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# Design & Calculation of Aquatic clean-up Bot (ARASAG)

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**Abstract- In recent years, the problem of river garbage pollution has become increasingly serious. The traditional manual dredging method has low cleaning efficiency and cleanliness, high labor costs, and safety hazards for personnel. There is an urgent need for innovative systems to protect freshwater ecology and river systems. This paper proposes a design scheme for an automated and efficient river cleaning machine, aiming to increase the total amount of floating pollutants collected autonomously, enhance the efficiency of river environment regular management, reduce costs by replacing manual labor with machines, and achieve the management goals of "clean water, clear river, clear taste, and beautiful scenery." Based on the requirements of the topic, this paper proposes and designs a high-automation river cleaning machine through theoretical, design, and modeling analysis. It mainly consists of an overall platform, interception system, conveyor system, sensor-equipped mechanical arm, garbage bin system, power system, and control system. Through scheme evaluation and design calculation, the buoyancy of the overall platform is optimized. The interception system is realized using a double-sided blocking support, and the conveyor system is used to collect floating pollutants in small areas of the river. The mechanical arm with sensors is used to intercept and collect large areas of floating pollutants in the river. After fully considering efficient waste compression and convenient unloading, the garbage bin system of the machine is designed. This paper studies and calculates each key component of the devices mentioned above, completes the corresponding main design and verification, and provides some guidance for the design and application of a highly automated river cleaning machine. This plays an important role in realizing the full automation of river cleaning machines to replace traditional manual work and reduce costs and has a positive significance for promoting the modernization and intelligent development of the river environmental protection industry.**

**Keywords: River channel cleaning machine; structural design; interception system.**

## I. INTRODUCTION

The escalating accumulation of marine debris, encompassing plastics, discarded materials, and other pollutants, poses a significant threat to aquatic ecosystems, necessitating innovative and sustainable solutions for its effective removal and management. Innovative technologies for cleaning waterways have emerged, categorized into passive systems (like booms and barriers) and active systems (such as autonomous vessels and drones). Notable advancements include autonomous cleanup vessels that utilize sensors and AI for independent navigation and shoreline robots that collect litter efficiently. Drones have transformed pollution assessment by providing real-time data for targeted cleanup. Additionally, bioengineering is being explored for sustainable solutions to break down pollutants. Let's dive in and look at current projects on River-based trash cleaning systems worldwide. They can be classified based on their operational mechanisms and energy sources. The classification difference line is blurry, often reflecting how they're deployed and how manufacturers position them, not a strict technical rule. Here's an overview of the primary categories:

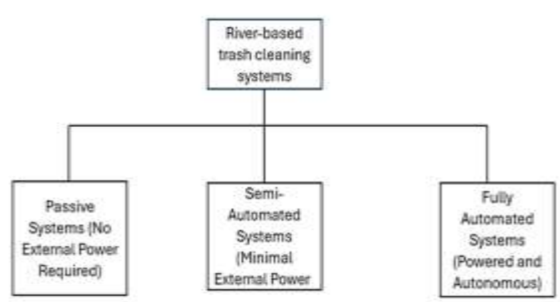



Figure 1: Classification of River-based Trash Cleaning System

**1. Passive Systems (No External Power Required):**

These systems utilize the river's natural current to collect debris without the need for external energy sources. For example:

**Trash Racks:** Fixed metal screens installed perpendicular to water flow to intercept large debris. Example: A trash rack is being installed in the Ghaggar River near Majri Chowk bridge in Panchkula, India, to intercept and contain solid waste flowing through the river.

**Floating Barriers and Booms**: Structures that guide floating trash to collection points. Example: Alpha MERS in India has deployed floating barriers in eight cities, capturing approximately 2,400 tons of plastic in their first year of operation.

**TrashTrawl:** A system using high-speed booms to guide waste into a collector, powered solely by the river's current. Example: PortBin's TrashTrawl operates in rivers with currents up to 3 knots, collecting waste in large mesh sacks without external energy.

Figure 1-1 Passive Systems

1- Trash Racks; 2- Floating Barriers and Booms; 3- TrashTrawl;

**2. Semi-Automated Systems (Minimal External Power)**

These systems combine passive collection methods with minimal power sources to enhance efficiency. For example:

**Mr. Trash Wheel:** A water wheel-powered trash interceptor that uses solar panels and the river's current to operate a conveyor belt, depositing trash into onboard dumpsters. Example: Installed in Baltimore's Inner Harbor

**Bandalong Litter Trap:** A floating trap that uses the river's current to guide debris into a containment area. Example: Deployed in the Anacostia River in Washington, D.C., capturing litter without impeding wildlife movement.

Figure 1-2 Semi-Automated Systems

1- Mr. Trash Wheel; 2- Bandalong Litter Trap;

**3. Fully Automated Systems (Powered and Autonomous):**

These systems are equipped with advanced technologies, including sensors and automated mechanisms, requiring external power sources. For example:

**The Interceptor:** A solar-powered barge with a conveyor belt system that autonomously collects and stores trash.Example: Developed by The Ocean Cleanup, Interceptors are operational in countries like Indonesia, Malaysia, and the Dominican Republic.

**Smart Trash Boom:** A boom system that can open and close to allow vessel passage, using sensors to detect approaching boats.Example: Riverine's Smart Trash Boom is being prepared for demonstration on the Delaware River.

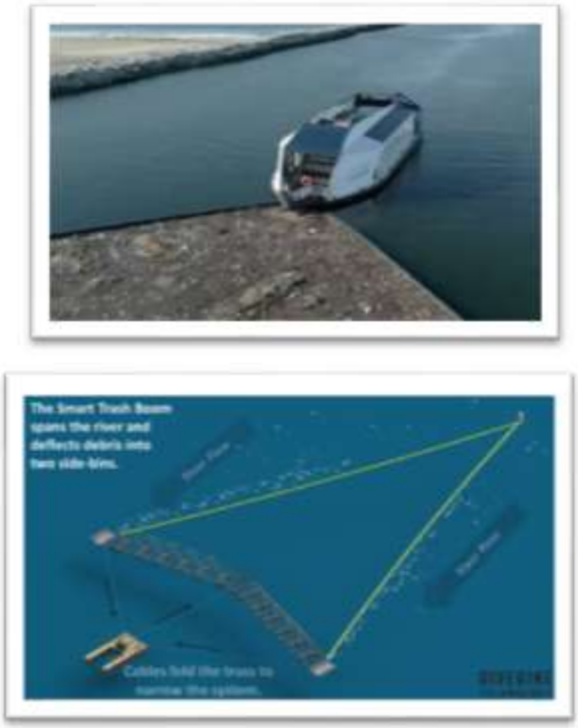



Figure 1-3 Fully Automated Systems
1- The Interceptor; 2- Smart Trash Boom.

Based on all the previous methods and knowledge, The Primary goal is to make a reliable and efficient Autonomous River-based trash-cleaning system device capable of thriving in diverse aquatic conditions with Heavy floating debris, Such as Tree trunks and branches, Tires and industrial rubber, bundled garbage bags, and Dead animals (in some river systems) Here's what I'm aiming to achieve:

Figure 1-4 Remains of Tree, Trunks

**Building the Base:** This involves designing and developing a stable and durable platform that can not only float effectively but also move smoothly and reliably across the surface of the river. The structure will be engineered using robust and long-lasting materials capable of withstanding constant exposure to water, varying weather conditions, and mechanical stresses, ensuring both buoyancy and operational longevity in challenging environments.

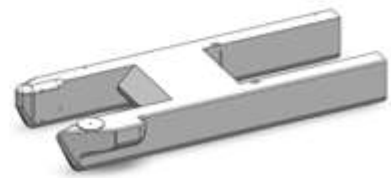


Figure 1-5 Platform

**Guiding the Garbage:** Creating a system to gently push the floating trash towards where it can be collected.

Figure 1-6 Barrier

**The Collection Crew:** Developing a two-pronged approach to grab the debris:
-A conveyor belt to continuously lift the general waste out of the water and into a container.

Figure 1-7 conveyor belt
-A robotic arm with a 'brain' (thanks to a camera and sensors) that can spot and grab bigger or tangled pieces of trash more carefully.

Figure 1-8 Robotic Hand

**Garbage Bin:** Designing a good-sized bin on board to store all the collected rubbish until it can be appropriately disposed of automatically.

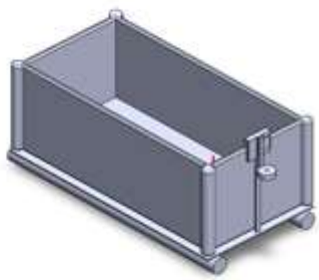


Figure 1-9 Garbage bin

**Powering up sensors and control systems Sustainably:** Using solar power with batteries to keep the machine running clean and for longer periods without needing to plug in.

**Calculation:** In this thesis, our primary focus will be on the mechanical analysis and design aspects of the conveyor belt system. The study will begin with the calculation of the power required to operate the conveyor belt efficiently, taking into consideration factors such as load capacity, belt speed, and frictional forces. Based on these calculations, we will proceed to select a suitable electric motor that meets the operational demands and ensures reliable performance. Following motor selection, we will carry out a comprehensive analysis of the gear transmission system, which includes determining the appropriate gear ratios and evaluating the mechanical efficiency and torque transmission capabilities. . In addition to this, the design and structural analysis of the rotating shafts and supporting bearings will be conducted to ensure they can withstand the applied loads and operate safely over prolonged periods.

**FEA:** Finally, to validate the structural integrity and performance of the key components, a Finite Element Analysis (FEA) will be performed. This simulation will help in identifying stress concentrations, potential failure points, and areas requiring design optimization.

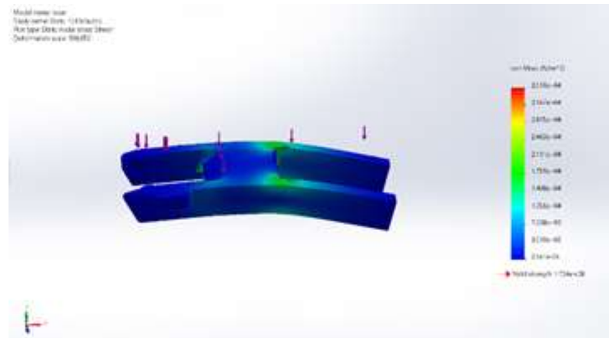


Figure 1-8 FEA

This thesis is all about figuring out the best way to put this machine to work in real rivers. Ultimately, I hope this research can contribute to cleaner rivers, healthier ecosystems, and inspire more ways to look after the environment. Detailed design parameters such as material selection, dimensions, and safety factors will be considered in this process. Lastly, A collaborative approach involving governments, NGOs, and the private sector, along with community engagement and education, is essential for effectively addressing water pollution and promoting responsible waste management to protect aquatic ecosystems. Innovative funding models and public-private partnerships are also crucial in driving these technologies forward, ensuring that the necessary resources are allocated to implement practical solutions on a larger scale.

## II. LITERATURE REVIEW

**Current Research:**

Existing research highlights a variety of approaches to river garbage cleaning, each with its strengths and limitations. Floating garbage, often accumulating in substantial quantities, negatively impacts water quality and endangers water conservation infrastructure, causing economic harm to agriculture, aquatic life, and tourism [1]. Currently, we have a range of technologies for managing river waste, from simple manual methods to advanced automated systems, each tailored to meet the specific challenges of different river environments. [2]. Sweepers can reduce damage by real-scale experiments [3]. Manual collection, while labor-intensive and costly, often proves necessary for removing large or awkwardly shaped debris that automated systems cannot handle. Automated systems, on the other hand, offer the potential for continuous operation and higher collection rates, but they typically require significant capital investment and ongoing maintenance. For instance, one study investigates the conceptual design of a comprehensive river-cleaning system capable of extracting both floating and suspended litter particles from watercourses, while also withstanding fluctuations in flow. Static and dynamic systems have been categorized to distinguish their effectiveness. The development of effective and environmentally benign methods for removing garbage from rivers is essential for safeguarding water resources and protecting aquatic life [4]. Various factors, including the type and density of the debris, the flow rate of the river, and the presence of obstacles or vegetation influence the performance of these devices.

**Studies on Different Components:**

- **Studies on Aquatic-Bots:**

With floating waste increasingly polluting aquatic environments, researchers have proposed various innovative solutions to address the challenge through automated cleanup machines. Hidayat (2021) laid the groundwork with a modular garbage collection design using conveyor belts and scooping arms, which supports early-stage calculations like load distribution, motor torque, and structural layout [5]. Building on this, Othman (2020) introduced an automated trash collector featuring power estimation, motor specification, and obstacle detection sensors—key elements for developing energy-efficient and autonomous bots. In 2019, Ruman examined the use of Arduino technology for cleaning marine surfaces. The study emphasized GPS navigation and real-time maneuverability, giving us insights into speed, motor selection, and path planning for improved efficiency.[7]. On the advanced end, Koskinopoulou (2021) proposed a vision-based categorization system for robotic waste sorting, which, although developed for industrial use, presents a valuable direction for integrating AI-based detection in future aquatic bots[8]. Together, these studies emphasize the importance of balancing mechanical simplicity, functional reliability, and energy efficiency. The integration of modular mechanical design, stable propulsion, sensor-based control, and AI-enhanced sorting forms a comprehensive foundation for designing and calculating an effective aquatic cleanup bot.

- **Studies on Conveyor belt:**

Conveyor belts are vital components in automated systems like aquatic cleanup bots that collect and transport floating debris. Jakubovičová (2021) notes that modern conveyor systems prioritize smart design and material choice to enhance efficiency, reduce friction, and adapt to changing loads which is really essential for aquatic environments where debris size and weight can vary.[9]. Tupkar (2024) highlighted the need the selection of materials that balance strength, flexibility, corrosion resistance, and cost-effectiveness, especially for conveyors handling water and abrasive waste.[10]. They also point out critical design parameters such as belt speed, tension, and load capacity, all essential for calculating and ensuring the reliable mechanical operation of the bot's conveyor system. Together, these studies provide a strong foundation for designing a durable, efficient, and corrosion-resistant conveyor subsystem that enables the aquatic cleanup bot to effectively collect and transport trash in challenging wet environments.

- **Studies on Robotic Hands:**

The development of six-axis robotic arms has greatly influenced automation in tasks requiring precision and flexibility, and these advancements are highly relevant to the design of a robotic hand for a garbage-cleaning machine. Bejo (2009) demonstrated the feasibility of implementing a 6-axis robotic arm controller using a low-cost microcontroller, which supports the creation of affordable solutions for real-world waste management applications [11]. Sahu (2017) conducted vibration analysis using FEA, highlighting the importance of structural stability in robotic systems, especially those operating in uneven or harsh environments like garbage collection sites [12].

Talli and Meti (2020) utilized robot visualization software to simulate and optimize robotic arm movements, a method useful for testing waste-handling strategies virtually before physical deployment [13]. Teja Priyanka (2024) focused on the design and actuator selection for six-axis arms in industrial settings, offering a framework for adapting similar designs to manipulate and sort waste with precision[14]. Tung (2023) developed a robot prototype, focusing on early testing and real-world application to create a robotic hand that might be helpful to handle various types of debris.[15]. Together, these studies provide a foundation for integrating low-cost, durable, and efficient robotic hand systems into autonomous garbage-cleaning machines.

- **Studies on Solar Panel:**

Several studies emphasize the viability of integrating solar panel systems into autonomous machinery, supporting the use of solar power for automated garbage-cleaning devices. In 2016, Kumar highlighted key design principles for solar energy systems, focusing on essential factors like panel orientation, sunlight availability, and storage, which are vital for outdoor autonomous machines.. [16]. Maka and Alabid (2022) emphasized the role of solar energy in sustainable development, suggesting its relevance for public service applications such as waste management [17]. Sarmah (2023) explored how different weather conditions affect solar panel performance, highlighting factors that influence energy availability for may many different devices. [18]. Thanh (2019) showed the advantages of integrating rooftop solar systems with battery storage which will help for the consistent performance during variable sunlight.[19]. Together, these studies support the integration of solar panels with battery systems into autonomous waste-cleaning machines to enhance energy efficiency, operational independence, and sustainability.

- **Studies on Catamaran:**

Research on catamaran platforms offers valuable insights for integrating such designs into autonomous garbage-cleaning machines, particularly for operations on water surfaces. Julianto et al. (2020) explored the hydrodynamic and structural characteristics of catamarans, emphasizing their stability and efficient load distribution—key for supporting machinery and waste collection units [20]. Lee (2007) explored the development of a small catamaran, emphasizing its maneuverability and effectiveness for operations in confined spaces, making it suitable for urban waterways.[21]. Li (2023) investigated the stability of a catamaran with an underwater camera and found it maintained balance despite the added equipment, which is really important for the sensor based autonomous systems[22]. Mandru and Pacuraru (2020) conducted experimental studies on hydrodynamics, confirming the catamaran's low resistance and smooth motion, which enhance energy efficiency, especially when powered by solar systems[23]. Wang et al. (2022) introduced a catamaran with shock-absorbing and energy-saving suspension features, offering further potential for sustainable, durable, and low-impact designs[24]. Collectively, these studies support the use of catamaran platforms for floating automated garbage cleaners due to their stability, adaptability, and energy-efficient structure.

Despite advancements in river garbage cleaning technology, several gaps remain in the literature, particularly concerning the design and optimization of integrated systems that combine multiple collection methods. The scalability of advanced removal systems is limited, often remaining confined to laboratory or small-scale applications [25]. Many existing designs worldwide is struggling to adapt to the diverse types of aquatic environment with diverse debris, from large logs to unwieldy plastic items. [26]. Removing Plastic Waste from Rivers: A Prototype-Scale Experimental Study on a Novel River-Cleaning Concept.

Furthermore, the long-term sustainability of these systems, including their energy consumption, maintenance requirements, and environmental impact, is often overlooked. The current research offers us on how to best place and operate collection devices to ensure they work without harming river ecosystems[27]. It is visible that there’s growing interest in using Automated robots for waste management to ease the workload for workers and improve efficiency. [28].

**Design Content of this Project**

A project like Ocean Cleanup has inspired me to make an effort to clean the aquatic environment [29]. My project will be inspired by the currently ongoing similar project all around the world. The project will try to integrate sustainable energy sources [30]such as solar power, which is a promising avenue for reducing the environmental footprint of river garbage collection systems.

**Conclusion**

In conclusion, the escalating problem of marine debris demands comprehensive strategies that combine technological advancements, collaborative efforts, and public engagement to protect aquatic ecosystems. By supporting innovative research and funding models, we can promote the development and implementation of efficient water purification solutions to ensure the integrity of our aquatic environment for future generations.

## III. RESEARCH DESIGN

**Methodology**

- **The Process Flow of The Project**

The methodology of this thesis, focusing on the development of the Aquatic Clean-up Bot (ARASAC), commenced with a thorough identification of the problems related to aquatic environment clean-up. This was followed by the design of a model for the ARASAC system.

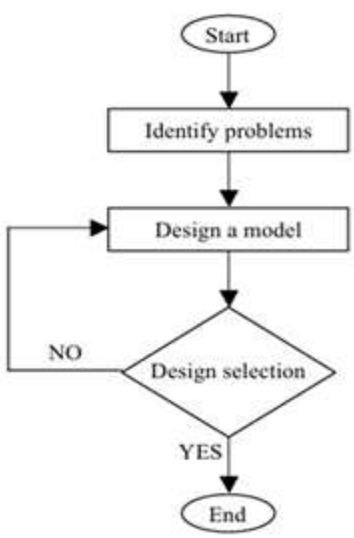



Figure 3-1: Flowchart of the design process

A crucial step in the process flow involved a design selection phase, where different design options were evaluated. If the design did not meet the required criteria (NO in the flowchart), the process returned to the design model stage for further refinement. Once a satisfactory design was achieved (YES in the flowchart), the project proceeded to the subsequent phases, including implementation, testing, and evaluation, culminating in the final product.

**Product Configuration**

The general shape, overall dimensions, and component specifications are determined during the configuration design stage. Actual measurements and measurement errors are addressed in the parametric design stage. Components can be classified into three main categories: standard parts, special-purpose parts, and standard assemblies. Standard parts are widely produced components, often manufactured in volumes reaching millions of units. Their specifications, including manufacturing materials, weight, and dimensions, are consistent across production. In contrast, special-purpose parts are produced for specific functions and are usually used as subsidiary components.

| Components | Quantity (items) |
|---|---|
| Barrier | 3 |
| Robotic Arm | 8 |
| Boat | 2 |
| Angular Mounting Conveyor Belt | 10 |
| Dustbin | 2 |
| Camera, Sensor | 3 |
| stairs | 1 |

Figure 3-2: List of items

**Concept Selection**

Where I come from the rivers are filled with large obstacles, I wanted to design this system keeping that in mind. By referring to the design improvements discussed earlier, the selection of the concept will focus on six main criteria:

**Barrier System for Garbage Control:** A barrier mechanism is installed to prevent garbage from flowing uncontrollably, ensuring efficient collection and minimizing environmental spread.

**Robotic Arms for Large Object Removal:** Robotic hands are integrated into the machine to automatically detect and remove large obstacles, such as wooden logs, which could block or damage the system.

**Automatic Garbage Bin Direction:** When the garbage bin reaches its full capacity, the machine automatically redirects the bin or triggers a notification system to ensure continuous operation without manual monitoring.

**Single-Operator Functionality:** The machine is designed for ease of use, requiring only one operator to manage and control its functions, thereby reducing workforce needs.

**Eco-Friendly Mechanical System:** The machine operates without motors or batteries. Instead, it uses the rotation of wheels to power the internal mechanisms, making it highly environmentally friendly and energy efficient.

**Low Maintenance and Easy Part Replacement:** The design avoids complex and specialized parts, reducing maintenance efforts and costs.

**Block Diagram**

The block diagram illustrates the core components and operational flow of the ARASAC system. The methodology centers around the design and functionality of this robotic system, which is composed of four key elements working in concert:

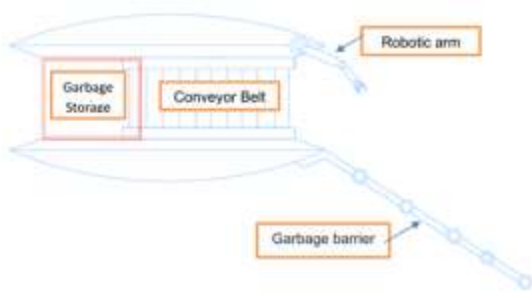



Figure 3-3: System Block Diagram.

The process flow, as depicted in the block diagram, involves the robotic arm actively collecting debris, transferring it to the conveyor belt, which then moves the waste to the garbage storage. The garbage barrier enhances this process by channeling floating debris effectively. The methodology of your thesis would detail each of these stages, including the design considerations, the control systems, and the testing procedures used to evaluate the performance of each component and the integrated system. Furthermore, the thesis would likely explore the interaction and synchronization of these components to ensure optimal waste collection and storage. The efficiency of the ARASAC system is directly tied to the effective operation of each of these components and their seamless integration.

**Final Design**

- Total Design

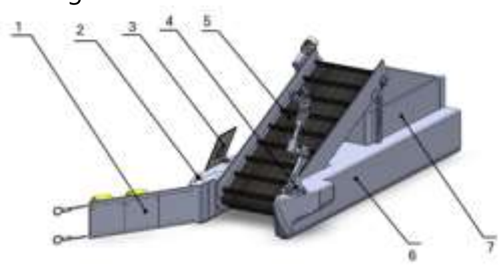



Figure 3-4 Final Design

1-Barrier System; 2-Camera; 3-Solar system; 4-Conveyorbelt System; 5-robotic Hand; 6-Platform; 7-Garbage Bin

**1. Barrier System:** Positioned at the front of the robot, the garbage barrier is designed to funnel and direct floating debris towards the robotic arm's collection area. This barrier increases the robot's efficiency by guiding waste into the collection zone. The design of the barrier, its shape, and the materials used are important aspects of the overall system design.

**2. Camera:** The camera system is on the left side of the "Barrier System," suggesting it's strategically positioned to monitor the incoming debris and the collection area. It likely plays a crucial role in enabling the robotic arm to accurately identify and collect waste or in navigating and monitoring the operational environment overall.

**3. Solar System:** “Solar system’’ visually appears to be a flat, rectangular panel located on the upper surface of the platform, directly behind the camera system. This placement maximizes exposure to sunlight. The "Solar system" is designed to harvest solar energy, which would be used to power the various components of the project, contributing to its energy efficiency and potentially extending its operational duration in remote or off-grid environments.

**4.Robotic Arm:** This component serves as the primary interface for interacting with the aquatic environment. The arm is designed for precise manipulation, enabling the robot to reach and collect debris of varying sizes and shapes. The methodology likely involves specifying the arm's degrees of freedom, reach, payload capacity, and the types of end-effectors (grippers or collection tools) used. The design and control algorithms for the robotic arm are crucial aspects of the thesis.

**5. Conveyor Belt:** Once the robotic arm has collected debris, it is transferred to a conveyor belt system. This belt continuously moves the collected waste towards the storage unit. The methodology would likely address the design of the conveyor system, including belt material, speed control, and the mechanism for transferring waste from the arm to the belt efficiently.

**6. Platform:** In the 3D design, the "Platform" appears to be the robot's main structural base or chassis, providing the foundation for all other components. It supports the Conveyor belt System, Conveyor belts are vital components in automated systems like aquatic cleanup bots that collect and transport floating debris. Jakubovičová et al. (2021) highlight how modern conveyor systems emphasize advanced mechanical design and material selection to optimize efficiency, reduce friction, and handle variable loading conditions—key factors for aquatic environments where debris size and weight can fluctuate.

Tupkar et al. (2024) further stress the importance of choosing materials that balance strength, flexibility, corrosion resistance, and cost-effectiveness, which is especially crucial for conveyors exposed to water and abrasive waste. They also point out critical design parameters such as belt speed, tension, and load capacity, all essential for calculating and ensuring the reliable mechanical operation of the bot’s conveyor system. Together, these studies provide a strong foundation for designing a durable, efficient, and corrosion-resistant conveyor subsystem that enables the aquatic cleanup bot to effectively collect and transport trash in challenging wet environments.and framework for the entire debris collection mechanism to operate effectively. Its robust design is crucial to withstand the operational stresses and to house all the integrated systems securely.

**7. Garbage Storage:** The conveyor belt deposits the collected garbage into a designated storage unit within the ARASAC. The capacity and design of this storage are important considerations. The methodology would likely detail the storage volume, the materials used, and any mechanisms for compacting or processing the waste to maximize storage

While not explicitly depicted in the visible parts of the 3D design, a sophisticated Control System forms the intelligent core of the entire garbage collection robot. This central processing unit orchestrates the functions of all integrated components, receiving inputs from the Camera System for visual data, managing power distribution from the Solar System, dictating the movement and speed of the Conveyor Belt System, and precisely coordinating the actions of the Robotic Hand for efficient debris collection.Crucially, an array of Sensors are seamlessly integrated throughout the design, even if largely hidden from view.

These sensors provide vital real-time data to the control system. For instance, the camera system itself acts as a visual sensor, while additional sensors are undoubtedly linked to the conveyor belt to monitor its operation and prevent jams, and to the robotic hand to ensure accurate grasping and manipulation of debris. Furthermore, a visible sensor associated with the Garbage Bin likely monitors its fill level, preventing overfilling and signaling when the bin requires emptying. Together, the control system and its network of sensors ensure autonomous, efficient, and safe operation of the robot, adapting to varying conditions and optimizing the debris collection process.

**Barrier System**

This is the assembly picture of the whole barrier system

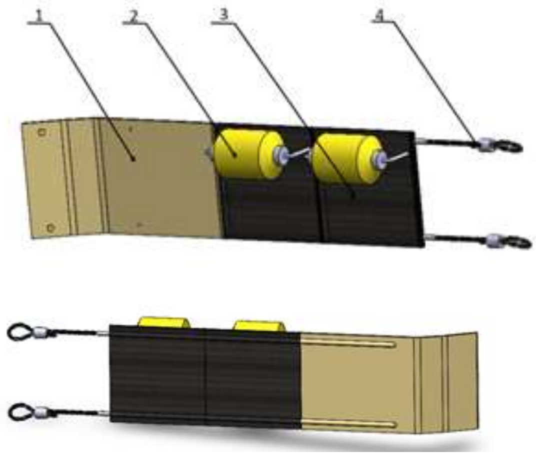



Figure 3-5 Barrier system
Mounted Barrier; 2- Barrier Floats (Drums/Booms); 3-Plastic Barrier; 4-Rope;

1.The Strong Barrier Connected to the Floating Dock/Boat

This component acts as a robust interface, transferring the significant tensile forces from the anchoring rope to the floating dock or boat. Its structural integrity and the method of connection are paramount for the overall stability and security of the entire river cleaning system.

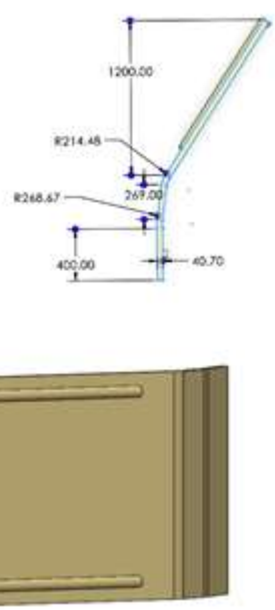



Figure 3-6 Barrier 2
1- Barrier 2 detailed view; 2- Barrier 2

**Purpose of the Strong Barrier**

The strong barrier serves several critical functions:

- **Primary Anchorage Point on the Floating Dock/Boat:** It acts as the designated and reinforced location on the floating dock or boat where the anchoring rope is securely attached. This point needs to be capable of withstanding the substantial and dynamic tensile loads exerted by the rope, which in turn are influenced by the river current and the accumulated debris against the main barrier system.
- **Load Distribution to the Floating Dock/Boat Structure:** The strong barrier is designed to distribute the concentrated load from the rope connection over a larger area of the floating dock or boat's structure. This prevents localized stress concentrations that could potentially damage the dock or boat.
- **Secure Attachment Mechanism:** It provides a reliable and robust mechanism, likely involving screws or bolts, to firmly attach the barrier structure to the floating dock or boat. This connection must remain secure and stable over prolonged use in a potentially turbulent aquatic environment.
- **Interface for the Rope Connection:** The strong barrier incorporates a durable and appropriately designed interface for attaching the rope. This could involve a strong eye bolt, a shackle attachment point, or another robust fitting that can withstand the continuous pull of the rope without failure or excessive wear.
- **Potential for Load Adjustment/Release:** Depending on the overall system design and operational requirements, the strong barrier might also incorporate features that allow for some level of adjustment in the rope's tension or a mechanism for quick release if necessary (e.g., during extreme weather events or for maintenance).
- **Material Requirements:** Must possess high tensile strength, excellent corrosion resistance, and good durability to withstand the aquatic environment and potential impacts.
- **Potential Materials:** Marine-grade stainless steel, high-strength marine-grade aluminum alloys, and potentially galvanized steel (for

freshwater). Fiber-reinforced composites are also a possibility.

**2.The Barrier Connected to Barrier Floats(Drums/Booms)**

This component forms the primary physical obstruction within the river, directly intercepting and retaining the floating garbage. It is designed to be connected along its length to a series of barrier floats, ensuring buoyancy and maintaining its position on the water's surface.

**Purpose of the Barrier**

1. **Debris Interception and Containment:** The primary goal of the barrier is to create a physical impediment to the flow of floating garbage. As the river current carries debris towards the system, the barrier acts as a net or screen, preventing the garbage from passing through. This allows the subsequent components, such as the conveyor belt and robotic arm, to collect and remove the accumulated waste.
2. **Surface Level Operation:** By being connected to floats, the barrier is designed to remain at or just below the water's surface. This ensures effective interception of floating debris, which is typically concentrated at the surface due to buoyancy.
3. **Flexibility and Adaptability:** The barrier needs to be flexible enough to conform to the natural undulations of the water surface and potential minor variations in river width or flow patterns. This ensures continuous and effective blockage of debris.
4. **Connection Interface for Floats:** The design must incorporate a reliable and durable mechanism for attachment to the barrier floats. This connection needs to withstand the forces exerted by the collected debris and the movement of the water.
5. **Material Requirements:** Should be lightweight, strong, durable, resistant to water, UV radiation, chemicals, abrasion, and biological fouling. Flexibility is also important.

Considering these factors, several materials could be suitable for the barrier:

Solid Plastic Sheeting: Smooth, easy to clean, good water/chemical resistance, but can be heavier and less flexible.

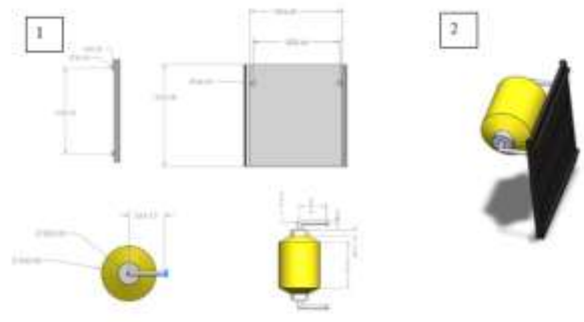



Figure 3-7 Barrier 1
Barrier 1 detailed view; 2- Barrier 1

**3. Rope Component of the Garbage Barrier System**

The rope constitutes a critical element of the garbage barrier system, serving as the primary tensile member that spans the width of the river and anchors the entire system to the floating dock/boat on one side and the riverbank on the opposite side. Its design and material selection are paramount to the system's stability, load-bearing capacity, and longevity in a dynamic aquatic environment.

**Purpose of the Rope**

The rope serves several key purposes within the garbage barrier system:

1. **Anchorage and Positional Stability:** The primary function of the rope is to securely anchor the barrier system across the river. By connecting the floating dock/boat to a fixed point on the opposite riverbank, the rope prevents the entire system from drifting downstream due to the force of the river current. This ensures that the barrier remains in an optimal position to intercept floating debris.
2. **Tensile Reinforcement and Structural Integrity:** As the barrier system encounters floating garbage, it experiences significant drag forces exerted by the accumulated debris and the flowing water. The rope acts as a crucial tensile element, absorbing and distributing these forces along its length. This reinforcement prevents excessive stress and deformation on the barrier components, maintaining the structural integrity of the entire system.

3. **Load Transfer:** The rope facilitates the transfer of loads generated by the intercepted garbage and the water current to the anchoring points (the floating dock/boat and the riverbank). The strength and elasticity of the rope determine the system's ability to withstand these dynamic loads without failure or significant displacement.
4. **Deployment and Retrieval:** Depending on the specific implementation, the rope might also play a role in the deployment and retrieval of the barrier system. Its flexibility allows for easier handling during installation and potential adjustments or removal for maintenance or during periods of high water flow.

**Material Requirements:** Must possess high tensile strength, excellent resistance to water, chemicals, UV radiation, and abrasion. Flexibility for deployment and retrieval is also important.

**Potential Materials:** High-Density Polyethylene (HDPE), Polypropylene (PP), Polyester (PET), Nylon (Polyamide), and high-performance fibers like Dyneema/Spectra are potential options, each with specific advantages and disadvantages regarding strength, degradation resistance, and cost.

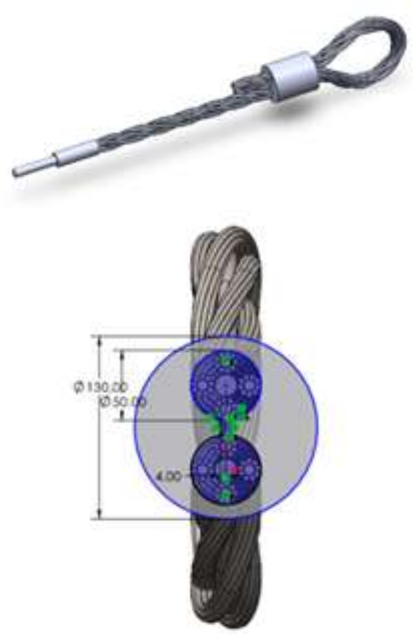



Figure 3-8 Rope
1-Rope ; 2- Rope detailed view

**Camera System**

Integrating a camera system can significantly enhance the capabilities of the automated river cleaning machine by providing visual information for monitoring, control, and data collection.

**Purpose:** To capture visual data of the river surface, the debris being collected, the operation of the robotic arm and conveyor belt, and the fill level of the garbage bin. Multiple cameras might be strategically placed to provide comprehensive coverage

**Considerations:**

**Resolution and Image Quality:** Sufficient resolution is needed to clearly identify debris, monitor the robotic arm's actions, and assess the garbage bin level.

**Field of View:** The camera(s) should have a wide enough field of view to cover the relevant areas of operation.

**Environmental Protection:** The cameras must be rugged and weatherproof (high IP rating) to withstand exposure to water splashes, humidity, and sunlight

.**Mounting:** Secure and stable mounting points are necessary to prevent vibrations and ensure consistent viewing angles.

**Lighting Conditions:** Consider the need for infrared (IR) capabilities or integrated lighting for operation in low-light conditions or at night.

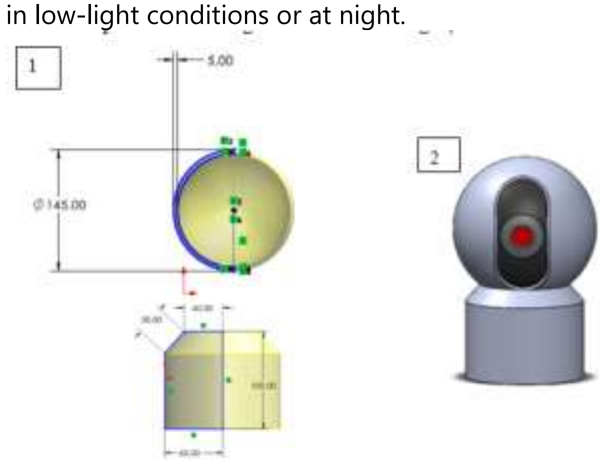



Figure 3-9 Camera system
1-Camera Case Detailed View; 2- Camera

**Applications:** Allows operators to visually monitor the machine's operation and the river conditions from a remote location. Image analysis can potentially be used to identify the type and size of debris being collected, providing valuable data for environmental studies. The camera feed can provide visual feedback to the robotic arm control system, enhancing the precision of grasping and manipulation tasks, especially for irregularly shaped objects. Allows for visual inspection of the conveyor belt's operation, detection of jams or blockages, and assessment of the effectiveness of debris removal. Provides a visual confirmation of the garbage bin's fill level, supplementing data from the bin level sensor

**Integrated Sensor, Solar Power, and Camera Systems:**

**Sensor System**

An effective sensor system is crucial for the autonomous operation and monitoring of the river cleaning machine. It provides real-time data about the river environment, the performance of the machine, and the status of collected debris. The specific sensors implemented will depend on the desired level of automation and the environmental parameters of interest. Potential sensors include

**Water Level Sensor:**

Purpose: To monitor the water level of the river. This information is vital for adjusting the barrier system's depth, ensuring the conveyor belt's effective interaction with the water surface, and detecting potential flooding conditions that might require the system to be temporarily shut down or adjusted.

**Technology:** To measure the water level accurately, ultrasonic sensors, pressure sensors, or float switches can be used.

**Debris Detection Sensor (near the barrier and/or conveyor belt intake):**

**Purpose:** To detect the presence and potentially the density or size of floating debris approaching the barrier or entering the conveyor belt. This information can be used to optimize the conveyor belt's speed, activate the robotic arm when larger items are detected, or provide data on the amount of collected waste over time.

**Technology:** Infrared, ultrasonic, or even simple optical sensors could be employed. Image analysis from the camera system (described later) could

**Conveyor Belt Load Sensor:**

**Purpose:** To monitor the load on the conveyor belt. This can help prevent overloading, detect blockages, and indicate the rate at which debris is being collected.

**Technology:** Strain gauges or load cells integrated into the conveyor belt frame or near the drive roller can measure the weight of the material on the belt.

**Garbage Bin Level Sensor (Connected with Garbage Bin):**

**Purpose:** To monitor the fill level of the garbage bin. This is essential for autonomous operation, allowing the system to signal when the bin is full and needs to be emptied, potentially triggering a notification or a temporary halt in collection.

**Technology:** The fill level can be determined using ultrasonic sensors, infrared sensors, or mechanical limit switches.

**Robotic Arm Position and Force Sensors:**

**Purpose:** To provide feedback on the robotic arm's movements, position, and force exerted during grasping. This is crucial for precise and controlled manipulation of debris and preventing damage to the arm or the environment.

**Technology:** Encoders, potentiometers, and force/torque sensors are commonly used in robotic arms.

**Solar Power System**

Integrating a solar power system offers a sustainable and potentially cost-effective energy source for the automated river cleaning machine, reducing its reliance on external power infrastructure. The key components of the solar power system would include:

**Solar Panels:**

**Purpose:** To convert sunlight into direct current (DC) electricity through the photovoltaic effect.

**Considerations:** The number and wattage of the solar panels will need to be calculated based on the total energy consumption of all the electrical components of the machine (motors, control system, sensors, robotic arm actuators, camera, etc.) and the average solar irradiance at the location in Singapore.

Factors like panel efficiency, orientation, and potential shading need to be considered.

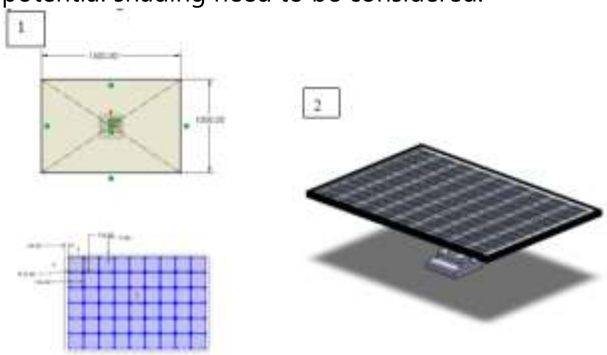



Figure 3-10 Solar System
1-Solar Detailed View; 2- Solar panel

**Solar Charge Controller:**

**Purpose:** To regulate the voltage and current from the solar panels to safely and efficiently charge the batteries and prevent overcharging or deep discharging.

**Technology:** MPPT (Maximum Power Point Tracking) charge controllers are often preferred as they optimize the power transfer from the panels to the batteries.

**Battery Bank:**

**Purpose:** To store the electrical energy generated by the solar panels, providing a continuous power supply to the machine, especially during periods of low sunlight or at night.

**Considerations:** The capacity of the battery bank will depend on the machine's energy consumption profile and the desired autonomy (how long it can operate without sufficient sunlight). Deep-cycle batteries (e.g., lithium-ion or lead-acid) are typically used for solar power systems due to their ability to withstand repeated charging and discharging cycles.

**Robotic Hand**

**The 6-Axis Robotic Arm for Debris Collection**

A 6-axis robotic arm is a highly versatile and precise piece of machinery designed for various industrial and research applications. Its six axes provide exceptional flexibility and dexterity, allowing it to perform complex tasks that require precise positioning and orientation in three-dimensional space. These six axes correspond to three translational degrees of freedom — allowing movement forward/backward (X-axis), up/down (Z-axis), and left/right (Y-axis) and three rotational degrees of freedom that control the orientation of the arm: pitch (rotation about the lateral axis), yaw (rotation about the vertical axis), and roll (rotation about the longitudinal axis).

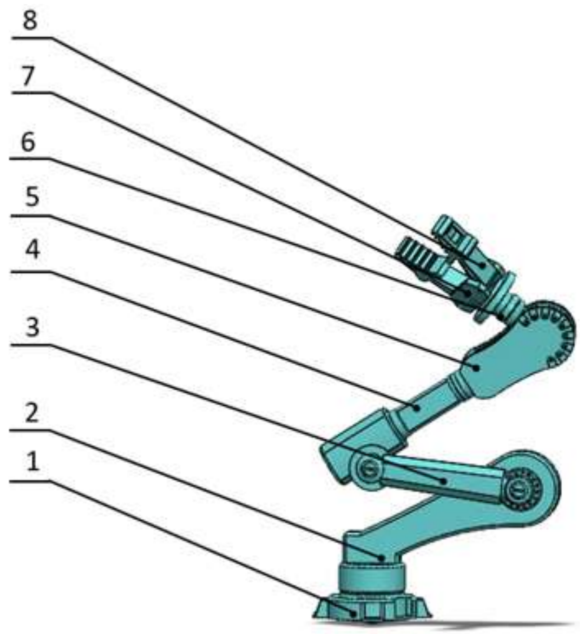



Figure 3-11 Robotic Hand
1-Base; 2- Shoulder; 3- Upper arm; 4-Elbow; 5- Forearm; 6-wrist; 7- Wrist mounting Plate; 8- End Factor

This configuration enables the robotic arm to mimic the movements of a human arm and wrist with remarkable precision, making it suitable for tasks ranging from assembly and welding to painting, inspection, and even delicate medical procedures. The ability to move and orient the end effector in almost any direction allows the arm to operate efficiently in confined or cluttered environments, such as between components in a tight assembly line or inside a machine's chassis.

**Base (Component 1)**

The base is the stationary foundation of the robotic arm. It provides a stable platform upon which the entire arm structure is mounted.

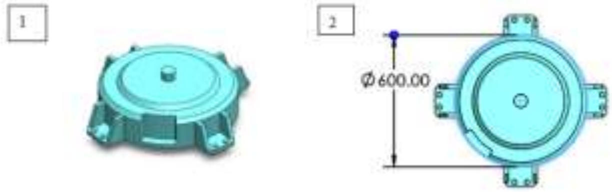



Figure 3-12 Base
1-Base; 2- Base Detail

**Purpose:**

**Support:** It supports the weight of the entire robotic arm and any payload (collected debris).

**Stability:** It anchors the arm to the main structure of the river cleaning machine (likely the floating dock or boat), ensuring stability during operation and movement.

**Housing:** It may house some of the initial drive components, control electronics, and cable routing.

**First Axis (Twist/Rotation):** Typically, the base allows for the first rotational movement of the arm around a vertical axis. This provides the arm with its ability to sweep across a horizontal plane.

**Material:** Often made from robust materials like steel or heavy-duty aluminum alloys to provide the necessary rigidity and strength. It needs to be securely fastened to the machine's structure.

**Shoulder (Component 2)**

The shoulder is the primary link connected to the base. It usually involves a rotary joint that allows the arm to move up and down in a vertical plane.

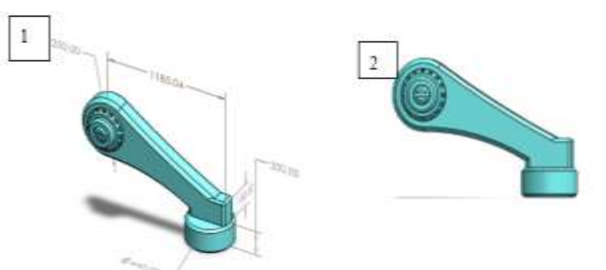



Figure 3-13 Robotic Hand
1-Ronotic Hand 2-Details

**Purpose:**

**Vertical Reach:** Provides the second degree of freedom, enabling the arm to adjust
It's vertical reach and position the subsequent links.

**Support:** Contributes to supporting the weight of the outer arm segments and the payload.

**Housing:** May contain the actuator (motor, gearbox) for the shoulder joint.

**Material:** Typically constructed from strong and lightweight materials like Aluminum alloys or composite materials minimize inertia and maximize efficiency.

Upper Arm (Bicep/Link 1) (Component 3)

This is the first major link of the arm, connected to the shoulder. It extends outwards and provides a significant portion of the arm's reach.

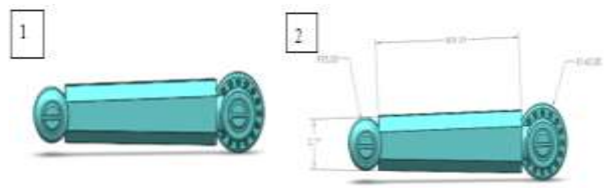



Figure 3-14 Upper arm
1-Upper Arm 2-Details

**Purpose:**

**Horizontal Reach:** Contributes to the arm's horizontal reach and ability to position
itself over the water.

**Linkage:** Acts as a structural connection between the shoulder and the elbow.

**Housing:** May enclose wiring and potentially some driving components.

**Material:** Similar to the shoulder, often made from aluminum alloys or composite materials to balance strength and weight.

**Elbow (Component 4)**

The elbow is the joint connecting the upper arm to the forearm. It is typically a rotary joint allowing for further movement in a vertical plane.

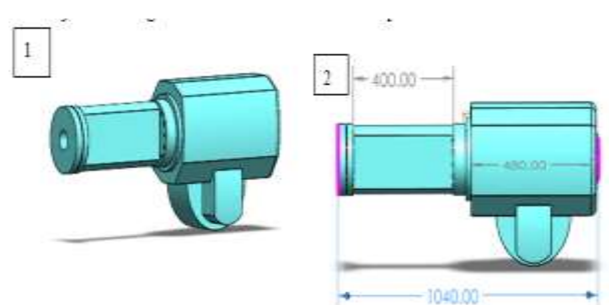



Figure 3-15 Elbow
1-Elbow;2-Details

**Purpose:**

**Articulation:** Provides the third degree of freedom, allowing the arm to bend and position the forearm and end effector more precisely.

**Reach Adjustment:** Further refines the arm's reach and ability to access different areas.

**Housing:** Contains the actuator (motor, gearbox) for the elbow joint.

**Material:** Similar to the shoulder and upper arm, often made from aluminum alloys or composite materials.

**Forearm (Link 2) (Component 5)**

This is the second major link of the arm, connected to the elbow. It extends towards the wrist and the end effector.

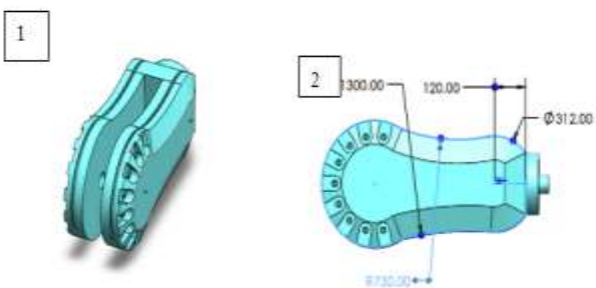



Figure 3-16 Formarm
1-Form Arm; 2-Details

**Purpose:**

**Positioning:** Fine-tunes the position of the wrist and the grabbing hands.

**Linkage:** Acts as a structural connection between the elbow and the wrist.

**Housing:** May enclose wiring and potentially some sensors.

**Material:** Typically made from lightweight and strong materials like aluminum alloys or composite materials.

**Wrist (Component 6)**

The wrist is a complex assembly of typically three rotary joints located at the end of the forearm. These joints provide the arm with its ability to orient the end effector (grabbing hands) in three-dimensional space.


Figure 3-17 wrist
1-Wrist;2-Details

**Purpose:**

Orientation Control (Pitch, Yaw, Roll): These three axes of rotation allow the grabbing hands to be oriented precisely to grasp debris at various angles and orientations.

**Dexterity:** Provides the necessary dexterity for complex manipulation tasks.

**Housing:** Contains the actuators (motors, gearboxes) for the wrist joints and may house sensors or camera components.

**Material:** Often made from high-strength aluminum alloys or specialized steels to handle the torques and stresses involved in orienting the end effector and payload.

**Wrist Mounting Plate/Adaptor (Component 7)**

This is a connecting interface between the final axis of the wrist and the grabbing hands (end effector). It provides a standardized platform for attaching different types of end effectors.

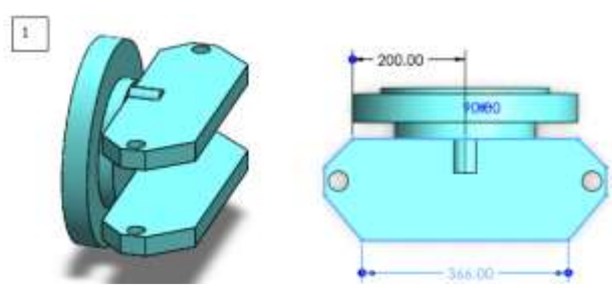



Figure 3-17 Wrist Mounting Pad
1-Wrist Mounting Pad ;2-Details

**Purpose:**

Mechanical Connection: Provides a secure and rigid mechanical connection for grabbing hands.

**Power and Signal Interface:** This may include connections for the power supply to the end effector (if it has active components) and signal lines for control and feedback from sensors in the end effector.

**Modularity:** Allows for the potential interchangeability of different end effectors if the system requires it.

**Material:** Typically made from strong and precisely machined materials like aluminum alloys or steel to ensure accurate alignment and secure attachment.

**Grabbing Hands (End Effector) (Component 8)**

This is the tool at the end of the robotic arm specifically designed to grasp and hold the floating debris. The design can vary greatly depending on the size, shape, and type of garbage being collected.

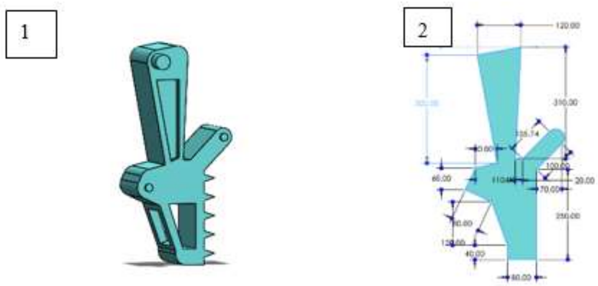



Figure 3-18 Grabbing Hands
1-Grabbing Hands,2-Details

**Purpose:**

**Grasping and Manipulation:** To securely grip and lift floating debris from the water.

**Holding:** To retain the collected debris while the arm moves it towards the garbage bin.

**Releasing:** To deposit the collected debris into the designated bin.

**Design Considerations:**

**Type of Gripper:** Could be a two-finger parallel jaw gripper, a multi-finger gripper, a scoop-like mechanism, or a specialized design based on the characteristics of the target debris.

**Actuation:** May be pneumatically, electrically, or hydraulically actuated.

**Sensing:** Could incorporate sensors (e.g., force sensors, proximity sensors) to provide feedback on the grasping process.

**Material:**

Needs to be corrosion-resistant and durable, potentially made from stainless steel, robust plastics, or coated metals.

The robotic arm's end effector is engineered to handle typical floating debris and larger, more challenging waste, such as tree trunks, and clear blockages obstructing the conveyor belt. Its multi-functional design allows it to adapt to various shapes and sizes of debris. A multi-fingered or claw-like gripping mechanism securely holds significant, slippery, or uneven materials. At the same time, high-torque or hydraulic actuators supply the necessary force to lift and maneuver heavy trunks without compromising stability.

The end effector coordinates with onboard sensors and cameras that detect real-time blockages to unclog the conveyor belt. When an obstruction is identified, such as tangled nets, plastic bags, or bulky debris, the arm can perform precise scraping, pulling, or lifting motions to clear the path. Some designs also allow the robotic hand to switch between gripping tools and cleaning attachments, making it versatile for collection and maintenance tasks.

**Conveyor Belt System**

The Conveyor Belt System for Debris Collection

The conveyor belt system is crucial for the continuous removal of collected debris from the water's surface and its transportation to the garbage bin. Here's a breakdown of its individual components:

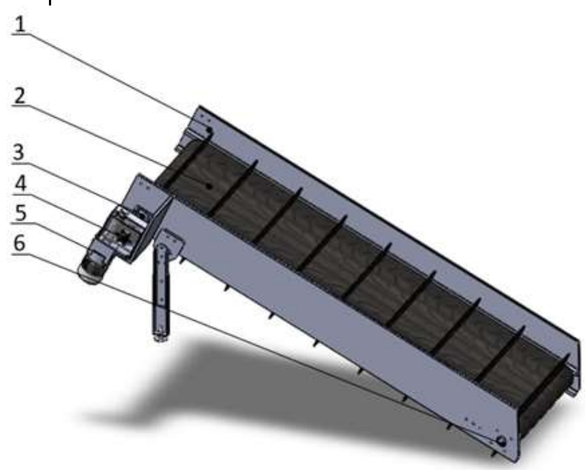



Figure 3-19 Conveyor Belt System
1-Main Frame; 2- Conveyor Belt; 3- Bearings; 4- Gear System; 5-Motor; 6-Roller

1**. Main Frame with (2 Mounting Pads)**

The main frame is the structural support for the entire conveyor belt system. It provides a rigid framework to which all other components (motor, worm gear, bearings, roller shafts, belt) are mounted.

The two mounting pads would be the interface points for attaching the conveyor system to the main structure of the river cleaning machine (e.g., the floating dock or boat).

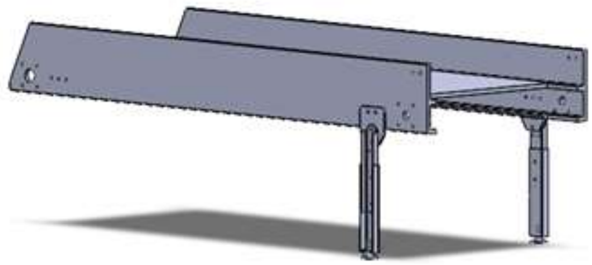


Figure 3-20 Main Frame

**Purpose:**

**Structural Support:** To hold all the components of the conveyor system in their correct relative positions and withstand the various loads (weight of components, weight of debris, belt tension, motor torque reaction).

**Alignment:** To ensure proper alignment of the roller shafts and belt for smooth and efficient operation.

**Mounting Interface:** The mounting pads provide secure points for attaching the conveyor system to the overall machine structure.

**Design Considerations:**

**Material:** Typically made from steel (e.g., welded steel sections like channels, angles, or tubes) for strength and rigidity. Corrosion protection (e.g., painting, galvanizing) is essential.

**Strength and Rigidity:** Must be designed to withstand the maximum expected loads without excessive deflection or deformation.

**Mounting Pad Design:** The design of the mounting pads will depend on the interface with the main machine structure. They might include bolt holes or other features for secure attachment. The location and design of these pads will influence the stability and load distribution of the conveyor system on the main machine.

**Accessibility for Maintenance:** The frame design should ideally allow for easy access to the various components for maintenance, cleaning, and belt replacement.

**5.Cleated Belt System**

The cleated belt is the flexible continuous loop that carries the debris. Cleats are raised protrusions on the belt surface that help to scoop and lift the debris, especially on an inclined conveyor.

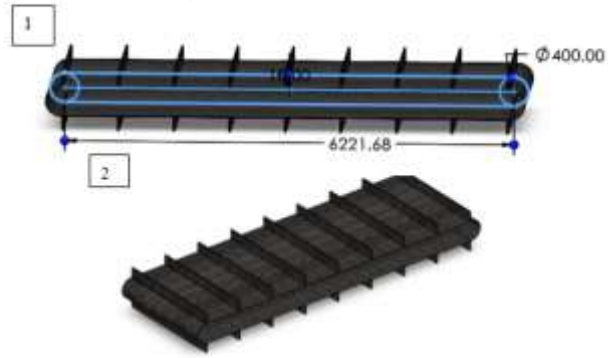



Figure 3-21 Cleated Belt
1-Details; 2-Belt

**Purpose:**

Debris Collection and Transportation: The primary function is to pick up floating debris from the water's surface as the lower part of the belt moves through the water and then lift and transport it upwards towards the garbage bin.

**Preventing Slippage:** The cleats positively engage with the debris, preventing it from sliding back down the inclined belt.

**Water Drainage:** The belt material and cleat design should ideally allow some water drainage as the debris is lifted.

**Design Considerations:**

**Belt Material:** Must be water-resistant, durable, and resistant to tearing and degradation from exposure to river water and collected debris. Common materials include rubber, PVC, polyurethane, or specialized conveyor belt materials.

Cleat Design (Shape, Height, Spacing): The shape and height of the cleats will depend on the size and type of debris being collected. The spacing between cleats will influence the carrying capacity and the ability to scoop debris effectively.

**Belt Width and Thickness:** Determined by the required carrying capacity and the loads it will experience.

**Jointing Method:** The belt needs to be joined into a continuous loop using a strong and durable method (e.g., mechanical fasteners or vulcanization).

**Tensioning:** The belt system will require a mechanism (often on the idler roller) to adjust and maintain the proper tension for efficient operation and to prevent slippage.

**2. Worm Gear**

The worm gear is a speed reduction mechanism that transmits power from the motor to the conveyor belt's roller shafts. It typically consists of a worm (a screw-like gear) meshing with a worm wheel (a toothed gear).

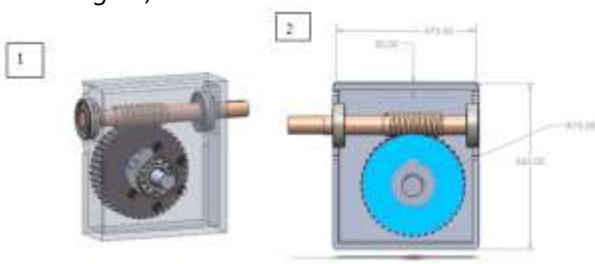



Figure 3-22 Gear Box
1-gear Box; 2-details

**Purpose:**

**Speed Reduction:** Reduces the high rotational speed of the motor to a lower, more suitable speed for the conveyor belt. You've indicated a motor speed of 960 r/min and a required roller shaft speed of 59.713 r/min, suggesting a significant speed reduction is needed.

**Torque Multiplication:** As speed is reduced, the torque is correspondingly increased (ideally, neglecting efficiency losses), providing the necessary force to drive the loaded belt.

**Change in Axis of Rotation:** Typically, the worm gear changes the axis of rotation by 90 degrees.

**Self-Locking Capability (Potential):** Some worm gear designs have a self-locking characteristic, preventing the conveyor belt from back-driving when the motor is stopped, which can be advantageous for inclined conveyors.

**Given Parameters (as you provided earlier):**

Number of threads (n) = 1
Number of worm wheel teeth (z2) = 44
Axial pitch (px) = 22 mm
Pitch diameter of the worm (d1) = 76.65 mm
Module (m) = 7 mm
Worm diameter factor (q) = 10.95
Center distance (a) = 192.325 mm

- **Derived Parameters (as calculated earlier):**

Gear ratio (i) = 44
Calculated output speed (N2) = 21.82 r/min (Note: This is different from the required roller shaft speed, indicating a potential need for further speed adjustment in the system).

**3. Two Different Pairs of Bearings**

Bearings are mechanical components that reduce friction between moving parts, allowing for smooth and efficient rotation of the roller shafts. You mentioned "two different pairs," implying different types or sizes are used at different locations.

**Purpose:**

**Support:** To support the radial and potentially axial loads acting on the roller shafts due to the belt tension and the weight of the debris.

**Friction Reduction:** To minimize friction during the rotation of the shafts, reducing power loss and wear.

**Alignment:** To help maintain the proper alignment of the roller shafts.

**Types and Locations (Hypothetical based on typical conveyor design):**

**Pair 1 (Motor/Worm Gear Output Shaft Bearings):** These bearings would support the worm gear's output shaft, which connects to one of the roller shafts. They must handle the radial and thrust loads generated by the gear meshing and the initial belt tension. These might be robust balls or roller bearings for moderate to high speeds and loads.


Figure 3-23 Bearings 1
1-Bearings; 2-Details

Pair 2 (Idler Roller Shaft Bearings): These bearings would support the shaft of the other roller (the idler roller), which is not directly driven by the worm gear. They would primarily need to handle the radial loads from the belt tension and the weight of the debris. These might be simpler ball bearings or sleeve bearings, depending on the load and speed requirements at the end.


Figure 3-24 Bearimngs2
1-Bearings; 2-Details

**Specifications to Consider:**

**Load Capacity (Static and Dynamic):** Must withstand the maximum expected loads.

**Speed Rating:** Suitable for the rotational speeds of the shafts.

**Sealing:** Adequate sealing to prevent ingress of water, dust, and debris, which can contaminate the bearing lubricant and cause premature failure.

**Lubrication:** Compatibility with the chosen lubricant and a means for relubrication if necessary.

**Mounting:** Designed for secure mounting within bearing housings on the main frame.

**4.Two Roller Shafts**

Roller shafts are cylindrical components that support and drive (or are driven by) the conveyor belt. The belt wraps around these rollers, and their rotation causes the belt to move.

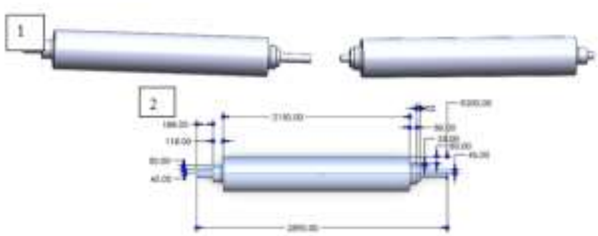



Figure 3-25 Roller
1-Roller; 2-Details

**Purpose:**

**Belt Support and Tensioning:** Provide a stable structure for the conveyor belt to run over and contribute to maintaining belt tension.

**Power Transmission (Drive Roller):** One of the shafts (the drive roller) is connected to the power source (via the worm gear) and transmits the rotational force to the belt through friction.

**Belt Guidance (Idler Roller):** The other shaft (the idler roller) provides a point for the belt to return and helps maintain its path. It may also incorporate a mechanism for belt tension adjustment.

**Design Considerations:**

**Diameter and Length:** Determined by the width of the conveyor belt and the required strength to resist bending under load.

Material: Typically made from steel or aluminum alloys with sufficient strength and corrosion resistance. The surface finish of the rollers is important for good belt traction and minimal wear.

**Surface Treatment (Drive Roller):** The drive roller might have a knurled or coated surface to increase friction with the belt and prevent slippage, especially when loaded with wet debris.

**Keyways or Other Mounting Features:** Designed with keyways or splines to connect to the worm gear output shaft (drive roller) and to accommodate bearings at both ends of both rollers.

**Belt Tracking Adjustment (Idler Roller**): The idler roller often incorporates a mechanism for adjusting its alignment to ensure the belt tracks straight and doesn't run off the sides.

**5.Motor**

The motor is the prime mover of the conveyor belt system, providing the necessary rotational force (torque) to drive the entire mechanism.

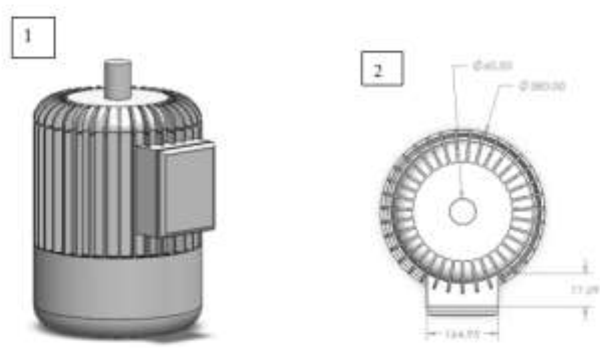



Figure 3-26 Motor
1-Motor, 2-Details

**Purpose:**

**Power Generation:** Converts electrical energy into mechanical rotational energy.

**Speed and Torque Output:** Provides the required rotational speed and torque to move the loaded conveyor belt at the desired velocity.

**Control Interface:** Allows for speed control (potentially variable depending on the system's needs) and on/off operation.

Specifications to Consider:

**Power Rating:** Sufficient to overcome the frictional forces of the belt, the weight of the debris being lifted, and any inertial loads during start-up and stopping. You mentioned an input motor power of 5.5 kW for the worm gear, and a required power of 2.23 kW for the conveyor belt might be a useful starting point for analyzing the load.

**Speed:** The full load speed of your motor is 960 r/min. This speed will be reduced by the worm gear to drive the roller shafts.

**Torque**: Must be adequate to handle the maximum expected load on the conveyor belt without stalling.

**Duty Cycle:** The motor should be rated for the expected operational duration and frequency of starts and stops.

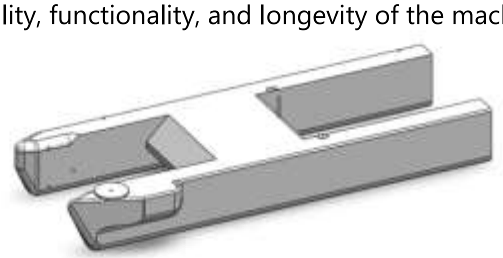
**Environmental Protection:** Given its proximity to water, the motor must have an appropriate IP (Ingress Protection) rating to protect against water splashes, humidity, and potentially dust.

**Mounting:** Designed with a suitable mounting interface to securely attach it to the main frame of the conveyor system.

**Platform**

**The Stationary Platform**

The stationary platform serves as the stable foundation for the entire automated river cleaning system, housing the barrier system's anchor point, the robotic arm, the conveyor belt, the garbage bin, and potentially the solar power system, sensors, and control electronics. Its design is critical for the overall stability, functionality, and longevity of the machine.



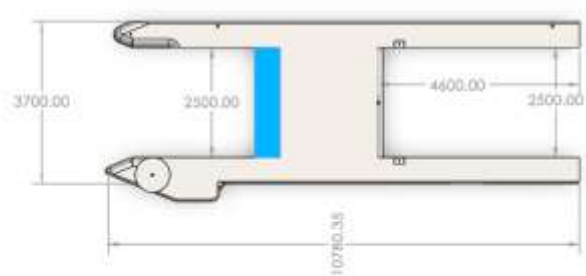



Figure 3-27 Platform
1-Platform, 2-Platform details

**Description:**

**Elevated Structure:** The platform is raised above the water level, supported by what seem to be vertical supports or columns resting on the riverbed or potentially anchored to the riverbanks. This elevation provides clearance for the conveyor belt to operate and for the garbage bin to be positioned.

**Modular Design (Potentially):** The interconnected beam structure suggests a potentially modular design, which could facilitate transportation, assembly, and maintenance.

**Mounting Points:** The platform likely incorporates specific mounting points or pads for securing the various components of the cleaning system, such as the strong barrier for the rope, the base of the robotic arm, and the main frame of the conveyor belt.

**Walkway/Access Area:** The platform appears to have some provision for access or a walkway, likely for maintenance and monitoring purposes.

**Size and Footprint:** The size appears sufficient to accommodate all the necessary components and potentially allow for some working space. The footprint is designed to provide adequate stability.

**Material Selection for the Platform**

The material selection for the platform is crucial for its structural integrity and resistance to the river environment. Key considerations include: Strength and Rigidity, Corrosion Resistance, Durability, Weather Resistance, and Weight.

**Center of Gravity (CG) Considerations**

The center of gravity (CG) of the entire system (platform + all mounted components + maximum expected garbage load) is a critical factor for stability.

**Low CG is Desirable:** A lower center of gravity enhances the platform's stability, making it less susceptible to tipping or overturning due to uneven loading, wind forces (if applicable), or minor shifts in weight distribution.

**Component Placement:** The placement of heavier components (e.g., the robotic arm base, the conveyor's motor and gearbox, and the garbage bin when full) should be considered, keeping the CG as low as possible.

**Load Distribution:** The design should aim for a balanced weight distribution across the platform to prevent excessive stress on any particular support structure and maintain a stable CG.

**Buoyancy Considerations (if partially floating**): If any part of the platform is intended to be buoyant (though the term "stationary" suggests it's fixed), the location of the center of buoyancy relative to the CG is also crucial for stability. However, buoyancy might be less of a primary concern for overall stability against overturning for a truly stationary platform anchored to the riverbed or banks.

### Automated Garbage Bin System

The garbage bin system is a crucial element for the efficient and autonomous operation of the river cleaning machine. It serves as the temporary storage for the collected debris before it is manually emptied. To further enhance autonomy, the system can be designed with an automated mechanism for replacing a full bin with an empty one.

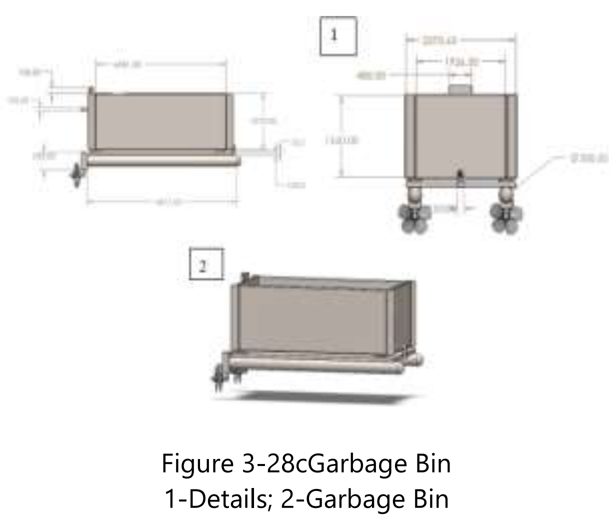



Figure 3-28cGarbage Bin
1-Details; 2-Garbage Bin

### Garbage Bin

The garbage bin is a container designed to hold the collected debris. Its size and material will depend on the estimated volume of collected waste and the frequency of emptying.

**Purpose:**

**Temporary Storage:** To hold the debris collected by the conveyor belt and/or the robotic arm.

**Containment:** To prevent the collected waste from falling back into the river or creating a mess on the platform.

### Conclusion

The synergistic integration of a barrier system, a sophisticated robotic arm, an efficient conveyor belt system, a sustainable solar power source, and an advanced camera system culminates in the creation of a highly refined and largely autonomous river cleaning machine, poised to address the pressing challenge of marine debris accumulation. The integration of a conveyor-belt mechanism facilitates the effective collection and removal of marine debris, including plastics and other floating refuse, thereby contributing to the mitigation of water pollution and the safeguarding of aquatic fauna from the detrimental impacts of marine debris.

## IV. RESEARCH CALCULATION

### Conveyor Belt Design Scheme

The conveyor belt design scheme outlines a comprehensive approach to developing an efficient and reliable conveyor system tailored for specific operational requirements. This scheme begins with the calculation of the conveyor belt's output, which involves determining the material flow rate, belt speed, and load capacity to ensure optimal performance. Based on these parameters, the appropriate motor is selected, taking into account factors such as power requirements, efficiency, and operating conditions. The design further includes the gear transmission system, where gear ratios and torque requirements are analyzed to enable smooth and efficient power transfer from the motor to the belt.

Additionally, the design of the shafts is carefully carried out to ensure they can withstand mechanical stresses and maintain proper alignment during operation. Suitable bearings are then chosen to support the shafts, reduce friction, and enhance the overall lifespan of the system. Together, these components form a cohesive and functional conveyor belt design, optimized for durability, performance, and mechanical efficiency.

**Determine the Required Output on Conveyor Belt:**

Required torque and power at the conveyor belt drive.

Parameter calculations:

1. Power of the Motor: HP
2. Torque of the Motor: Nm
3. Speed of the Motor: RPM

**1. Conveyor belt speed and load requirements:**

We can calculate the power only based on the Load and the linear Speed.

The parameters we need to know

**Set 1:**

Conveyor Length = 6.2 m

Conveyor Width = 2.2 m

**Set 2:**

Total Load = 200kg (Estimated)

**Set 3:**

Mass of the belt = Total Area × Unit Density

= (2 × 6.2 ×2.2)m^2 × 2.3 kg/m^2

= 62.7kg (4-1)

**Set 4:**

Total load on Conveyor Belt = Total Load + Belt Mass

= (200 + 62.7) kg

=262.7 kg (4-2)

**Set 5:**

μ, coefficient of friction 0.2 (4-3)

**Set 6:**

Material to be transferred in 5 sec from one end to another , total length 6.2

Speed of conveyor = 6.2÷5=1.25 m/s (4-4)

**Set 7:**

Inclined Angle=26° (4-5)

**Set 8:**

Gravitational Force component (Pulling Material Downhill)

F(gravity) = (Total Load on Conveyor belt)×g×sinθ

=262.7×9.81×0.438

≈1128.76N (4-6)

Frictional Force component (Resisting Motion)

F(friction) = (Total Load on Conveyor belt)×g×μ×cosθ

=262.7×9.81×0.2×0.899

≈463.36N (4-7)

F(total)= F(gravity)+F(friction)

=1592.12N (4-8)

**1.Select the motor**

**(1) Select the type of motor**

According to the working requirements and working conditions, three-phase asynchronous motors are selected. The enclosed self-cooled structure has a voltage of 380V and Y series.

**(2) Select the rated power of the motor**

The performance parameters of the conveyor belt are selected from the sixth group of data in Table 1, namely:

| Conveyor working tension F/N | Conveyor working speed $v/m{\cdot}s^{-1}$ | Reel diameter D/mm |
|---|---|---|
| 1592.12 N | 1.25 m/s | 400mm |

Table 4.1

The power required by the working machine is :

$$P\_w= \frac{Fv}{1000} = \frac{1592.12\ N \times 1.25\frac{m}{s}}{1000} = 1.99\ \text{kW} \quad (4\text{-}9)$$

**2. The total transmission efficiency from the motor to the working machine is:**

The total transmission efficiency $\eta = \eta1_{\text{gear}}^{2} \times \eta2_{\text{Bearing}}^{4} \times \eta3_{\text{Coupling}}^{2} \times \eta4_{\text{Roller}}^{1}$

Among them η1, η2, η3, η4 are the efficiency of gear drive, Ball bearing, elastic sleeve pin coupling and roller, respectively.

Gear meshing efficiency: η1 = 0.97(level 8 accuracy)

Efficiency of Bearing: η2 = 0.99(ball bearings)

Efficiency of Coupling: η3 = 0.99
Efficiency of Roller: η4 = 0.96

The total transmission efficiency, η = $\eta1_{\text{gear}}^{2} \times \eta2_{\text{Bearing}}^{4} \times \eta3_{\text{Coupling}}^{2} \times \eta4_{\text{Roller}}^{1}$

$$= 0.97^{2} \times 0.99^{4} \times 0.99^{2} \times 0.96$$

$$= 0.85040512567$$
$$\approx 0.852 \quad \textbf{(4-10)}$$

3. The power required by the motor is:

$$\boldsymbol{P_d} = \frac{\boldsymbol{P_w}}{\boldsymbol{\eta}} = \frac{1.99\,kW}{0.852} = 2.34 \text{ kW}$$ (4-11)

Because of the rated power of the motor Ped ≥ Pd (4-12)
Check Appendix 50 of "Mechanical Basics" P499 and select the rated power of the motor as 2.2kW, which meets the rated power of the motor.

**(3) Determine the speed of the motor**
Working speed of transmission roller shaft:

$$\boldsymbol{n_w} = \frac{\boldsymbol{60 \times v \times 1000}}{\boldsymbol{\pi D}} = \frac{60 \times 1.25 \times 1000}{3.1416 \times 400} = \boldsymbol{59.713} \text{ r/min}$$ (4-13)

**(4) Determine the model of the motor**
Here is a comparison of synchronous speed of 1500r/min and 1000r/min and the data and total transmission ratios are listed [31] (page 115,116):

**Technical data of the motor**

| motor model | Rated power（kw） | Synchronize Rotating speed（r/min） | Full load speed（r/min） | Rated torque | Total transmission ratio |
|---|---|---|---|---|---|
| Y123S-4 | 5.5 | 1500 | 1440 | 2.2 | 21.98 |
| Y132 M2-6 | 5.5 | 1000 | 960 | 2.0 | 14.66 |

Table 4.2

From this comparison I have decided to select Y132M2-6 for its compact structure.
It's Parameter:
Type: Y132M2-6 (4-14)
Rated Power: 5.5kW (4-15)
Synchronous Speed: 1000r/min (4-16)

**(5) Distribution of Drive Ratio:**
The total transmission ratio of reducer i_(reducer )=14.66 according to table 4.
Take the high-level Gear transmission ratio:
$i_1 = \sqrt{1.35 \times i_{reducer}} = 4.448$ (4-17)
So, the low-level gear transmission ratio:
$i_2 = i_{reducer}/i_1) = 3.294$ (4-18)

Calculate the motion and power parameters of the transmission
1. **Motor Shaft (0 shaft)**

$$P_0 = 2.34\,\text{kW}$$

$$n_0 = 960\,\text{r/min}$$

$$T_0 = \frac{9.55 \times 2.34}{960} = \frac{22.347}{960} \approx 0.02328\,\text{kNm} = 23.28\,\text{Nm}$$ (4-19)

**2.High-Speed Shaft (1 shaft)**

$$P_1 = P_0 \times \eta_{coupling} \times \eta_{bearing} = 2.34 \times 0.99 = 2.3166\,\text{kW} \quad \textbf{(4-20)}$$

$$n_1 = n_0 = 960\,r/min \quad \textbf{(4-21)}$$

$$T_1 = \frac{9.55 \times 2.3166}{960} \approx \frac{22.1226}{960} \approx 0.02304\,\text{kNm} = 23.04\,\text{Nm} \quad \textbf{(4-22)}$$

**3.Low-Speed Shaft (2shaft)**

$$P_3 = P_1 \times \eta_{gear} \times \eta_{bearing} = 2.3166 \times 0.99 = 2.2934\,\text{kW}$$ (4-23)

Let's define a gear ratio (we still have not calculated) i_2. Since it's not specified, we'll leave n_3 In terms of $n_3 = \frac{n_1}{i_2} = \frac{960}{3.294}\ \text{r/min} = 291.439\ \text{r/min}$ **(4-24)**

$T_3 = \frac{9.55\times2.2934}{n_3} = \frac{21.916\times3.294}{960} \approx 0.075199\ \text{kNm} = 75.199\ \text{Nm}$ **(4-25)**

**4.Roller Shaft (3 shaft)**

$P_4 = P_3 \times \eta_{coupling} \times \eta_{bearing} = 2.2934 \times 0.99 = 2.2705\ \text{kW}$ **(4-26)**

$n_4 = n_3 = \frac{960}{3.294}\frac{\text{r}}{\text{min}} = 291.439\text{r/min}$ **(4-27)**

$T_4 = \frac{9.55\times2.2705}{n_4} = \frac{21.684\times3.294}{960} \approx 0.07440\text{kNm} = 74.4\ \text{Nm}$ **(4-28)**

**Design of transmission parts (Gear transmission)**

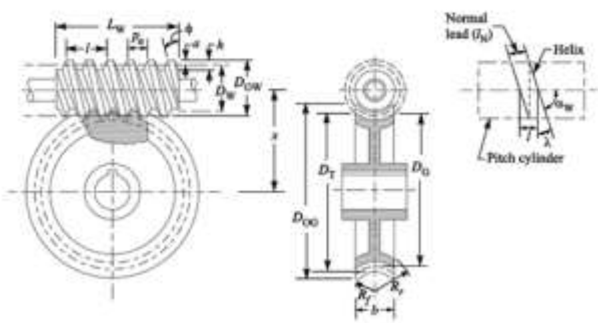


Figure 4.1

The following parameters, in connection with worm gearing, are essential from the subject point of view:

**Number of Worm Threads (n):** The parameter n denotes the number of independent helical threads (or starts) on the worm shaft in a worm gear mechanism. A single-start worm (n=1) features a solitary continuous helical thread extending along the worm's cylindrical body. In contrast, multi-start worms (n = 2 for a double-start worm) incorporate multiple parallel threads, evenly spaced and helically wound around the worm's axis. The number of "starts" directly influences the gear's mechanical advantage and transmission ratio, as each additional thread increases the axial advancement of the worm gear per complete revolution of the worm. Multi-start configurations are often employed to enhance load capacity, reduce sliding friction, or improve efficiency, though they require greater manufacturing precision than single-start designs. In my Design, the number of worm threads is 1.

So, n = 1 (4-29)

Number of Worm Wheel/Gear teeth: Worm wheel teeth are designed to mesh with the worm's threads, often employing conjugate action for smooth motion. Their profile is adapted to the worm's helix angle and thread. A key feature is often throating, where the wheel's face is curved to envelop the worm, increasing contact. The number of teeth (T_G) dictates the reduction ratio.

So, $T_G$= 44 (4-30)

Axial pitch: The axial pitch of a worm, is defined as the axial distance-measured parallel to the worm's rotational axis- between corresponding points on two adjacent threads. This parameter is critical in the design and function of worm gear systems. Notably, when the worm and worm gear shafts are oriented orthogonally (at 90 degrees), the axial pitch (Pa) of the worm is geometrically equivalent to the circular pitch (Pc) of the mating worm gear. The circular pitch (Pc) denotes the circumferential distance between corresponding tooth profiles on the gear, measured along its pitch circle. This equivalence ensures proper meshing and kinematic compatibility between the worm and gear in right-angle drive configurations.

For my design the pitch is 22mm.

So, Pa= 22mm (4-31)

**Lead:** Lead refers to the linear axial displacement of a point on the worm thread along its rotational axis during one complete revolution of the worm. This parameter is a fundamental characteristic of worm geometry, governing the axial advancement of the mating gear. In single-start threads, lead l is equivalent to the axial pitch Pa. However, in multi-start thread configurations, the lead corresponds to the product of the axial pitch Pa and the number of threads starts (n). The relationship is mathematically expressed as:

Where:

Pa = Axial pitch of the worm =22

n = Number of threads starts = 1

l = Pa × n = 22 × 1 = 22

So, l is 22 (4-32)

**Lead Angle:** The lead angle (denoted as $\lambda$) is defined as the angle formed between the tangent to the thread helix at the pitch cylinder and a plane normal (perpendicular) to the worm's axis. This angle is fundamental to the kinematic behavior of the worm gear pair, governing mechanical advantage, efficiency, and self-locking capability. It is mathematically expressed as:

$D_w$ = pitch circle diameter of the worm =76.65

$$\tan \lambda = \frac{l}{\pi \times D_w} = \frac{22}{3.14 \times 76.65} = 0.0915$$

$$\lambda = tan^{-1} \times 0.0915 = 5.229^\circ$$

A 5.229˚ lead angle is possible, especially for worms with a smaller number of threads (in this case, 1) and a larger pitch diameter. A lower lead angle can contribute to the self-locking capability of a worm gear set, meaning the worm can drive the gear but not easily drive the worm.

So, the Lead angle $\lambda$ is 5.229˚ (4-33)

**Tooth Pressure Angle:** This is measured in a plane containing the worm's axis and is equal to one-half the thread profile angle. The following table shows the recommended values of lead angle (λ) and tooth pressure angle.

| | | | | |
|---|---|---|---|---|
| Lead angle | 0-16 | 16-25 | 25-35 | 35-45 |
| Pressure angle | 14.5 | 20 | 25 | 30 |

So, from the table we can get the pressure angle: 14.5˚ (4-34)

Helix Angle: The helix angle (denoted as γ) refers to the angle between a tangent to the thread helix and a plane perpendicular to the worm's axis (the transverse plane). It essentially describes how steeply the thread wraps around the worm's cylinder. It is closely related to the lead angle, which is the angle between a tangent to the thread helix and a plane containing the worm's axis. The helix angle and the lead angle are complementary to the pitch cylinder.

$\gamma + \lambda = 90^\circ$

$\gamma = 84.7771^\circ$

So, the helix angle γ is 84.7771˚ (4-35)

Velocity ratio: It is the ratio of the speed of the worm in r.p.m. to the speed of the worm gear in r.p.m., or in other words, we can say, the number of teeth determines the ratio on the worm wheel (T_G) And the number of threads on the worm n. Mathematically, velocity ratio,

T_G= Number of teeth in the worm gear/wheel = 44

n = Number of threads starts = 1

V.R. = T_G/n = 44/1 = 44 (4-36)

The ratios like 44:1 is well within the typical capabilities of worm gear sets. Ratios can commonly range from around 5:1 to 75:1 or even higher in single stage.

So, the Velocity ratio is 44:1 (4-37)

Module (m): The module is a fundamental size parameter of the gear teeth. For a meshing gear with a pitch circle diameter (D_w) and number of teeth (T_G), For worms, it dictates the size of the teeth and ensures proper meshing with the worm gear/wheel. There are two types of modules. One is Axial another one is normal module. The axial Module is measured along the axis of the worm; this determines the axial pitch. The normal module is perpendicular to the teeth surface, relevant for stress calculation but not the primary sizing parameter here. We will calculate the axial module:

$$\mathbf{m} = \frac{P_a}{\pi} = \frac{22}{\pi} = \mathbf{7.007} \approx \mathbf{7}$$

So, the module m = 7. (4-38)

Worm Diameter Factor (q): It is the ratio of the mean diameter of the worm (D_w) to the module (m). Mathematically, A higher value of q generally means a larger worm diameter, which can increase the load carrying capacity. In summary, the worm diameter (D_w) is equal to the Worm Diameter Factor (q) multiplied by the module (m).

This is expressed as:

$$\mathbf{q} = \frac{D_w}{m} = \frac{76.65}{7} = \mathbf{10.95.}$$

So, q is 10.95, (4-39)

**The pitch diameter of the worm gear:** The pitch diameter of the worm gear can be calculated with this formula:

$$D_G = m \times T_G = 7 \times 44 = 308\text{mm}$$

So, D_G is 308mm (4-40)

**Centre distance:** The center distance (a) of a worm gear set is the distance between the axis of the worm and the axis of the worm wheel. It can be calculated using the pitch diameters of the worm (D_w) and the worm Gear/wheel (D_G):

$$a = \frac{D_w + D_G}{2}$$

Substituting these into the center distance formula, we get:

$$a = \frac{m \times (q + T_G)}{2} = \frac{7 \times (10.95 + 44)}{2} = \mathbf{192.325\ mm}$$

**(4-41)**

So, to find the center distance, you typically need to know the axial module (m), the worm diameter factor (q), and the number of teeth on the worm wheel (T_G).

So, a is 192.325 mm. (4-42)

Efficiency of Worm Gearing: The efficiency of worm gearing may be defined as the ratio of work done by the worm gear to the work done by the worm.

Mathematically, the efficiency of worm gearing is given by

$\mu$ = Coefficient of friction = a typical coefficient of steel-to-steel friction = 0.05

$\lambda$ = Lead angle= 5.229°

$\phi$= friction angle,

To get the friction angle, tan$\phi$ =$\mu$

$$\phi = tan^{-1} 0.05$$

$$= 2.865$$

$$\eta = \frac{tan\lambda}{\tan(\lambda + \phi)} = \frac{tan 5.229}{\tan(5.229 + 2.865)} = \mathbf{0.64}$$

This means the efficiency of the worm gear set is approximately 64%. (4-43)

Worm gear efficiency of 64% can be considered moderate. Here's a breakdown to help you judge:

**Typical Range:** Worm gear efficiencies generally range from around 20% to 90%. Efficiency is heavily influenced by the lead angle of the worm and the reduction ratio. Higher reduction ratios typically result in lower efficiencies.

**Comparison to Other Gears:** Compared to some other types of gears like spur or helical gears (which can often achieve efficiencies in the high 90%), 64% is lower. This is due to the significant sliding action between the worm and the worm wheel.

In summary, 64% is a reasonable efficiency for a worm gear, likely better than gears with very high reduction ratios but lower than some other types of gear drives.

Given that your lead angle is quite small (5.229°), efficiency in the 60s is not unexpected. Higher lead angles generally lead to better efficiency.

**Design of Shafts**

Given Parameters:

Number of threads (n) = 1

Number of worm wheel teeth (tg) = 44

Axial pitch (p) = 22 mm

Pitch diameter of the worm (dw) = 76.65 mm

Module (m) = 7 mm

Worm diameter factor (q) = 10.95

Center distance (a) = 192.325 mm

Input motor power = 5.5 kW

Required power for the conveyor belt = 2.23 kW

Motor full load speed = 960 r/min

Required speed for the roller shaft = 59.713 r/min

We will focus on calculating the forces, moments, and stresses on the worm shaft to determine a suitable diameter.

**1. Determine the speeds and velocity ratio:**

- Motor speed, $N_{motor} = 960$ rpm

Required roller shaft speed $N_{gear} = 59.713$ rpm

Velocity ratio, V.R.=N_motor/N_gear =, $V.R. = \frac{N_{motor}}{N_{gear}} = \frac{960}{59.713} \approx 16.08$

The velocity ratio for a worm gear is also given by: $V.R.=\frac{t_g}{n}$Where t_g is the number of worm wheel teeth and n is the number of threads. $V.R.=\frac{44}{1}=44$ There seems to be a discrepancy between the velocity ratio calculated from the speeds and the number of teeth/threads. We will proceed using the parameters related to the worm and gear design.

**2. Calculate the torque on the worm shaft:**

First, let's find the torque on the gear shaft (driven by the motor): P_motor$\frac{2\pi N_{motor}T_{motor}}{60}$ $T_{motor}=\frac{60\times P_{motor}}{2\pi N_{motor}}=\frac{60\times 5.5\times 10^3}{2\pi\times 960}\approx 54.7$ N-m

$$=54.7\times 10^3 \text{ N-mm} \quad (4\text{-}45)$$

Now, considering the power transmitted to the conveyor belt, we can estimate the torque on the gear (worm wheel): P_gear $P_{gear}=\frac{2\pi N_{gear}T_{gear}}{60}$

$T_{gear}=\frac{60\times P_{gear}}{2\pi N_{gear}}=\frac{60\times 2.23\times 10^3}{2\pi\times 59.713}$

$\approx 357.2$ N-m $=357.2\times 10^3$ N-mm **(4-46)**

Assuming an efficiency (η) for the worm gear drive (let's assume η=0.8 for now, if you have a more accurate value, please provide it), the torque on the worm shaft (T_worm) can be estimated: : $T_{gear}\approx T_{worm}\times V.R.\times\eta$ $T_{worm}\approx\frac{T_{gear}}{V.R.\times\eta}=\frac{357.2\times 10^3}{44\times 0.8}\approx 10.17\times 10^3$ N-mm **(4-47)**

Alternatively, we can relate the input power to the worm shaft torque directly: : $P_{motor}\times\eta\approx\frac{2\pi N_{motor}T_{worm}}{60}$ $T_{worm}\approx\frac{60\times P_{motor}\times\eta}{2\pi N_{motor}}=\frac{60\times 5.5\times 10^3\times 0.8}{2\pi\times 960}\approx 43.76$ N-m $=43.76\times 10^3$ N-mm **(4-48)**

The provided images seem to consider the torque acting on the worm gear first. Let's follow that approach and use the value related to the output power. So, we'll use T_worm≈10.17× 〖10〗^3 " N-mm" .

**3. Calculate the forces on the worm shaft:**

We need to determine the tangential (W_t), axial (W_a), and radial (W_r) forces acting on the worm. These forces are related to the torque and the geometry of the worm.

Pitch diameter of the worm, d_w=76.65 mm (4-49)

The tangential force on the worm (W_(t,w)) is related to the torque on the worm: $T_{worm}=\frac{W_{t,w}\times d_w}{2}$

$W_{t,w}=\frac{2\times T_{worm}}{d_w}=\frac{2\times 10.17\times 10^3}{76.65}\approx 265.4$ N**(4-50)**

This tangential force on the worm is the axial force on the worm gear $(W_{a,g})$. $W_{a,g}=W_{t,w}\approx 265.4$ N **(4-51)**

The axial force on the worm (W_(a,w)) is the tangential force on the worm gear (W_(t,g)). We can find W_(t,g) from the torque on the gear: T_gear $T_{gear}=\frac{W_{t,g}\times d_g}{2}$We need the pitch diameter of the gear (d_g). We know the module $m=7$and the number of $t_g=44$, so:$d_g=m\times t_g=7\times 44=308$ mm $W_{t,g}=\frac{2\times T_{gear}}{d_g}=\frac{2\times 357.2\times 10^3}{308}\approx 2319.5$ So, the axial force on the worm is:W:$W_{a,w}=W_{t,g}\approx 2319.5$ N **(4-52)**

The radial force (W_r) depends on the pressure angle (α). Assuming a standard pressure angle of 〖20〗^∘: $W_r=W_{t,g}\tan\alpha=2319.5\times\tan(20^\circ)\approx 846.3$ N **(4-53)**

Distance between 2 bearings, $a_w=\frac{L_w}{2}=\frac{408.10}{2}=204.05$ mm. **(4-55)**

Now,

- Bending Moments: Assume the worm gear is located centrally between the bearings.

The distance from each bearing to the gear mesh is $M_{vr} = \frac{W_r \times a_w \times (L_w - a_w)}{L_w} = \frac{846.3 \times 204.05 \times 204.05}{408.10} = \frac{35290899.3}{408.10} \approx$ 86476.1 N-mm **(4-56)**

- Bending moment due to W_(t,w) (horizontal plane): $M_{ht} = \frac{W_{t,w} \times a_w \times (L_w - a_w)}{L_w} = \frac{265.4 \times 204.05 \times 204.05}{408.10} = \frac{11063680.7}{408.10}$
- $\approx$ 27109.7 N-mm **(4-57)**

- Resultant Bending Moment **($M_{bw}$):** $M_{bw} = \sqrt{M_{vr}^2 + M_{ht}^2} = \sqrt{(86476.1)^2 + (27109.7)^2} = \sqrt{7478028830 + 734939731} = \sqrt{8212968561} \approx$ 90625.4 N-mm **(4-58)**

Torque on the worm shaft **($T_{worm}$):** $10.17 \times 10^3$ N-mm

Equivalent Twisting Moment (T_(eq,w)): **($T_{eq,w}$):**

$T_{eq,w} = \sqrt{M_{bw}^2 + T_{worm}^2} =$

$\sqrt{(90625.4)^2 + (10170)^2} =$

$\sqrt{8212968561 + 103428900} =$

$\sqrt{8316397461}$

$\approx$ 91194.3 N-mmb **(4-59)**

Equivalent Bending Moment $M_{eq,w} = \frac{1}{2}\left(M_{bw} + T_{eq,w}\right) = \frac{1}{2}(90625.4 + 91194.3) =$

90909.85 N-mm **(4-60)**

Required Shaft Diameter (based on strength): Let's assume an allowable shear stress τ_all=50 MPa.

T_(eq,w)=π/16 τ_all d_w^3 $\tau_{all} = 50$ MPa.

$T_{eq,w} = \frac{\pi}{16}\tau_{all} d_w^3$ $d_w^3 = \frac{16 \times T_{eq,w}}{\pi \times \tau_{all}} = \frac{16 \times 91194.3}{\pi \times 50} \approx$ 9309.8 $d_w = \sqrt[3]{9309.8} \approx 21.06$ mm **(4-61)**

$\sigma_{all} = 100$ MPa. $M_{eq,w} = \frac{\pi}{32}\sigma_{all} d_w^3$

$d_w^3 = \frac{32 \times M_{eq,w}}{\pi \times \sigma_{all}} = \frac{32 \times 90909.85}{\pi \times 100} \approx 9257.7$

$d_w = \sqrt[3]{9257.7} \approx 21.0$ mm **(4-62)**

The required diameter based on strength is around 21 mm, much smaller than the 70 mm bore of the bearings. This confirms that the 70 mm diameter is likely chosen for other reasons (like stiffness, bearing size availability, or existing design standards).

**Worm Wheel Shaft Design (Bearing distance L_g=284.42 mm, bore diameter 70 mm):**

**Forces on the worm wheel:**

- Tangential ($W_{t,g}$): 2319.5 N (axial on worm)
- Axial ($W_{a,g}$): 265.4 N (tangential on worm)
- Radial ($W_r$): 846.3 N

**Bending Moments:** Assume the worm wheel is located centrally between the bearings. The distance from each bearing to the gear mesh is $a_g = L_g/2 = 284.42/2 = 142.21$ mm. **(4-63)**

**Bending moment due to $W_{a,g}$ (horizontal plane):** $M_{ha} = \frac{W_{a,g} \times a_g \times (L_g - a_g)}{L_g} = \frac{265.4 \times 142.21 \times 142.21}{284.42} = \frac{5380898.6}{284.42}$ $\approx$ 18911.8 N-mm **(4-64)**

**Bending moment due to $W_r$ (vertical plane):** $M_{vr} = \frac{W_r \times a_g \times (L_g - a_g)}{L_g} = \frac{846.3 \times 142.21 \times 142.21}{284.42} = \frac{17180354.8}{284.42} \approx$ 60405.6 N-mm **(4-65)**

**Resultant Bending Moment ($M_{bg}$):** $M_{bg} = \sqrt{M_{ha}^2 + M_{vr}^2} = \sqrt{(18911.8)^2 + (60405.6)^2} = \sqrt{357650985 + 3648830797} = \sqrt{4006481782}$ $\approx$ 63300.09 N-mm **(4-66)**

**Torque on the worm wheel shaft ($T_{gear}$):** $357.2 \times 10^3$ N-mm

**Equivalent Twisting Moment ($T_{eq,g}$):** $T_{eq,g} = \sqrt{M_{bg}^2 + T_{gear}^2} = \sqrt{(63300.09)^2 + (357.2 \times 10^3)^2} = \sqrt{4006481782 + 127591840000} = \sqrt{131598321782} \approx$ 362764.8 N-mm **(4-68)**

**Equivalent Bending Moment ($M_{eq,g}$):** $M_{eq,g} = \frac{1}{2}\left(M_{bg} + T_{eq,g}\right) = \frac{1}{2}(63300.09 + 362764.8) =$ 213032.45 N-mm **(4-69)**

**Required Shaft Diameter (based on strength):**

Using $\tau_{all} = 50$ MPa: $d_g^3 = \frac{16\times T_{eq,g}}{\pi\times\tau_{all}} = \frac{16\times 362764.8}{\pi\times 50} \approx$ 37093.8 $d_g = \sqrt[3]{37093.8} \approx 33.4$ mm **(4-70)**

Using $\sigma_{all} = 100$ MPa: $d_g^3 = \frac{32\times M_{eq,g}}{\pi\times\sigma_{all}} = \frac{32\times 213032.45}{\pi\times 100} \approx$ 21700.8 $d_g = \sqrt[3]{21700.8} \approx 27.9$ mm **(4-71)**

The required diameter for the worm wheel shaft based on strength is around 33.4 mm (using equivalent twisting moment), which is also smaller than the 70 mm bore of the bearings.

**Conclusion on Shaft Design:**

The calculations show that the minimum required shaft diameters based on strength are significantly smaller than the 70 mm bore of the bearings. This strongly suggests that the 70 mm diameter is chosen based on other factors such as:

- **Bearing Availability:** It might be a standard size that fits the overall design.
- **Stiffness:** A larger diameter provides greater stiffness, reducing deflection under load, which is important for gear meshing and bearing life.
- **Housings and Mountings:** The design of the housings and other components might be based on a 70 mm shaft diameter.
- **Factor of Safety:** A larger diameter inherently provides a higher factor of safety against failure.
- **Keyway Size:** If keyways are used to mount the worm and worm wheel, a larger shaft diameter allows for larger and stronger keyways.

**Bearing Design**

**Worm Shaft Bearing Design (70 mm bore, 1 pair):**

1. **Loads:**
   - Radial load ($W_r$): 846.3 N (shared by the two bearings)
   - Axial load ($W_{a,w}$): 2319.5 N (handled by both bearings)
   - Speed ($n_w$): 960 rpm
2. **Bearing Selection (Example):** Two SKF 7314 BE single row angular contact ball bearings (70 mm bore). These are suitable for handling both radial and axial loads. We'll mount them in a back-to-back or face-to-face configuration to handle thrust in both directions.
3. **Equivalent Dynamic Load ($P$) for one bearing:** We need the $X$ and $Y$ factors from the SKF 7314 BE datasheet. Assuming $F_a/(VF_r) > e$, the formula is $P = XF_r + YF_a$. Let's get approximate values from memory (you should use the datasheet for precise values): $X \approx 0.56$, $Y \approx 1.7$, $V = 1$.
   Assuming each bearing takes half the radial load and the full axial load: $F_r = 846.3/2 = 423.15$ N
   $F_a = 2319.5$ N **(4-77)**
   $P = (0.56 \times 423.15) + (1.7 \times 2319.5) = 237 +$ $3943.15 = 4180.15$ N **(4-72)**
4. **Basic Dynamic Load Rating ($C$) of SKF 7314 BE:** From the datasheet (approximately), $C = 95.6$ kN = 95600 N. **(4-73)**
5. **Bearing Life ($L_{10}$):** $L_{10} = \left(\frac{C}{P}\right)^3 = \left(\frac{95600}{4180.15}\right)^3 =$ $(22.87)^3 \approx 11930$ million revolutions. **(4-74)**
6. **Life in Hours ($L_{10h}$):** $L_{10h} = \frac{L_{10}\times 10^6}{n_w\times 60} = \frac{11930\times 10^6}{960\times 60} \approx$ 207118 hours. **(4-75)**
   This life is significantly longer than a typical desired life of 20,000 hours, indicating that the chosen bearings are likely suitable for the worm shaft.

**Worm Wheel Shaft Bearing Design (70 mm bore, 1 pair):**

1. **Loads:**
   - Radial load ($W_r$): 846.3 N (shared by the two bearings)
   - Axial load ($W_{a,g}$): 265.4 N (handled by both bearings)
   - Speed ($n_g$): 59.713 rpm
2. **Bearing Selection (Example):** Two SKF 6314 deep groove ball bearings (70 mm bore). These can handle both radial and moderate axial loads.
3. **Equivalent Dynamic Load ($P$) for one bearing:** We need the $X, Y$, and $e$ factors from the SKF 6314 datasheet. Let's use approximate values: $X \approx 0.56$, $Y \approx 1.2$ (if $F_a/(VF_r) > e$), $V = 1$. We need to check $e$. For deep groove ball bearings, $e$ is typically around 0.3.
   Assuming each bearing takes half the radial load and the full axial load: $F_r = 846.3/2 = 423.15$ N
   $F_a = 265.4$ N **(4-76)**
   $F_a/(VF_r) = 265.4/(1 \times 423.15) \approx 0.627$. Since $0.627 > 0.3$ (our assumed $e$), we use the combined load formula.
   $P = (0.56 \times 423.15) + (1.2 \times 265.4) = 237 +$ $318.48 = 555.48$ N **(4-77)**

4. **Basic Dynamic Load Rating ($C$) of SKF 6314:** From the datasheet (approximately), $C = 95$ kN = 95000 N. **(4-78)**
5. **Bearing Life ($L_{10}$):** $L_{10} = \left(\frac{C}{P}\right)^3 = \left(\frac{95000}{555.48}\right)^3 = (170.99)^3 \approx 4.99 \times 10^6$ million revolutions. **(4-79)**
6. **Life in Hours ($L_{10h}$):** $L_{10h} = \frac{L_{10} \times 10^6}{n_g \times 60} = \frac{4.99 \times 10^{12}}{59.713 \times 60} \approx 1.39 \times 10^9$ hours. **(4-80)**
This calculated life for the deep groove ball bearings on the worm wheel shaft is also extremely long, suggesting they are more than adequate for the loads and speed.

**Coupling**
**Initial Calculations (Assuming Light Shock Loading):**
Let's assume **light shock loading** for now →
**Service Factor** $K_s = 1.25$ **(4-81)**
**Coupling 1 (Motor to Worm Shaft):**
Torque:
$T_{design} = T_0 \times K_s = 23.28 \times 1.25 = 29.1\,\text{Nm}$ **(4-82)**
Shaft diameters: 60 mm on both sides
**Recommendation:** Use a **flexible jaw or elastomer coupling**, e.g., **Lovejoy L150 or L190** with pilot bore 60 mm (Must be custom-bored or have taper-lock bush)
**Coupling 1 (Motor to Worm Shaft):**

- Torque:
  $T_{design} = 74.4 \times 1.25 = 93\,\text{Nm}$ **(4-83)**
- Shaft diameters: 60 mm and 70 mm
- **Recommendation:** Use a **flexible gear coupling or grid coupling**, e.g., **SKF or Falk gear coupling** sized for ≥ 282 Nm and mixed bore sizes

**FEA**
**FEA RESULT OF PLATFORM:**
"Finite Element Analysis (FEA) was conducted to evaluate the structural integrity of the boat platform under a static load of 9800 N, representing a mass of 1000 kg. The analysis,

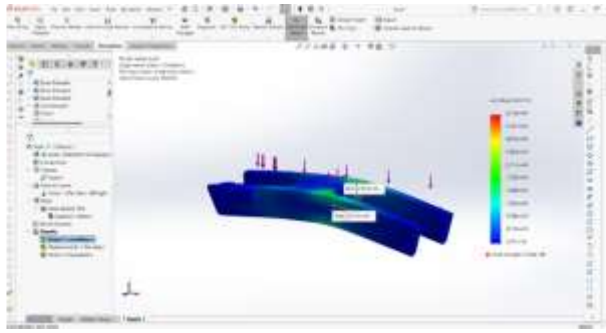


Figure 4.2: PLATFORM FEA

employing a 316 Stainless Steel material model, revealed a complex von Mises stress distribution across the platform's geometry, with peak stresses concentrated in the vicinity of the applied loads and geometric transitions. The maximum calculated von Mises stress was approximately 31.51 kPa, significantly below the material's yield strength of 172.4 MPa. This indicates that under the analyzed static loading conditions, the platform is not predicted to experience permanent deformation due to yielding. While a simplified estimation yields a high factor of safety against yielding, localized stress concentrations and other potential failure modes warrant further consideration in a comprehensive structural evaluation."

**FEA RESULT OF BARRIER:**
The figure shows the von Mises stress distribution on a barrier assembly subjected to a downward force of 1962 N (derived from 200 kg × 9.81 m/s$^2$) distributed along its top surface, indicated by the purple arrows. The barrier is fixed at its ends, as shown by the green supports.

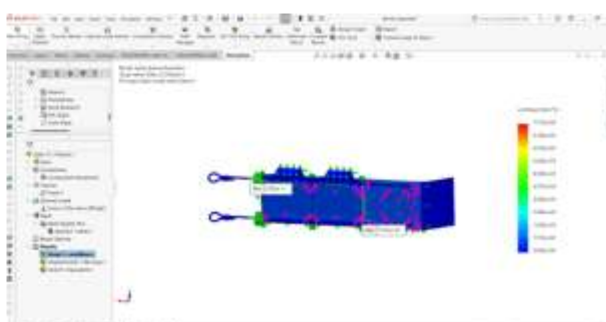


Figure 4.3: BARRIER FEA

**Stress Distribution:** The color gradient on the barrier represents the von Mises stress levels, ranging from blue (low stress) to red (high stress). The legend on the right provides the corresponding stress values in N/m² (Pascals).

**Maximum Stress:** The analysis reveals a maximum von Mises stress of approximately 7.515e+03 N/m² (7.515 kPa), located at the points where the barrier is fixed and where the load is applied. These are likely areas of stress concentration due to the constraints and applied forces.
**Minimum Stress:** The minimum von Mises stress is approximately 5.935e-11 N/m², essentially zero, observed in areas experiencing minimal stress.
**Material:** While the specific material isn't explicitly labeled in the image, the study name "Static 2(-Default-)" suggests it's using a default material setting within SolidWorks for this analysis.

**FEA RESULT OF GARBAGE BIN:**
The figure displays the von Mises stress distribution on a garbage bin subjected to a downward force of 1962 N (derived from 200 kg × 9.81 m/s²) distributed across the internal base, indicated by the purple arrows.The bin is fixed at the bottom edges, likely representing contact with the ground, as indicated by the green supports.

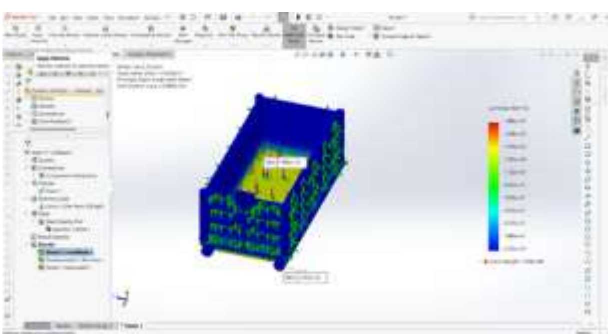


Figure 4.4 : GARBAGE BIN FEA

**Stress Distribution:** The color gradient on the bin represents the von Mises stress levels, ranging from blue (low stress) to red (high stress). The legend on the right shows the corresponding stress values in N/m² (Pascals).
**Maximum Stress:** The analysis indicates a maximum von Mises stress of approximately 1.886e+02 N/m² (188.6 Pa), located at the bottom corners and edges of the bin where it's fixed. These are likely stress concentration points due to the reaction forces at the supports.
**Minimum Stress:** The minimum von Mises stress is approximately 0.00e+00 N/m², observed in areas experiencing minimal deformation and load.
**Yield Strength:** The material's yield strength is given as 1.724e+08 N/m² (172.4 MPa), indicated by the red horizontal line on the stress legend.
**Deformation Scale:** The deformation scale is a very large 5.01699e+09, indicating that the displayed deformation is extremely exaggerated for visualization purposes. The actual deformation is minuscule.
**Material:** The study name in the FeatureManager tree indicates the material used is "Dustbin (Default)". The actual properties of this default material would need to be specified in your thesis for a complete an

## V. CONCLUSION

This thesis addresses the Design and Calculation of the Aquatic Clean-up Bot (ARASAG), focusing on improving the efficiency of river environment management, particularly in the handling of large objects such as tree trunks and industrial plastic waste. We aim to reduce costs by replacing manual labor with machines, while striving to achieve our objectives of "clean water, clear rivers, a fresh taste, and beautiful scenery." Through systematic theoretical analysis, experimental validation, and performance optimization, the following key contributions and achievements were accomplished:

(1) A methodology that integrates flowcharts, product configuration, and concept selection has been designed and implemented. This system employs an advanced autonomous robotic control system to ensure efficient waste collection and stable operation across diverse scenarios.

(2) Comprehensive investigations were undertaken to examine the design and analysis of the waste collection mechanism and the efficiency of the propulsion system in different water currents. This process included the development of 3D models, which were used to optimize the design for effectively capturing various waste sizes

while minimizing energy consumption for long-term operation.

(3) The feasibility and effectiveness of the calculated design parameters for the conveyor belt system were thoroughly evaluated. This evaluation included detailed calculations of force and power requirements for various waste loads and conveyor speeds and simulations of the conveyor's performance under dynamic operating conditions. The findings confirmed the conveyor belt system can efficiently transport collected waste without slippage or excessive power consumption. Additionally, they highlighted its potential to ensure continuous and reliable waste removal from the aquatic environment.

(4) Additionally, a thorough structural and economic analysis was conducted. This included verifying the strength of critical components using fundamental mechanical principles and performing Finite Element Analysis (FEA) to confirm their structural integrity and performance under expected loads. The analysis demonstrated that the proposed design exhibits strong structural performance and economic feasibility. It highlighted advantages such as reliability, cost-effectiveness, and long-term operational efficiency when compared to traditional methods.

While this thesis presents a comprehensive analysis, it is important to acknowledge its limitations. Key areas requiring further exploration include the calculation of forces exerted by the six-axis robotic hand, an accurate assessment of the project's total weight, and a detailed evaluation of the overall project costs. Additionally, field testing is essential to validate the theoretical findings and ensure practical applicability. Addressing these aspects in future work will enhance the robustness of the research and its contributions to the field.

## REFERENCE

1. Yao, Chengkai. 2021. “Floating Garbage Collector Based on OpenMV.” Journal of Physics: Conference Series 1952(3):032058. doi:10.1088/1742-6596/1952/3/032058.
2. Nair, Sreejith S., A. P. Sudheer, and M. L. Joy. 2019. “Design and Fabrication of River Cleaning Robot.” Pp. 1–8 in Proceedings of the Advances in Robotics 2019. Chennai India: ACM.
3. Kim, Sung-Joong, Do-Joon Jung, Joon-Gu Kang, Hong-Koo Yeo, and Jong-Tae Kim. 2016. “Verification on Debris Reduction Ability of the Sweeper by Real Scale Experiment.” Journal of the Korea Academia-Industrial Cooperation Society 17(9):34–44. doi:10.5762/kais.2016.17.9.34.
4. Amini, Adib, Youngwoon Kim, Jie Zhang, Treavor Boyer, and Qiong Zhang. 2015. “Environmental and Economic Sustainability of Ion Exchange Drinking Water Treatment for Organics Removal.” Journal of Cleaner Production 104:413–21. doi:10.1016/j.jclepro.2015.05.056.
5. Hidayat, A. M., A. H. Hamisa, R. Razman, and A. H. Yunus. 2021. “Preliminary Design Concept of Garbage Collecting Machine.” Journal of Physics: Conference Series 2000(1):012001. doi:10.1088/1742-6596/2000/1/012001.
6. Othman, Hirdy, Mohammad Iskandar Petra, Liyanage Chandratilak De Silva, and Wahyu Caesarendra. 2020. “Automated Trash Collector Design.” Journal of Physics: Conference Series 1444(1):012040. doi:10.1088/1742-6596/1444/1/012040.
7. Ruman, Md. Raseduzzaman, Mukta Das, S. M. Istiaque Mahmud, and Shantanu Kumar Nath. 2019. “Automated Marine Surface Trash Cleaner.” Pp. 1–4 in 2019 IEEE 5th International Conference for Convergence in Technology (I2CT). Bombay, India: IEEE.
8. Koskinopoulou, Maria, Fredy Raptopoulos, George Papadopoulos, Nikitas Mavrakis, and Michail Maniadakis. 2021. “Robotic Waste Sorting Technology: Toward a Vision-Based Categorization System for the Industrial Robotic Separation of Recyclable Waste.” IEEE Robotics & Automation Magazine 28(2):50–60. doi:10.1109/mra.2021.3066040.
9. Jakubovičová, L., P. Kopas, M. Vaško, and M. Handrik. 2021. “Technical Solution of the Modern Conveyor System.” IOP Conference Series: Materials Science and Engineering 1199(1):012031. doi:10.1088/1757-899x/1199/1/012031.
10. Tupkar, Rupali, Devesh Kumar, and Chandrashekhar Sakhale. 2024. “Material

Selection and Parametric Evaluation for Medium Duty Belt Conveyor: A Review on Current Status and Future Directions." Materials Today: Proceedings. doi:10.1016/j.matpr.2024.04.021.

11. Bejo, Agus, Wanchalerm Pora, and Hiroaki Kunieda. 2009. "Development of a 6-Axis Robotic Arm Controller Implemented on a Low-Cost Microcontroller." Pp. 328–31 in 2009 6th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology. Chonburi, Thailand: IEEE
12. Sahu, Supriya, B. B. Choudhury, and B. B. Biswal. 2017. "A Vibration Analysis of a 6 Axis Industrial Robot Using FEA." Materials Today: Proceedings 4(2):2403–10. doi:10.1016/j.matpr.2017.02.090.
13. Talli, Amit, and Vinod Kumar V Meti. 2020. "Design, Simulation, and Analysis of a 6-Axis Robot Using Robot Visualization Software." IOP Conference Series: Materials Science and Engineering 872(1):012040. doi:10.1088/1757-899X/872/1/012040.
14. Teja Priyanka, D., G. Narasimha Swamy, V. Naga Prudhvi Raj, E. Naga Lakshmi, M. Maha Tej, and M. Purna Jayanthi. 2024. "Design and Development of Six-Axis Robotic Arm for Industrial Applications." Pp. 273–83 in Proceedings of Congress on Control, Robotics, and Mechatronics. Vol. 364, Smart Innovation, Systems and Technologies, edited by P. K. Jha, B. Tripathi, E. Natarajan, and H. Sharma. Singapore: Springer Nature Singapore.
15. Tung, Tran Thanh, Nguyen Van Tinh, Dinh Thi Phuong Thao, and Tran Vu Minh. 2023. "Development of a Prototype 6 Degree of Freedom Robot Arm." Results in Engineering 18:101049. doi:10.1016/j.rineng.2023.101049.
16. Kumar Moluguri, Naresh, Ch. Rama Murthy, and V. Harshavardhan. 2016. "Solar Energy System and Design - Review." Materials Today: Proceedings 3(10):3637–45. doi:10.1016/j.matpr.2016.11.007.
17. Maka, Ali O. M., and Jamal M. Alabid. 2022. "Solar Energy Technology and Its Roles in Sustainable Development." Clean Energy 6(3):476–83. doi:10.1093/ce/zkac023.
18. Sarmah, Pranjal, Dipankar Das, Madhurjya Saikia, Virendra Kumar, Surendra Kumar Yadav, Prabhu Paramasivam, and Seshathiri Dhanasekaran. 2023. "Comprehensive Analysis of Solar Panel Performance and Correlations with Meteorological Parameters." ACS Omega 8(50):47897–904. doi:10.1021/acsomega.3c06442.
19. Thanh, Tung Nguyen, Phap Vu Minh, Kien Duong Trung, and Tuan Do Anh. 2021a. "Study on Performance of Rooftop Solar Power Generation Combined with Battery Storage at Office Building in Northeast Region, Vietnam." Sustainability 13(19):11093. doi:10.3390/su131911093.
20. Julianto, Rizki Ispramudita, Teguh Muttaqie, Ristiyanto Adiputra, Syamsul Hadi, Raymundus Lullus Lambang Govinda Hidajat, and Aditya Rio Prabowo. 2020. "Hydrodynamic and Structural Investigations of Catamaran Design." Procedia Structural Integrity 27:93–100. doi:10.1016/j.prostr.2020.07.013.
21. Lee, Seung-Hee, Young-Gill Lee, and Sang-Hyun Kim. 2007. "On the Development of a Small Catamaran Boat." Ocean Engineering 34(14–15):2061–73. doi:10.1016/j.oceaneng.2007.02.011.
22. Li, Qiao, Guanglei Xu, Jinxin Zhou, Shuchuang Dong, Yoichi Mizukami, and Daisuke Kitazawa. 2023. "An Experimental Study on the Stability of a Catamaran Boat Equipped with an Underwater Camera." Pp. 1–5 in 2023 IEEE Underwater Technology (UT). Tokyo, Japan: IEEE.
23. Mandru, A., and F. Pacuraru. 2020. "Experimental Study on Catamaran Hydrodynamics." IOP Conference Series: Materials Science and Engineering 916(1):012060. doi:10.1088/1757-899X/916/1/012060.
24. Wang, Ziting, Wenbo Li, and Yibin Shao. 2022. "Research on a New Type of Catamaran with Shock-Absorbing and Energy-Saving Suspension Structure." Highlights in Science, Engineering and Technology 15:128–35. doi:10.54097/hset.v15i.2214.
25. Amen, Rabia, Alhassan Ibrahim, Waqar Shafqat, and El Barbary Hassan. 2023. "A Critical Review on PFAS Removal from Water: Removal Mechanism and Future Challenges." Sustainability 15(23):16173. doi:10.3390/su152316173.

26. Fuchs, Yannic, Susanne Scherbaum, Richard Huber, Nils Rüther, and Arnd Hartlieb. 2024. "Removing Plastic Waste from Rivers: A Prototype-Scale Experimental Study on a Novel River-Cleaning Concept." Water 16(2):248. doi:10.3390/w16020248.
27. Li, Li, Gyumin Lee, and Doosun Kang. 2025. "Energy Consumption and Greenhouse Gas (GHG) Emissions in Urban Wastewater Treatment Facilities: A Case Study of Seoul Metropolitan City (SMC)." Water 17(4):464. doi:10.3390/w17040464.
28. Fang, Bingbing, Jiacheng Yu, Zhonghao Chen, Ahmed I. Osman, Mohamed Farghali, Ikko Ihara, Essam H. Hamza, David W. Rooney, and Pow-Seng Yap. 2023. "Artificial Intelligence for Waste Management in Smart Cities: A Review." Environmental Chemistry Letters 21(4):1959–89. doi:10.1007/s10311-023-01604-3.
29. Morrison, Evan, Alexandra Shipman, Shradha Shrestha, Evan Squier, and Kaitlin Stack Whitney. 2019. "Evaluating The Ocean Cleanup, a Marine Debris Removal Project in the North Pacific Gyre, Using SWOT Analysis." Case Studies in the Environment 3(1):1–6. doi:10.1525/cse.2018.001875.
30. Cheng, Tianhao, Daiki Kojima, Hao Hu, Hiroshi Onoda, and Andante Hadi Pandyaswargo. 2024. "Optimizing Waste Sorting for Sustainability: An AI-Powered Robotic Solution for Beverage Container Recycling." Sustainability 16(23):10155. doi:10.3390/su162310155.
31. 机械设计课程设计=Course Design for Machinery Design: 英文/何波主编,一西安: 西北工业大学出版社,2017.6 : ISBN 978-7-5612-5384-7