made sure the robotic arm was functional. A sustainable material was selected for the robot as well as a low-maintenance end effector (fly cutter).

5. Demonstrate use of 2D and 3D CAD software:

   By drawing a free hand sketch, then designing 3D parts on Autodesk Inventor and assembling them, we were able to demonstrate our ability to do 2D and 3D CAD Parts. Finally, we did 2D working drawings, which could be used in the manufacturing process of the design.

Appendix B

For our final robotic arm design, we chose to use the aluminum alloy 5000 series in building our product for several reasons. One of the unique properties of aluminum is that it is very lightweight, versatile and is a remarkably high strength material, moreover due to its low melting point and malleability it can be easily reshaped to fit many purposes. The main reason we chose aluminum alloy as the main material for our robot is that it is considered one of the most sustainable raw materials and can be recycled without losing quality or any of its physical properties. (Duration Windows, n.d.)

Appendix C

A. External Forces Acting on the Part

The external forces acting on the parts, such as pressure, heat, and humidity, were not considered in this study as they were beyond its scope. This means that the simulations did not account for the effects of these environmental factors on the product's performance and behavior.

B. Deformation on Parts

In the context of mass production, achieving zero or minimal deformation in parts may not be practical or cost-effective. While advanced machinery can reduce deformation, it would significantly increase production costs beyond the allocated budget. Therefore, a balance must be struck between minimizing deformation and maintaining affordability.

C. The Factor of Safety on Parts

To ensure the product's reliability and durability during mass production, stress analysis simulations and Finite Element Analysis (FEA) are crucial. These analyses help determine if the materials selected for parts subjected to high loads can withstand continuous or excessive pressure without yielding, fracturing, or bending. Additionally, Von-Misses analysis should be performed on critical components, such as the gearbox, to assess the material's resistance to fracture or yield under various load conditions.

Appendix D

Additional Details:

Pressure Analysis: Conducting pressure analysis simulations would involve applying different pressure levels to the parts to evaluate their resistance to deformation or failure. This would provide insights into the product's performance under various pressure conditions, such as those encountered during transportation or handling.

Heat Analysis: Heat analysis simulations would assess the product's response to different temperature ranges. This is particularly important for parts that may be exposed to extreme temperatures during use or storage. The simulations would help identify potential material degradation or performance issues due to heat exposure.

Humidity Analysis: Humidity analysis simulations would evaluate the product's behavior in humid environments. This is crucial for parts that may be susceptible to corrosion. The simulations would help determine the product's suitability for use in humid climates or conditions.

Deformation Analysis: Advanced deformation analysis techniques, such as Computational Fluid Dynamics (CFD) simulations, could be employed to precisely predict the deformation behavior of parts under various load conditions. This would enable engineers to optimize the design and material selection to minimize deformation within acceptable limits.

The factor of Safety Calculation: The factor of safety is a critical parameter used in engineering design to ensure that components can withstand loads beyond their expected operating conditions. It is calculated by dividing the ultimate strength of the material by the maximum expected load. A higher factor of safety indicates a more robust design with a lower risk of failure.

Appendix E

Relevant Links:
Inventor Assembly and Parts
2D Working Drawings
Gantt Chart
Animation
PPT

Appendix F

Peer Grading						
Grades		Omar	Seif	Feras	Malik	Average
	Omar	…	2	3	2	2.33
	Seif	3	…	3	3	3
	Feras	3	2	…	2	2.33
	Malik	3	3	3	…	3

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Feras Adel / ID: 202201619
Seif Salama / ID: 202200639
Malik Anas / ID: 202301110