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DESIGN AND DEVELOPMENT OF UMNMANNED GROUND VEHICLE (UGV) WITH SPHERICAL WHEELS

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PROJECT REPORT

Design and Development of Unmanned Ground Vehicle (UGV) with Spherical Wheels

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ABSTRACT

An unmanned ground vehicle is a mobile robot that moves around without any human and it is generally remote operated. The UGV's chassis is constructed from lightweight yet durable materials, allowing for ease of transport and deployment in various environments. The UGV's modular design allows for easy customization and integration of additional sensors and payloads. Its quality of being light weight and compact makes it highly desirable to be used in missions that involve high levels of risk and danger like surveillance, inspection, reconnaissance. Since previous models of UGVs consisted of two or four wheels, the limitation lied in the maneuverability of the robot. Our project was aimed to design and develop a prototype of UGV which was omni directional. Spherical wheels, introduced as new type of omni-wheels were designed, 3D printed, and the rest of the body was manufactured keeping in mind to keep the robot lightweight as possible. The wheels had an active rotational component as well as a passive one. Complete calculations and analysis of the wheels were done using ANSYS and the research was concluded with suggestions of materials that could be used for the manufacturing of wheels on an industrial scale to make the robot throwable.

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ANCROYNMS

UGV Unmanned Ground Vehicle

ODV Omni- Directional Vehicle

OCU Operationa**l** Control Unit

PCTPE Plasticized Copolyamide Thermoplastic Elastomer

TPU Thermoplastic

CAD Computer-Aided Design

Chapter 1 – INTRODUCTION

Unmanned ground vehicles (UGVs), commonly referred to as such in the engineering domain, encompass a category of autonomous robots. UGVs are distinguished as robotic conveyances that traverse terrestrial surfaces devoid of human involvement, employing either self-governance or remote manipulation. These vehicles incorporate an array of sensory apparatus, including Global Positioning System (GPS) receivers, Light Detection and Ranging (LiDAR) devices, and cameras, enabling them to procure spatial data concerning their environs and effectively navigate intricate landscapes. UGVs find wide-ranging applications across sectors such as defense, agriculture, and industry, wherein they undertake an assortment of endeavors spanning from information gathering and monitoring to logistical transportation. Notably, with the advent of cutting-edge advancements in artificial intelligence (AI) and robotics, UGVs are progressively capable of operating within arduous terrains and executing intricate tasks with a remarkable degree of precision.

Unmanned Ground Vehicles (UGVs) are experiencing surging popularity across diverse sectors due to their notable technical prowess. UGVs, operating autonomously or under teleoperation, undertake terrestrial operations devoid of human intervention. These vehicles find extensive technical utility spanning numerous industries. In the military domain, UGVs fulfill critical roles encompassing transportation, logistics, and surveillance. Equipped with an array of sensors and cameras, UGVs adeptly navigate intricate landscapes while simultaneously gathering comprehensive environmental data. UGVs offer a plethora of technical advantages in comparison to manned vehicles, particularly for tasks demanding the utmost precision and accuracy. They demonstrate exceptional accuracy in executing intricate endeavors and excel in hazardous environments. Additionally, UGVs' compact size and affordability render them highly cost-effective. These vehicles are also harnessed in cloud seeding operations and monitoring, necessitating multiple sensors and real-time data processing systems capable of handling diverse formats. Nevertheless, the current state of computing technology poses limitations in achieving human-like levels of autonomy in UGVs. Anticipated future advancements encompassing hardware technology, specialized digital hardware, and multimodal sensory approaches hold promise for surmounting these limitations.

UGVs have certain advantages over traditional manned vehicles, which require a human presence for their operation, that enlist efficiency, improved safety, and enhanced versatility. Along with these, unmanned ground vehicles (UGVs) offer a plethora of advantages compared to manned counterparts, particularly in high-risk scenarios where human safety is jeopardized. UGVs excel in environments deemed perilous or inhospitable for human presence, such as minefields, nuclear power plants, and disaster-stricken areas. They prove instrumental in executing monotonous or laborious activities like patrolling, reconnaissance, and surveillance. Furthermore, UGVs can be designed to possess a smaller form factor and exhibit enhanced affordability relative to manned vehicles, rendering them economically viable for tasks that do not necessitate human intervention. In contrast, manned vehicles have limitations in terms of their size and maneuverability in tight or hazardous spaces. They also require human operators who can be at risk in hazardous environments. Manned vehicles can also be expensive to operate and maintain, particularly in comparison to UGVs.

Unmanned Ground Vehicles (UGVs) exhibit unmatched versatility and adaptability, making them an indispensable solution for addressing multifaceted challenges across a wide range of industries. This comprehensive article delves into the extraordinary applications and potential of UGVs within various technical domains.

Military Applications:
The integration of UGVs in the military sector has witnessed extensive progress, encompassing pivotal roles in reconnaissance, surveillance, logistics, and transportation. These UGVs effectively augment human-operated systems while mitigating risks to human lives in hazardous environments, including minefields and nuclear facilities. Equipped with advanced sensors and communication systems, UGVs provide invaluable situational awareness and facilitate swift decision-making processes on the battlefield.

Agricultural Advancements:
UGVs present compelling solutions in the realm of agriculture, revolutionizing efficiency and productivity. Autonomous UGVs excel in tasks such as precision spraying, crop monitoring, and yield estimation, resulting in optimized resource utilization and increased crop yields. Leveraging advanced sensors such as LiDAR and multispectral cameras, UGVs acquire real-time data, enabling intelligent decision-making for farmers and agronomists.

Industrial Automation:
UGVs have emerged as invaluable assets in industrial automation, facilitating material handling, inventory management, and assembly line operations. These autonomous vehicles navigate intricate factory environments, leveraging sensor fusion and perception algorithms to ensure safe and efficient operations. UGVs enhance productivity, reduce labor costs, and improve workplace safety by undertaking repetitive or hazardous tasks.

Disaster Response and Search and Rescue:
UGVs play a pivotal role in search and rescue operations during natural disasters or emergency situations. Equipped with sensors, cameras, and robotic arms, these vehicles adeptly navigate through challenging terrains, detect survivors amidst the rubble, and deliver vital supplies. UGVs enable first responders to access perilous areas, minimizing human risks and expediting rescue efforts.

Exploration and Surveying:
UGVs prove invaluable in exploration missions, both on Earth and beyond. They are deployed in harsh and remote environments, such as polar regions and extraterrestrial terrains, to gather scientific data and conduct geological surveys. UGVs equipped with cutting-edge imaging systems and drilling tools contribute to our understanding of inaccessible areas, facilitating scientific breakthroughs and resource exploration.

Within the existing UGV models at the facility, a recurring issue has been identified regarding the design of the robotic vehicle. To address this challenge, a solution in the form of an omni-directional vehicle (ODV) is being proposed. The ODV represents an advanced ground support utility vehicle with exceptional capabilities, allowing it to successfully perform a wide array of tasks while possessing a remarkable zero-degree turning radius.

The key element contributing to the ODV's outstanding maneuverability is the integration of a rotary hitch mechanism, strategically positioned on its outer ring. This unique feature enables the ODV to seamlessly execute pushing or pulling actions, resulting in heightened versatility and efficiency when undertaking various operations. Whether it involves pushing substantial loads or pulling equipment, the ODV's design and functionality establish it as an invaluable asset within numerous industrial and logistical contexts.

To realize the implementation of the ODV model, an innovative wheel design has been proposed. These wheels are derived from the concepts of omni and Mecanum wheels yet reimagined with a spherical shape comprising dual hemispheres. This specific design facilitates effortless maneuverability, even in passive mode, granting the ODV enhanced operational flexibility. Additionally, the utilization of spherical wheels presents a notable advantage in terms of cost-effectiveness during the production phase, surpassing the cost of current market-available wheels with comparable applications.

The introduction of the Omni Directional Vehicle (ODV), featuring state-of-the-art capabilities and an innovative wheel design, holds the potential to effectively mitigate the prevailing issues of redundancy. This pioneering development offers a compelling solution that aligns with the operational demands of the facility. As a result, the facility's UGV fleet is poised to experience substantial improvements, leading to optimized performance across a multitude of tasks and operational scenarios.

The future of UGVs holds immense potential, driven by ongoing advancements in AI, machine learning, and sensor technology. Enhancements in computing power, energy efficiency, and communication systems will continue to fuel innovation in UGV capabilities. However, challenges persist, such as achieving higher levels of autonomy, ensuring robust cybersecurity measures, and addressing ethical considerations surrounding UGV deployment. Unmanned Ground Vehicles (UGVs) have revolutionized diverse industries through their exceptional capabilities and technical advancements. From military operations and agriculture to industrial automation, disaster response, and exploration, UGVs consistently demonstrate their potential in enhancing productivity, safety, and efficiency.

Chapter 2 - BACKGROUND AND LITERATURE REVIEW

2.1 Background

An Unmanned Ground Vehicle (UGV) is a vehicle that operates on ground without the need of a human. It is generally remote operated. As the operations undertaken by a UGV are done without a human, it is used in missions that present danger or inconvenience, such a reconnaissance, surveillance, inspection, etc.
A UGV with omni or Mecanum wheels has more degrees of mobility due to the nature of the wheels. This is due to the fact that these wheels have an active rotational component as well as a passive one. This greater freedom of movement allows for greater ease of control in direction changes. With this new feature, the UGV can be more effective in operations and will overall be easier to operate even in inexperienced hands.

2.2 Motivation

From four-wheeler to two-wheeler, UGVs have gone through many redesigning and such extensive work on such types of UGVs have given way to their production on industrial scale in Pakistan. However, very little work has been done on the use of spherical wheels and incorporating them onto a UGV will widen the scope of such types of wheels in the industry.

2.3 Models and Types

In the past, many different types of UGVs have been built. Given below will be a few generic wheeled UGVs as well as some omni-wheeled based UGVs. The purpose of this is to be able to compare the different types of UGV in both design and performance.

2.3.1 Sand Flea Bot (2009)

[1]Sand flea bot is the creation of researchers at Sandia National Laboratories and Boston Dynamics in 2009. Sand Flea is a water-resistant robot that can function in tough environments such as high humidity, salt, oil, and sand extremes. It can work in temperatures ranging from -15°C to 45°C (5°F to 113°F), which could be a problem given that the US military plans to test nine of these robots in Afghanistan, where summer temperatures can reach 49°C (120°F).
The bot's dimensions are stated 33cm x 45.7cm x 15.2cm (13" L x 18" W x 6"H) and weighs 5 kg (11 pounds). The bot is a generic 4 wheeled bot that has a unique function to jump. Jump height ranges from to 8 meters (3.3 to 26 feet). It is powered by a rechargeable Li-7 polymer battery that enables 2 hours of operation and can move at 5.5 km/h (3.4 mph).

The Sand Flea robot’s back end is controlled by a piston actuator. A disposable CO2 fuel cartridge powers the piston actuator and provides enough energy for 25 hops. The robot has a customizable launch angle and laser-based range that makes targeting before launch easier. It is controlled by an Operator control unit (OCU) with live video feed.
The on-board cameras have adjusted 6W visible and 6W infrared for recon in the dark, and the resolution is 1280x960 pixels for pictures and 320x240 pixels for video streaming.
The bot utilizes gyro stabilization while midair to keep itself level as well as provide good camera angles. The robot's movement is invertible when it lands on its other side since the wheels are larger than its main body. The wheels are also designed to cushion the impact of landing.

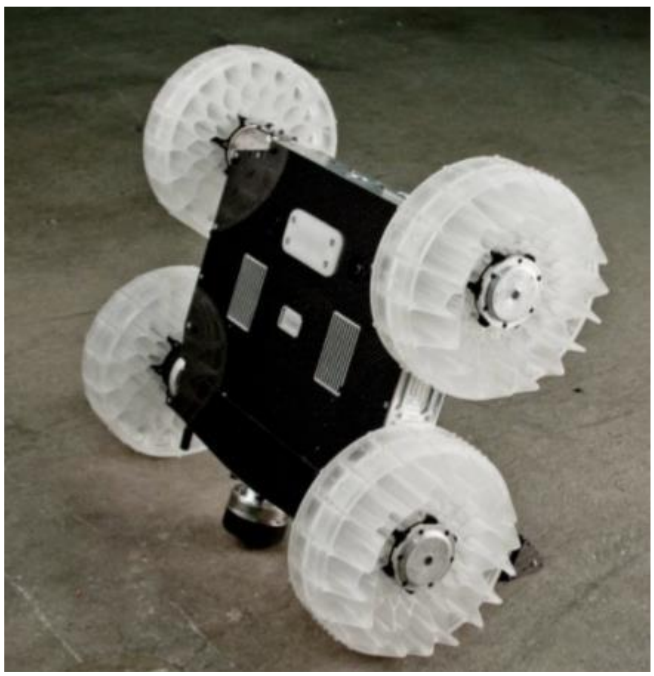


Figure 1. Sand Flea Robot (2009)

2.3.2 Nerva LG (2012)

“NERVA LG[2] is the first product in the Nexter Robotics line, which also consists of NERVA-S mini robot and NERVA-HD multi-mission robot”. A thermal imaging / infrared camera with uncooled detector allow operations in low light / night conditions.
The robot has a length of 350mm, width of 310mm and height of 150mm, and weighs 4.5kg.

The robot features a pusher actuator for mechanical action on suspicious objects, an audio intercom bi-directional communication system to receive operator voice and predefined sounds.
It is compatible with payloads such as CBRN detectors, lighting system, exploration, and self-mapping kits, anti-IED tool kit, non-lethal grenade, and smoke generator together with anti-intruder and position-marking devices.

Figure 2. Nerva LG (2012)

2.3.3 Nerva S

NERVA S[3] is a 2-wheeled compact robotic platform, equipped with one day high-Definition camera, one thermal camera and one microphone; it is operated using standard based equipment. As a highly rugged platform, NERVAS can be thrown without any damage on concrete floors at distances over several meters, even from a moving vehicle. Very compact when in transport configuration, NERVAS is powered in seconds by simply extending the rear tail; this one is also used for balancing the platform. The figure and parameters are shown below:

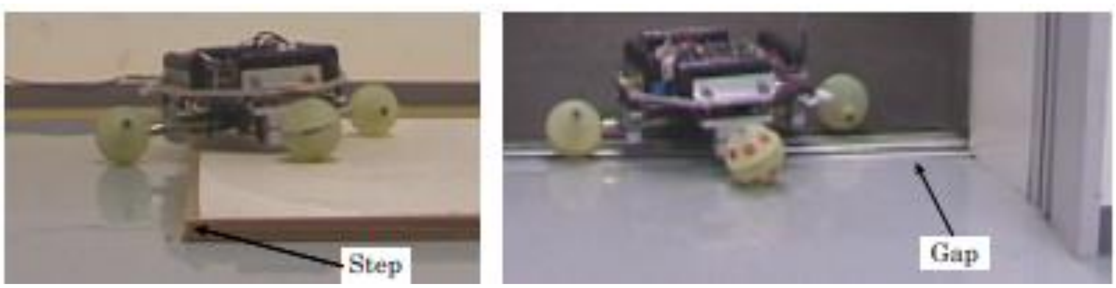
Figure 3. Nerva S

Table 1. Nerva S Parameters

Parameters	**Values**
Weight	<3kg (when fully equipped)
Speed	0-4km/h and 0-10km/h
Dimensions	31.5cm x 24.5cm x 17cm
Shock resistance	Tested on concrete with a 3m drop
Audio	Build-in microphone
Video	HD camera with 360-degree rotation and night vision
Radio range	Over 200m LOS and 50m in buildings
Obstacle clearance	9cm (standard heavy all-terrain wheels)
Endurance	Over 5 hours (static observation)
Waterproofness	Standard: IP65 Optional: Improved waterproofness (support total immersion for a short while)

2.3.4 Holonomic Omnidirectional Motion UGV (2007)

Designed by [4]Kenjiro Tadakuma and Riichiro Tadakuma, this UGV was built for the purpose of being used in narrow spaces allowing it to fully utilize its omni-directional movement. This concept was also developed to test the utility of omni-balls. As shown in figure (4), the bot had the capability to climb steps as well as traverse gaps. Omni-ball has one active and two passive rotational axes. The active rotational axis produces a propelling force which is perpendicular to the passive rotational axis.



(a) Step Climbing Motion (b) Gap Traversing Motion

Figure 4. Motions of Prototype Vehicle

Table 2. Omni-Ball Specifications

Diameter	80mm
Maximum Diameter of Barrel Wheel	11mm
Length of Barrel Wheel	12mm
Material of Hemispherical Wheel	Polyurethane Rubber
Load Capacity per wheel	114 kg
Weight (One wheel)	319.6g

2.3.5 Throwable tetrahedral robot with transformation capability (2009)

The throwable tetrahedral robot was developed by [5]Kenjiro Tadakuma, Riichiro Tadakuma and Keigi Nagatani. It is the first bot in in this review that utilizes omni-ball. For the arbitrary movement, we combine three propelling forces. It also has an application if the operation is performed in a narrow space. It also has a camera which is mounted on it.

It has a tetrahedral design where one leg is set to be vertically up in standard position. However, if the user so chooses, the leg can be lowered to transform the bot from a 3-wheeler to a 4-wheeler. This unique mechanism gives the bot a ladder like function that allows it to climb over large objects.

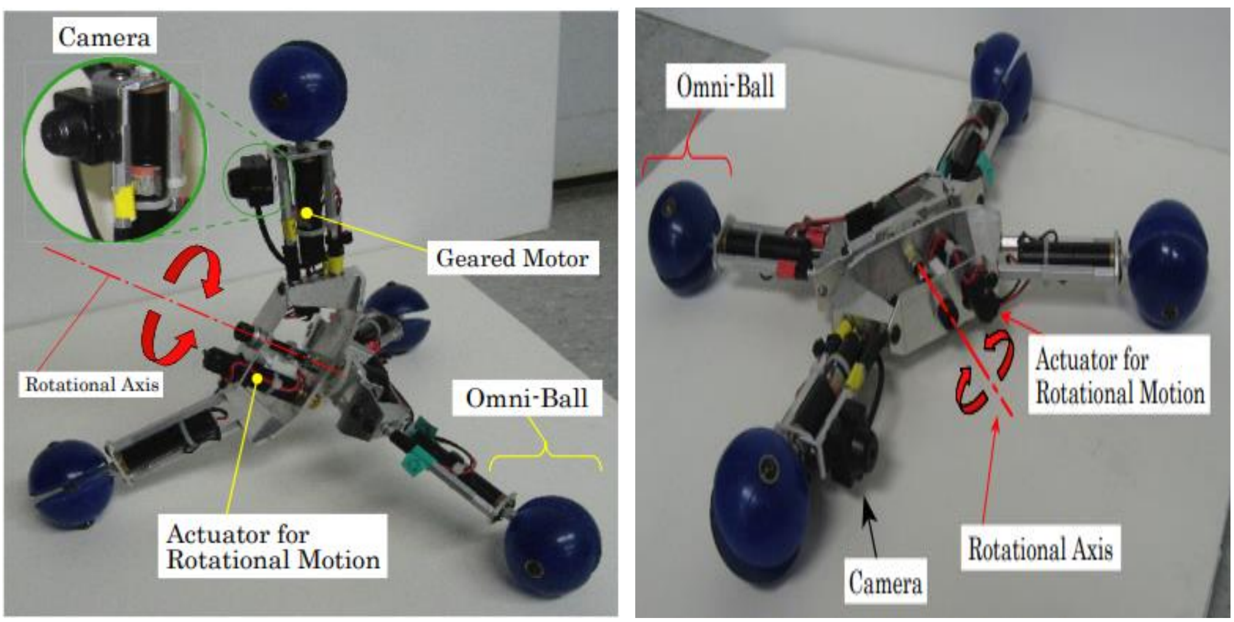


Figure 5. Overview of Mechanical Prototype

Table 3. Specifications of Tetrahedral Robot

Length on Side in Tetrahedral Mode	294.4mm
Height in Tetrahedral Mode	248.6mm
Short Width in 4-Wheeled Mode	234.4mm
Long Width in 4-Wheeled Mode	294.4mm
Height in 4-Wheeled Mode	45mm
Weight	467g
Diameter of Wheel	45mm
Motor	2.5W
Battery	12V/5Ah
Height of Camera	192mm

2.3.6 Three Omni Directional Mobile Robot (2015)

[6]Developed by Galgamuwa, Liyange, Ekanayake, Samaranayake from the University of Peradeniya, Sri Lanka, the bot uses traditional omni wheels unlike the previous bot, which uses omni balls. Unlike the transformation bot, this is solely a 3-wheeler. Each wheel is separated from the other by an angle of 120 degrees. One of the unique profiles of this bot is that it is PID tuned unlike any other bot in this paper. In other words, it is not remote operated but uses mounted sensors to scope the environment. However, our focus is on the wheels.

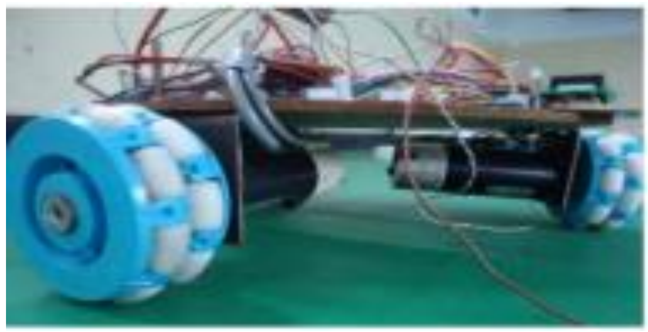


Figure 6. Three Omni Directional Mobile Robot (2015)

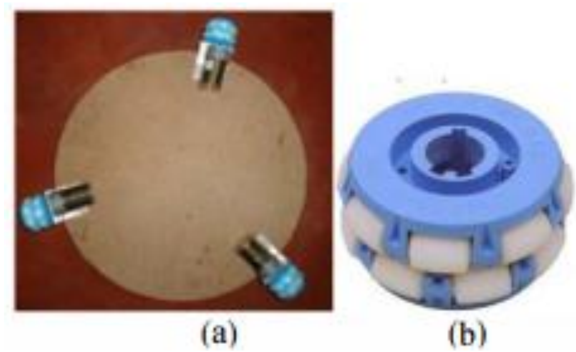


Figure 7. (a). Mechanical structure of Omni Bot (b). Omni Wheel

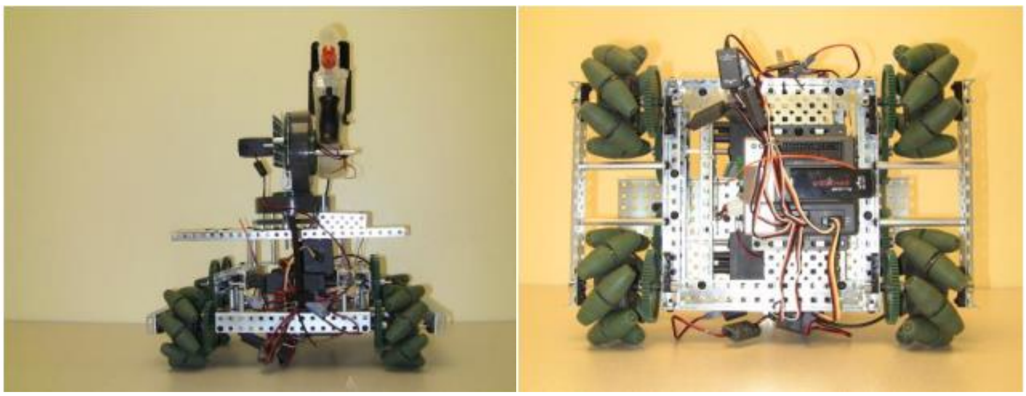
The given parameters are shown. It should be noted that the authors have not offered conclusive values for multiple parameters but rather a range. They are as follows:

Table 4. Parameters of Omni Bot

Parameters	**Value**
Controller	STM32F4 DISCOVERY
Driver	Pololu MDOlb
Motor	0-24V
PWM sequence	10Hz-10 KHz
Motor speed	60-600 rpm
Wheel Diameter	4-20 cm

2.3.7 Semi-Autonomous UGV with Omnidirectional Mobility and Auto-Targeting

[7]Designed by Cardenas Irvin, Shao Leo, Jong-Hoon Kim from Florida International University, the bot is like the mobile robot, however this one has 4 omni wheels. It was built with the purpose to have a gun mounted on its base, however for the sake of our research, we are not interest in that aspect of the bot. The bot has an aluminum structure for lightness and strength.



a) Front View 8. Multiple Views b) Bottom View

Bot Parameters available are:

Table 5. Parameters of Semi-Autonomous UGV

Parameter	Values
Dimensions	15.32” x 11.61”
Controller	Cortex
Connection Type	UART
Battery	7.2-volt main battery and a 9-volt backup

Bot Mobility is specified as follows:

Table 6. Movement Parameters

Movement	Velocity	Percentage/Power
Forwards/Backwards	1 foot/6.40 sec	100%
Horizontal	1 foot/7.30 sec	88%
Diagonal - 45 Degree	1 foot/11.55 sec	55%

2.4 Wheels and Drivers

Wheels are an integral part of an unmanned ground vehicle. Wheels ensure smooth mobility of the UGV when subjected to different terrains. The wheels should be able to support the load of the robot and should not deform when subjected to weights. There is a list of different types of wheels that can be used for UGVs and have been used in the industry.

2.4.1 Types of Wheels

1. Fixed/Standard Wheels
2. Omni Wheels
3. Omni Ball
4. Mecanum Wheels
5. Ball Wheels
6. Castor Wheels

2.4.1.1 Fixed/Standard Wheels:

These are the most common types of wheels. These wheels have two degrees of freedom, which means they can move forward and backwards and not side to side. They come in all sizes as we have witnessed them being used in small remote-control cars to trucks and other locomotive vehicles. These wheels are mostly used as drive wheels as they are controlled by some motors and very seldom, they are used as idler wheels. They can be used indoors as well as outdoors. Most of the wheels are made from cast aluminum alloy.

Figure 9. Standard Wheel

2.4.1.2 Omni Wheel:

Theses wheels can move in all directions; forward, backward, and sideways. These wheels have rollers mounted on the circumference of the wheel. The rollers are cylindrical in shape and their number can vary on each omni wheel. [8]The axis of rotation of the rollers is perpendicular to the axis of the wheel. This configuration allows the wheel to be an omnidirectional wheel. They can be equally used as drive wheels as well as idler wheels.

Figure 10. Omni Wheel

2.4.1.3 Omni-Ball:

An omni-ball wheel is like omni wheel except that the wheel is spherical in shape. The sphere is divided into two hemispheres. Two hemispheres rotate passively, and the active rotational axis lies in the center of the Omni-Ball. Two tiny rollers are attached to the circumference of the hemispheres for smooth rotation and locomotion of the robot.

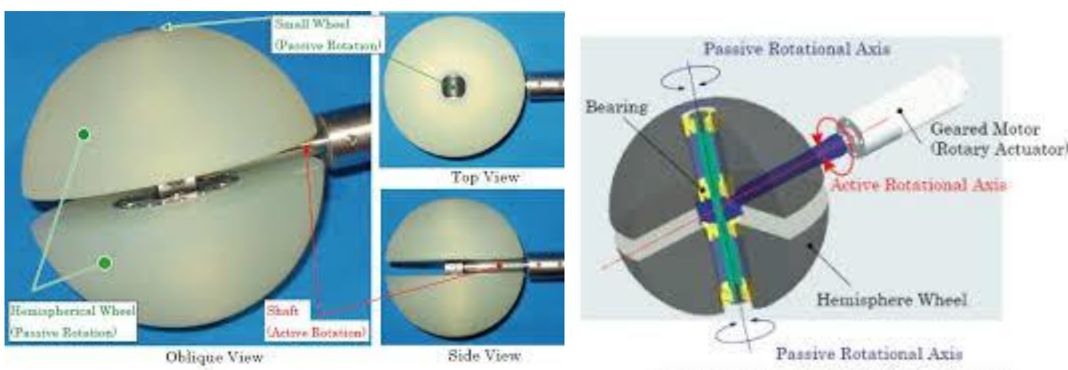


Figure 11. Basic Structure of Omni Ball

2.4.1.4 Mecanum Wheels:

Mecanum wheels are similar to omni wheels except that the rollers are places at an angle of 45° with respect to the axis of the base wheel. The angle of the rollers is the reason why Mecanum wheels are also known as Swedish 45° Wheels[9]. These are one of the most common wheels used in the industry. The use of four Mecanum wheels on a robot chassis allows the robot to rotate on the spot.

Figure 12. Mecanum Wheels

2.4.1.5 Ball Wheels:

The mechanism of ball wheel consists of a sphere that is attached to two or three castor wheels or ball rollers which are driven by motors. The controlled speed of the motors allows the sphere to rotate in the desired direction and make the robot mobile. These wheels are mostly used as idler wheels.

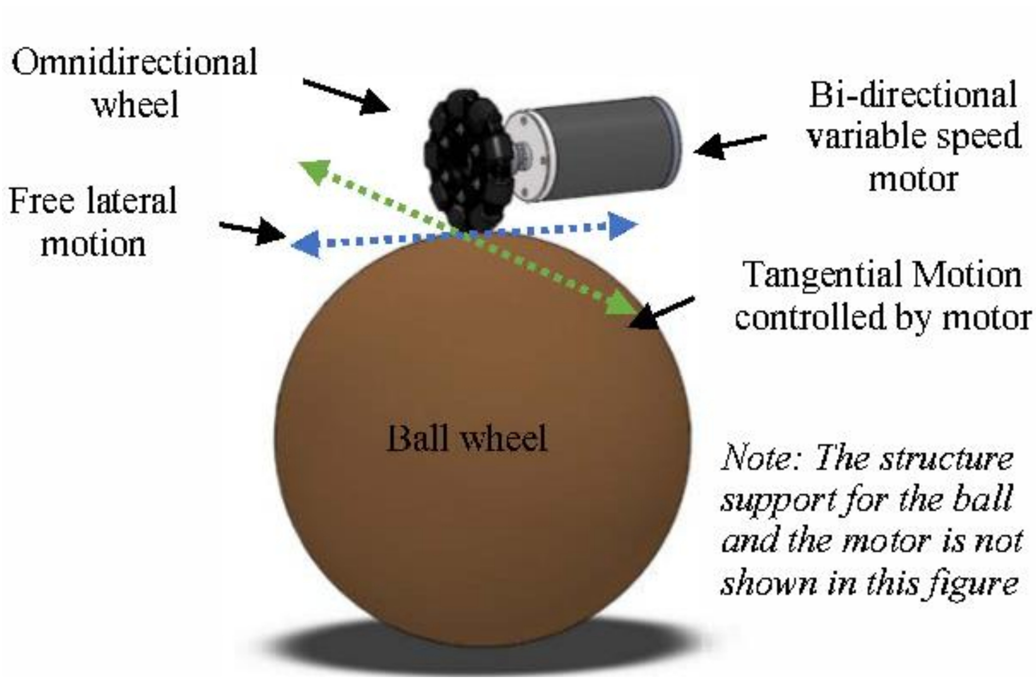


Figure 13. Basic Structure of Ball Wheel

2.4.1.6 Castor Wheels:

[10]Castor wheels have wide application in medical equipment, manufacturing, furniture etc. Many manufacturers divide castor wheels into two categories: rigid wheels and swivel wheels. Rigid wheel consists of a standard wheel that can move just forward and backwards. However, swivel wheels allow the wheel to rotate 360° with respect to the vertical axis along with the free movement of the wheel forward and backwards. This allows the end user to achieve an omnidirectional mobility. Another special type of castor wheel is the castor ball wheel. A sphere is used in place of a wheel, and it provides movement in all directions. These wheels are mostly used indoors and as idler wheels.

a) Castor Swivel Wheel b) Castor Ball Wheel

Figure 14. Types of Castors Wheels

2.4.2 Comparison of Wheels

Table 7. Comparison of Different Types of Wheels

Type of Wheel	Manufacturing Complexity	Sensitivity to Rough Surface	Sensitivity to Small Objects on a surface	Degree of Freedom	Maximum Load
Standard	Low	Low	Low	2	40-60 kg
Caster	Low	Low	Low	1, 2, 3	15 kg
Omni	Medium	High	High	3	2-30 kg
Mecanum	High	High	High	3	7-15 kg

Displayed in Table, we have a comprehensive comparison of all the different types of wheels that have been stated in the above headings. The table summarizes the concept that for rough terrains, standard wheels are a better choice. However, omni wheels provide holonomic movement of the robot but are sensitive to rough terrains. The selection of wheels depends on the application of the robot and an awareness of the environment in which it will be operating.

Chapter 3 - METHODOLOGY

3.1 Designing

When undertaking UGV design, numerous pivotal aspects necessitate careful consideration. Among these, environmental factors take precedence, as the operational context profoundly impacts UGV performance. In the military domain, for instance, UGVs must exhibit robustness to endure hostile surroundings characterized by extreme temperatures and rugged terrains. Moreover, UGVs must demonstrate exceptional efficacy in executing designated tasks within such environments, thereby warranting the integration of specialized sensors and equipment. Another pivotal aspect to deliberate pertains to the desired level of autonomy for the UGV. While numerous UGVs possess a certain degree of autonomous capabilities, achieving levels of autonomy closely akin to human proficiency necessitates cutting-edge computing technologies and multimodal sensory approaches.

The project's initiation involves the design phase, where the team has presented a proposal to undertake the remodeling of the existing UGV, incorporating a redesigned body structure and an innovative tire configuration. The prior UGV models exhibited repetitive characteristics and lacked advancements in the design domain, necessitating a fresh approach. Multiple design concepts have been proposed and subjected to rigorous evaluation. Through a meticulous selection process, the final designs have been determined, featuring notable improvements and enhancements compared to their predecessors. These selected designs have been tailored to fulfill the specific requirements and objectives of the project.

The proposed body design takes into consideration crucial factors such as structural integrity, weight distribution, aerodynamics, and ergonomics. Employing meticulous analysis and simulation techniques, the team has ensured that the new body design not only enhances visual appeal but also optimizes performance and functionality in real-world scenarios.

In conjunction with the body design, an innovative tire configuration has been introduced to augment the UGV's maneuverability, traction, and overall performance. This tire design integrates cutting-edge engineering principles influenced by state-of-the-art technologies such as omni and Mecanum wheels. By employing a spherical geometry comprising dual hemispheres, the novel tire design delivers unparalleled agility, minimized friction, and heightened stability throughout operational tasks. The selected designs have undergone a comprehensive evaluation encompassing feasibility studies, prototype testing, and performance analysis. This exhaustive assessment has substantiated their aptness in achieving the desired project objectives. These designs epitomize the culmination of engineering acumen and inventive thinking, forging a path towards an upgraded UGV equipped with amplified capabilities and superior performance across diverse operational environments.

The CAD models have been made utilizing SOLIDWORKS software.

3.1.1 Designs of Wheels

The project initiation involves the conceptualization and design of an innovative omni-directional wheel, which derives inspiration from the spherical design paradigm. The initial impetus was derived from a scholarly research publication authored by a cohort of engineering students affiliated with the esteemed Massachusetts Institute of Technology (MIT). Subsequently, multiple design iterations and prototypes were generated during the ideation phase, with each specimen undergoing rigorous evaluation and meticulous analysis.

The primary objective of the proposed design is to amplify the wheel's maneuverability, stability, and overall performance across diverse operational scenarios. By harnessing the inherent advantages offered by the spherical design concept, the project team endeavors to optimize the wheel's capacity to move in multiple directions, thereby facilitating heightened agility and versatility.

Through an exacting selection process, a definitive model for the prototype is elected. This chosen embodiment epitomizes the culmination of comprehensive research, technical proficiency, and performance-based considerations. It is envisaged that the adopted design will function as a cornerstone for the development of a superlative omni-directional wheel, thereby demonstrating augmented capabilities and effectively fulfilling the predetermined project objectives.

3.1.1.1 Prototype I

The initial prototype of the wheel, although developed for experimental purposes, faced significant shortcomings. These issues mainly arose from the deviation of its shape, which was intended to be spherical but ended up being ellipsoidal due to inaccuracies in dimensional measurements. Consequently, the assembly process became overly complex, deviating from the desired simplicity. Moreover, the initial prototype included unnecessary components, leading to increased material usage and overall weight. Through subsequent analysis and evaluation, it was identified that multiple parts were redundant and could be eliminated in the final model.

Considering these deficiencies, the initial prototype was rejected as unsuitable for further development. However, the lessons learned from this iterative process proved invaluable. They provided valuable insights into refining the wheel's design and optimizing its performance characteristics in subsequent iterations.

The rejection of the initial prototype paved the way for the development of an improved wheel design. By addressing the shape discrepancies, streamlining the assembly process, and eliminating unnecessary components, the subsequent iterations aimed to achieve a more efficient and effective solution. The knowledge gained from this experience served as a foundation for enhancing the wheel's functionality and advancing its overall performance.

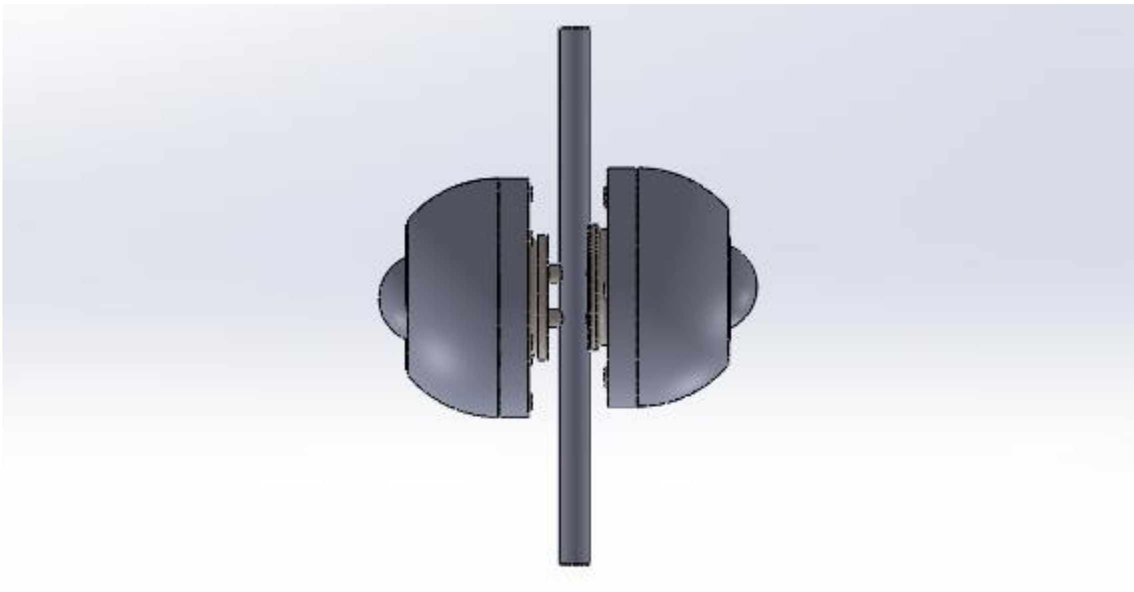


Figure 15. CAD Model of Prototype I of Wheel

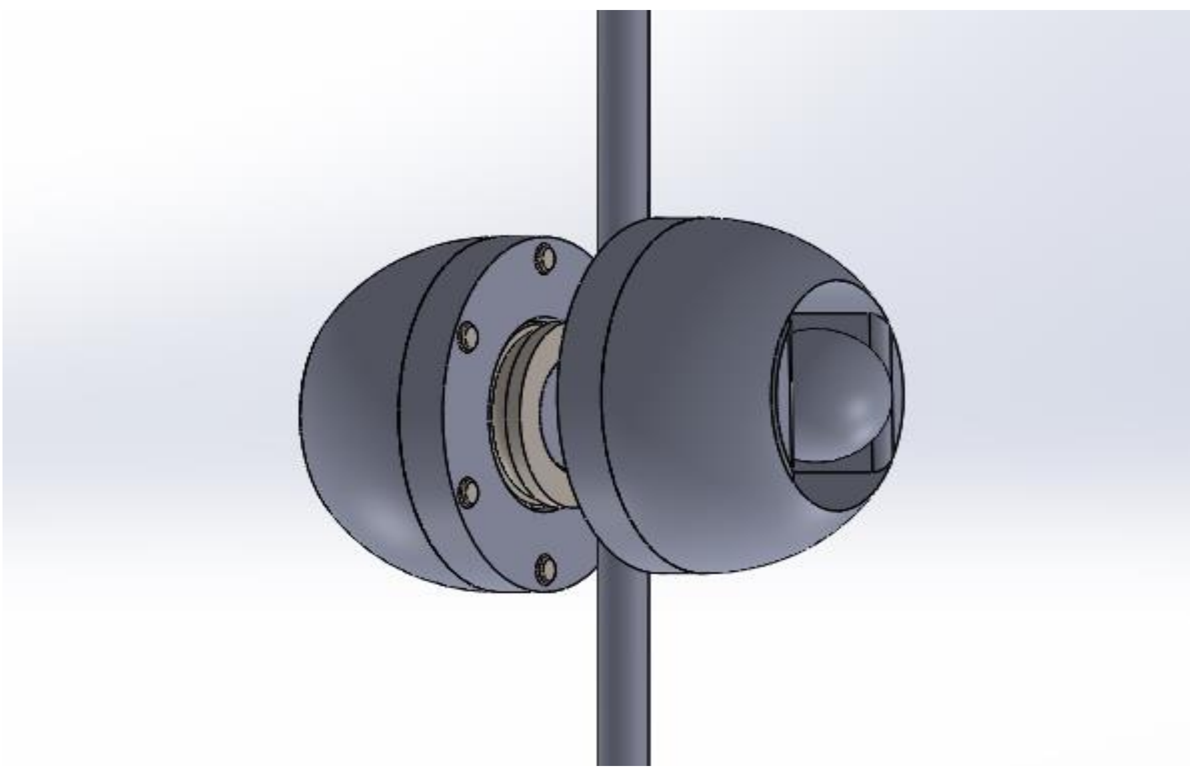


Figure 16. CAD Model of Prototype I of Wheel (Side View)

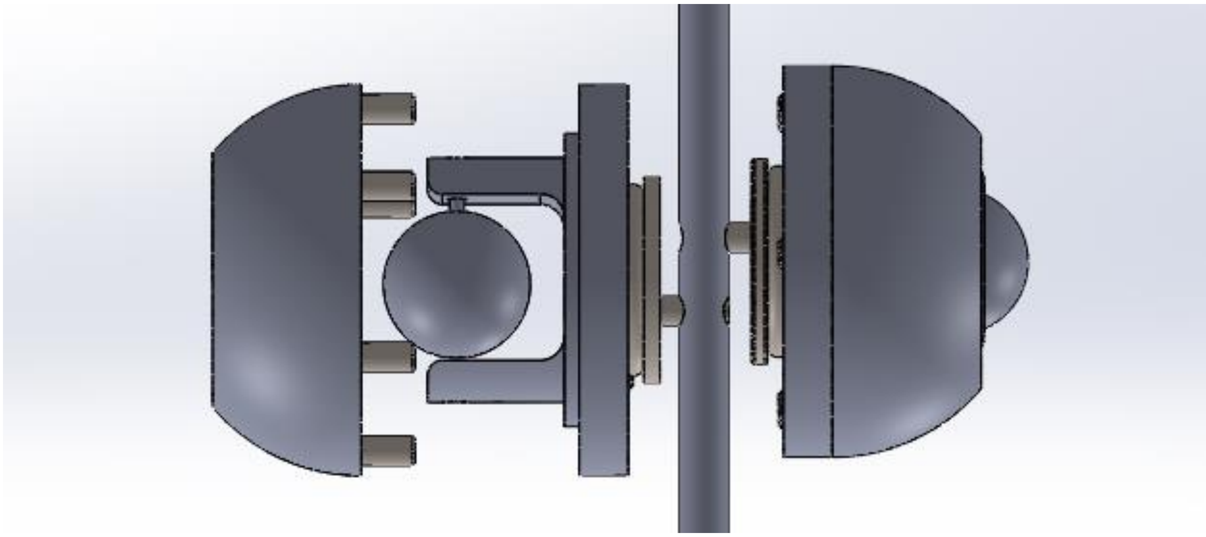


Figure 17. CAD Model of Prototype I of Wheel (Split View)

3.1.1.1 Prototype II

Through an extensive parameter testing process, precise dimensional specifications for achieving a spherical shape were determined. These refined dimensions were subsequently employed in the development of the modified wheel design, which has been incorporated into the final model. Notably, this revised design demonstrates notable improvements in terms of weight reduction and material efficiency, primarily attributed to the elimination of redundant components.

In adherence to the specified requirements, the modified model exhibits a flawless spherical shape, showcasing an optimal implementation of the acquired dimensions. The attainment of a precise spherical configuration ensures alignment with the desired design objectives and enhances the wheel's overall performance.

The meticulous refinement of the wheel's dimensions and the subsequent implementation of the modified design are reflective of a rigorous optimization process. This iterative approach has successfully addressed previous shortcomings and yielded a final model that exemplifies superior attributes such as lightweight construction, optimized material usage, and adherence to the specified spherical shape requirements.

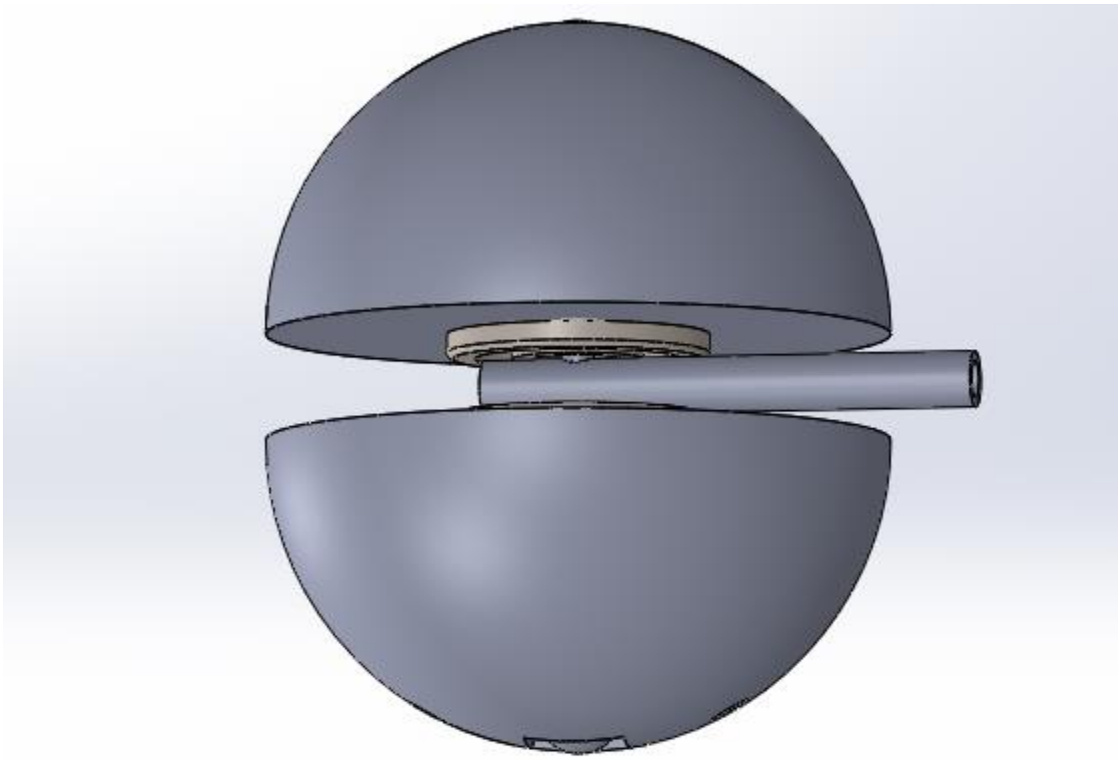


Figure 18. CAD Model of Prototype II of Wheel

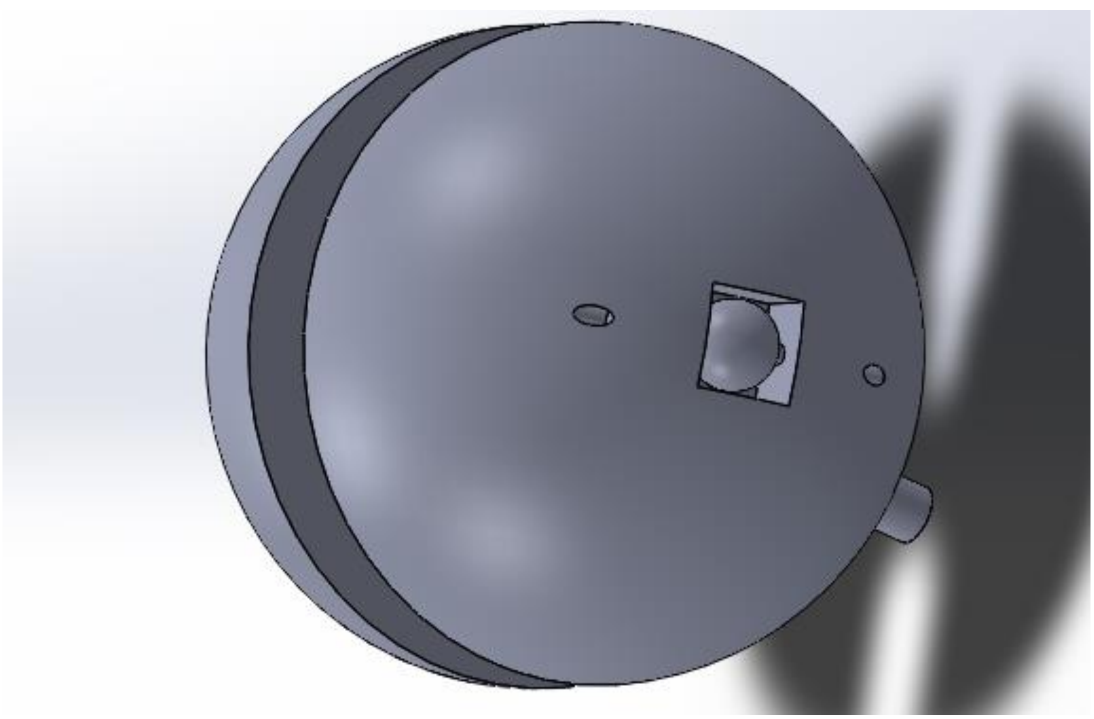


Figure 19. CAD Model of Prototype II of Wheel (Side View)

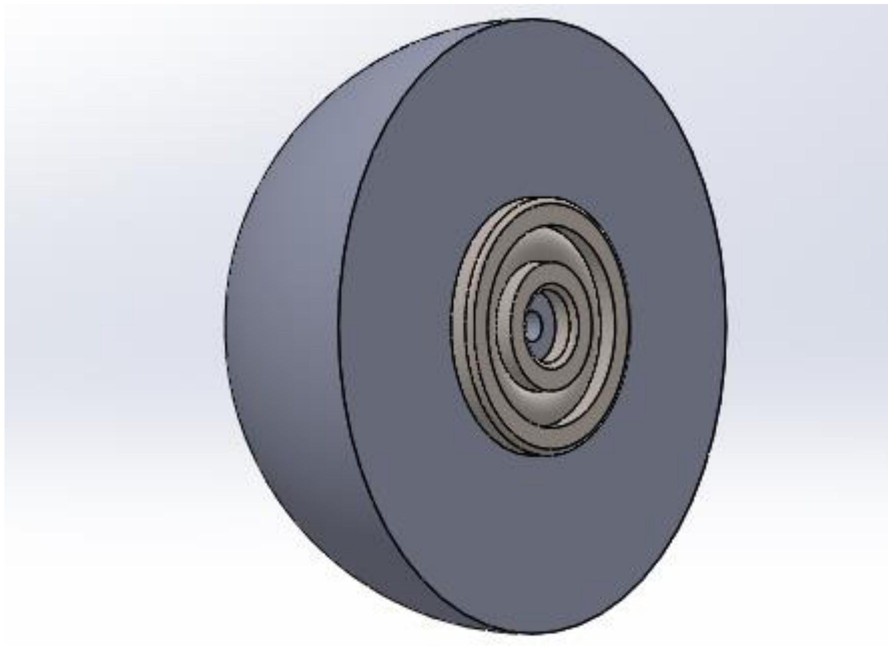


Figure 20. CAD Model of Prototype II of Wheel (Cross-Sectional View)

3.1.2 Designs of Body

Following the completion of the wheel modeling phase, a comprehensive redesign of the body structure was imperative to align it with the specific application requirements. This entailed deviating from the conventional cylindrical model featured in previous iterations. Multiple designs were developed for the body, encompassing both the integration of older wheels and the new prototype. These designs are depicted below, showcasing the evolutionary progression of the body design.

3.1.2.1 Prototype I:

The initial body design of the UGV, influenced by the previous wheel design, posed several limitations and drawbacks. Its lack of throwability and reliance on specific orientation hindered its functional capabilities. Moreover, the design exhibited geometric complexity and fragility due to its hollow frame structure, making it unsuitable for the desired application. Consequently, the design was deemed unsatisfactory and rejected, prompting the need for an alternative approach to address these limitations and ensure the UGV's effectiveness and durability.

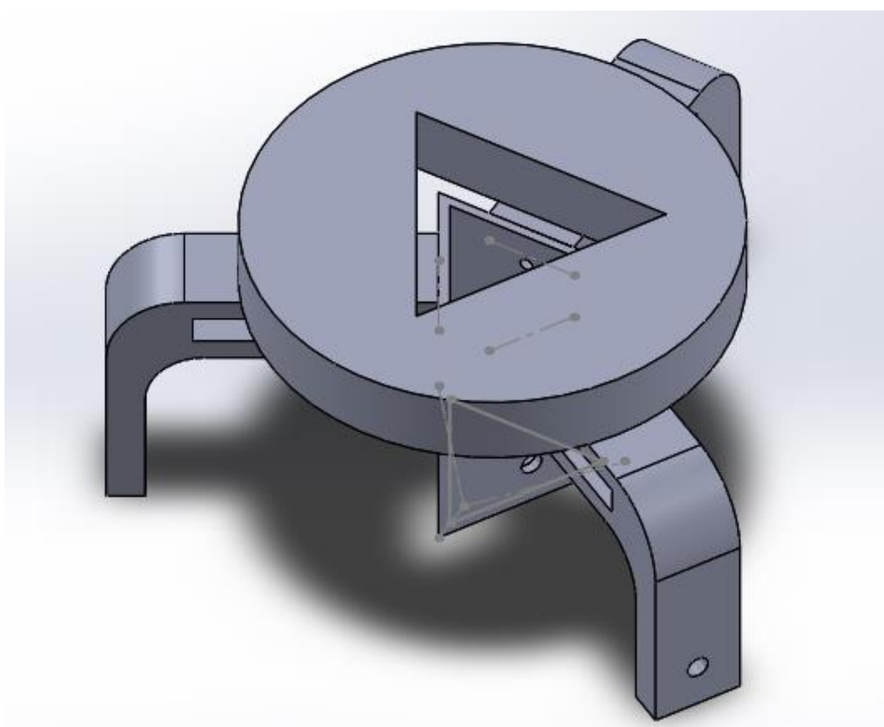


Figure 21. CAD Model of Prototype I without Wheels (Bird-eye View)

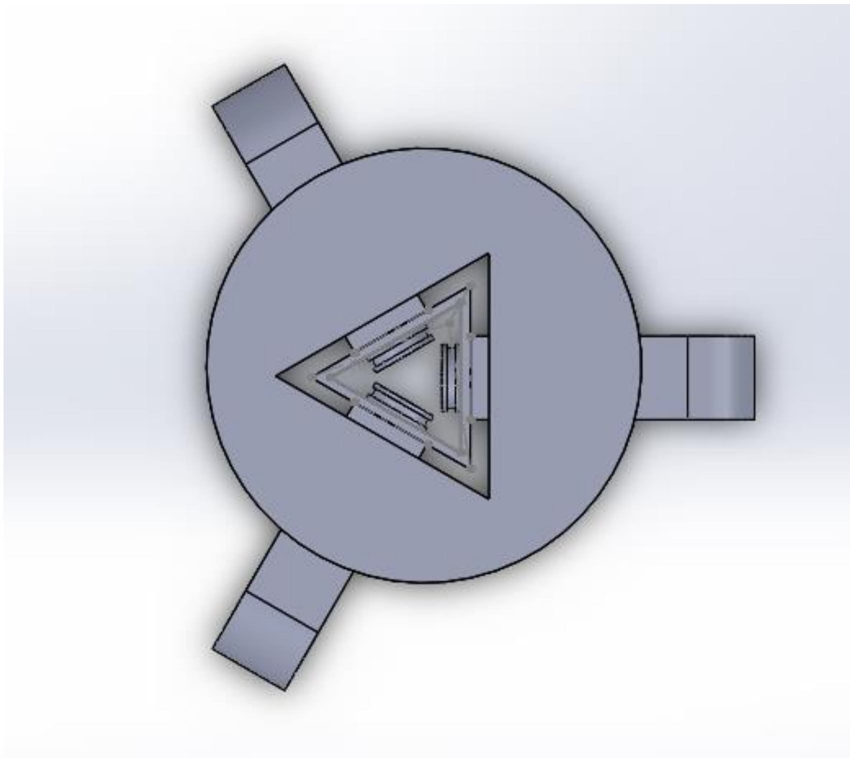


Figure 22. CAD Model of Prototype I without Wheels (Top View)

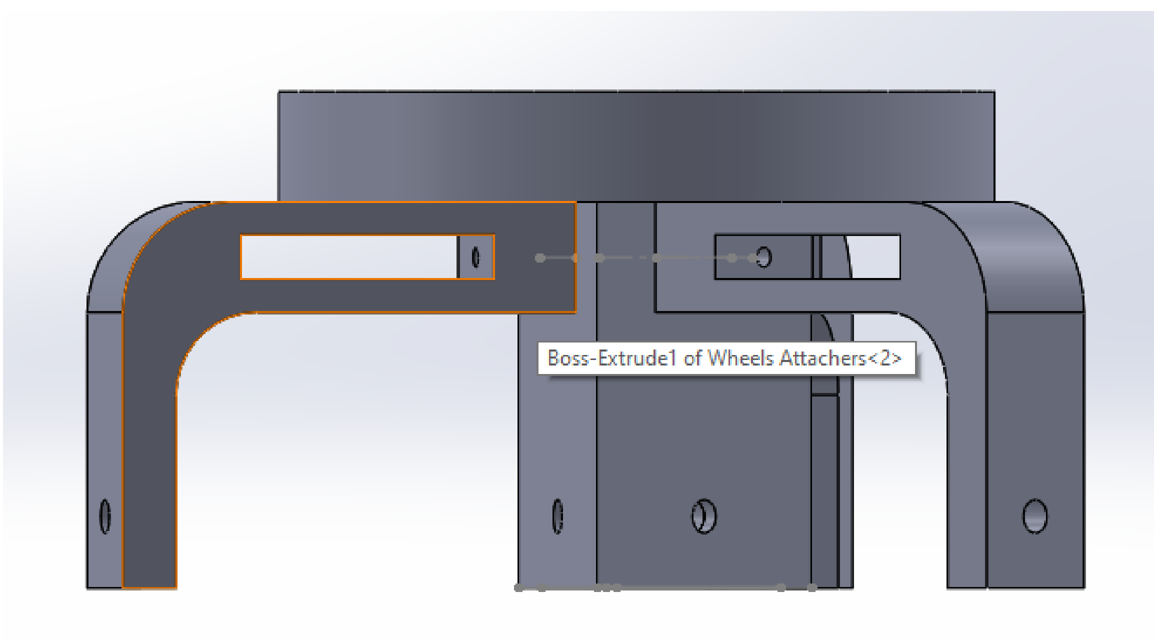


Figure 23. CAD Model of Prototype I without Wheels (Side View)

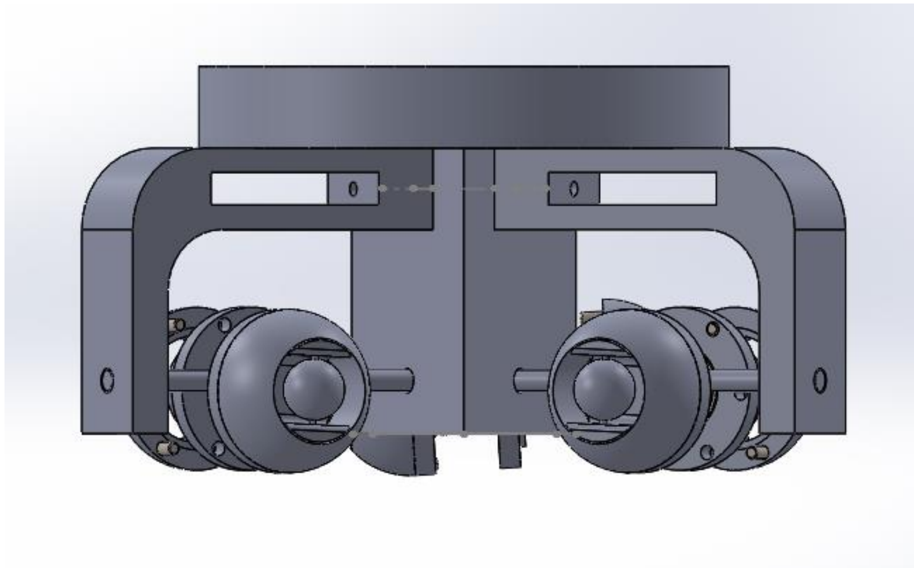


Figure 24. CAD Model of Prototype I with Old Wheels

3.1.2.2 Prototype II:

The subsequent design incorporated the newly developed wheel prototype into the body design. This design showcased improved compatibility between the wheel and the body structure, resulting in enhanced performance characteristics and more seamless integration. This alternative design aimed to address the limitations of the previous model by introducing an invertible configuration. However, this proposed design exhibited a drawback in terms of a reduced throwing range due to the utilization of hollow cylinders for support. Additionally, the exposure of electronics in this design posed a significant risk of damage. Consequently, this design was also deemed unsuitable and rejected. The findings from this evaluation process highlighted the importance of developing a body design that balances functionality, durability, and protection of critical components. Further iterations and refinements were pursued to achieve an optimal body design for the UGV, ensuring improved performance and safeguarding of essential electronics.

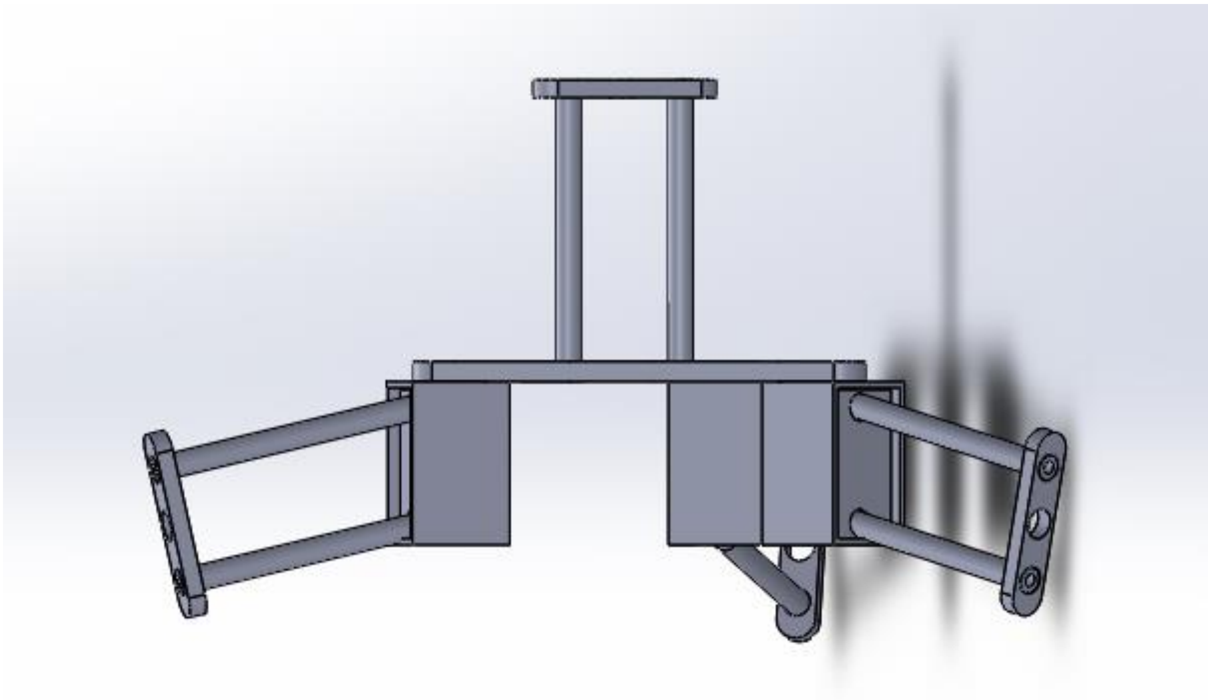


Figure 25. CAD Model of Prototype II (Side view)

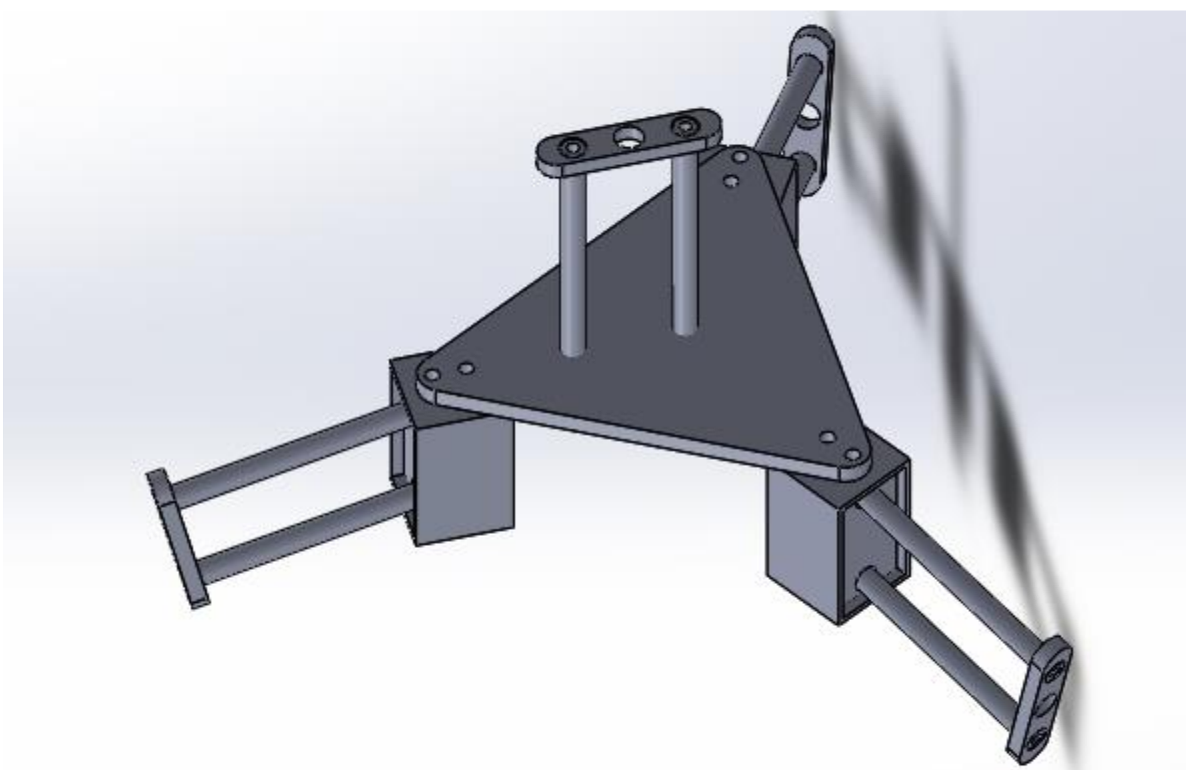


Figure 26. CAD Model of Prototype II (Top view)

3.1.2.3 Prototype III

This design exhibited enhanced compatibility with the novel wheel prototype, yielding a configuration characterized by improved efficiency and visually pleasing aesthetics. The prototype-II model has been revised and developed with slight modifications to address the issues identified in the previous design iteration, specifically focusing on the invertibility feature and the protection of exposed electronics. This updated design incorporates two acrylic plates as the primary structural components, securely fastened to motor holders using screws for enhanced stability and structural integrity. The motor holders, designed as cuboids, feature cylindrical holes precisely matching the dimensions of the motors, ensuring a secure fit and preventing potential damage during operation. These cylinders effectively hold the motors in place, minimizing the risk of displacement. Prototype III represents a significant improvement over the previous design iteration.

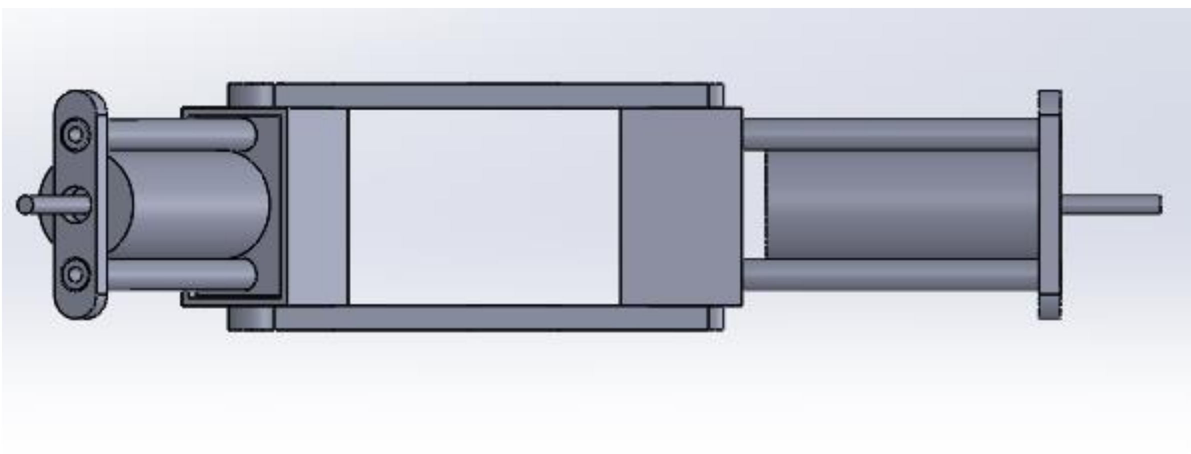


Figure 27. CAD Model of Prototype III (Side view)

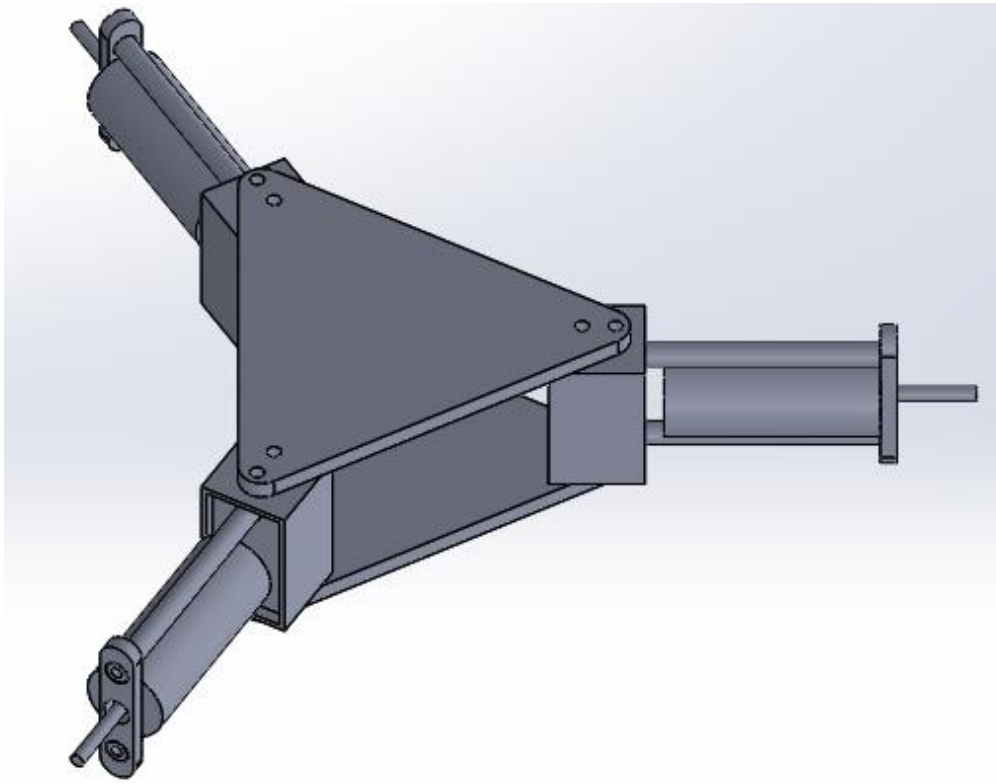


Figure 28. CAD Model of Prototype III (Top view)

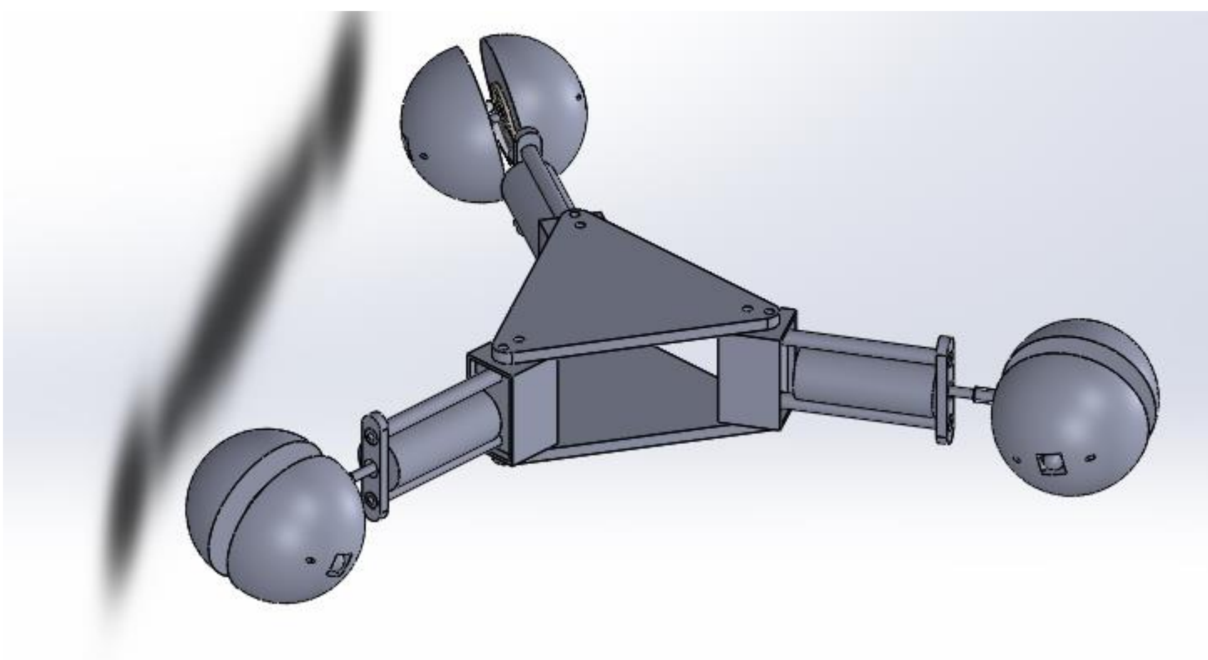


Figure 29. CAD Model of Prototype III with Final Wheels

3.1.2.4 Prototype IV:

Building upon the insights gained from the previous designs, the final iteration featured a completely reimagined body design. It departed from the traditional cylindrical form and incorporated optimized weight distribution and improved aerodynamics. This design demonstrated superior compatibility with the new wheel prototype, resulting in a more efficient and aesthetically appealing configuration.

To address the issue of exposed motors, modifications were made to the design. The motors were repositioned inwards, situated between the acrylic plates, providing a protective enclosure. Additionally, the surface area of the plates was expanded to accommodate additional electronic components, ensuring their integration within the UGV. To optimize the UGV's performance, slight adjustments were made to the design of the plates, focusing on weight distribution. These alterations were essential in ensuring the proper functioning and stability of the UGV, while also addressing concerns regarding motor exposure and accommodating additional electronics.

The selection of the final design was the culmination of a meticulous evaluation process, encompassing comprehensive performance analysis, rigorous simulations, and thorough feasibility assessments. The design was chosen based on its exceptional performance, strict adherence to application requirements, and overall harmonization with the UGV system. These iterative design endeavors epitomize the amalgamation of engineering prowess and innovative thinking, resulting in a body design that maximizes functionality and optimizes the UGV's operational capabilities across a range of scenarios.

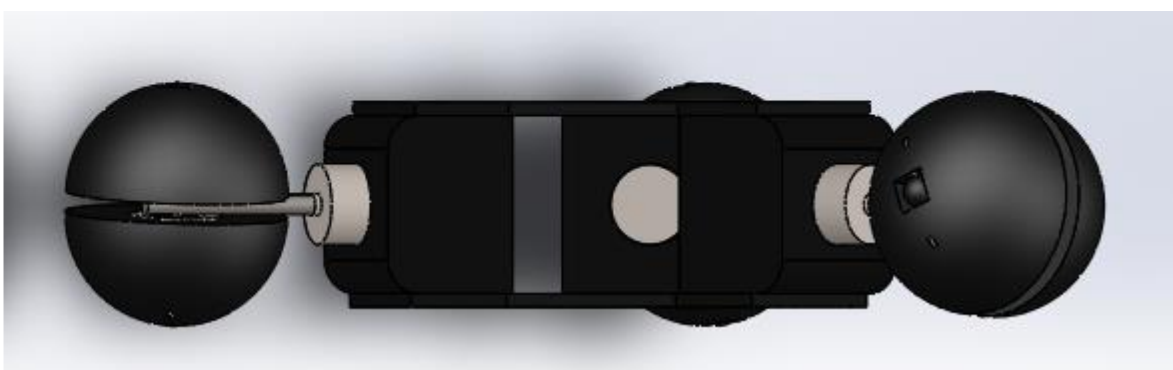


Figure 30. CAD Model of Prototype IV with Final Wheels (Side View)

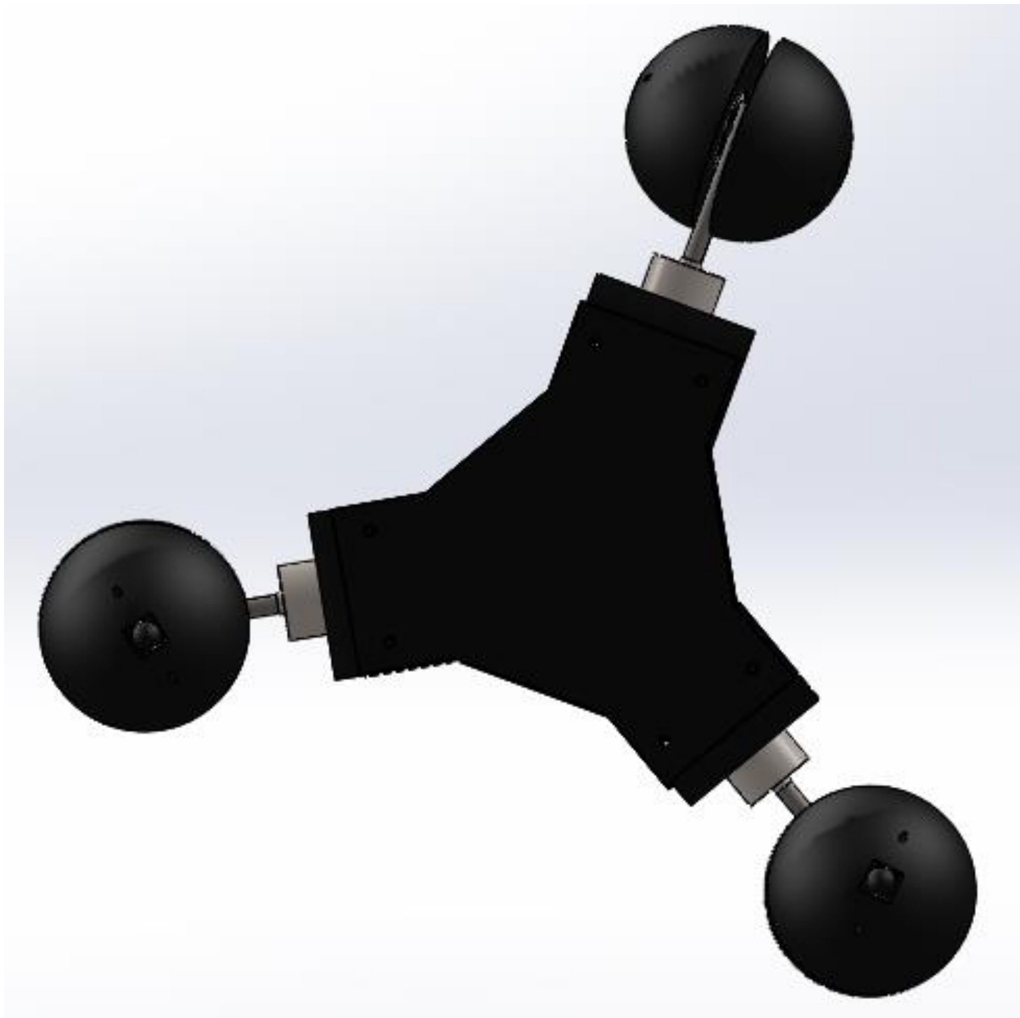


Figure 31. CAD Model of Prototype IV with Final Wheels (Top View)

3.2 Analysis

Upon completion of the design and modeling phase for the body and wheel components, a comprehensive battery of physical tests is conducted to evaluate their performance under diverse and challenging conditions. These tests encompass the examination of critical factors such as drag force, friction force, and impact force. The objective is to assess the structural response and endurance of the body and wheel under these demanding circumstances.

In addition to these assessments, the bodies undergo tests to determine their tolerance and maximum weight capacity, along with other pertinent parameters. These evaluations offer valuable insights into the ability of bodies to withstand varying loads and forces without experiencing failure or compromising their functionality.

To ensure the accuracy and reliability of the results, stringent testing protocols and methodologies are employed. The data acquired from these tests are meticulously recorded and subjected to thorough analysis. The final outcomes, which comprehensively outline the performance characteristics and limitations of the bodies and wheels, are documented, and appended to the overall project report.

This extensive testing phase assumes a crucial role in verifying the design integrity and suitability of the bodies and wheels for their intended applications. It empowers engineers and designers to make well-informed decisions, refine the design if necessary, and furnish stakeholders and end-users with evidence regarding the components' performance and durability.

The analysis and testing phase utilizes Ansys software to conduct comprehensive assessments.

3.2.1 Wheel Analysis

The final design of the wheel, incorporating the chosen material, undergoes a comprehensive analysis using ANSYS software. This analysis comprises both static and dynamic evaluations to assess the performance and behavior of the wheel under various conditions. ANSYS software, renowned for its advanced simulation capabilities, is utilized to conduct these analyses. It enables engineers to simulate and predict the behavior of the wheel accurately. By inputting the design parameters, material properties, and loading conditions, ANSYS generates comprehensive results that include stress distribution, deformation, and safety factors. These results provide a quantitative assessment of the wheel's performance and aid in making informed decisions regarding design modifications or material choices.

The attached results from the ANSYS analysis serve as crucial documentation of the wheel's performance characteristics. They provide evidence of the design's suitability, ensuring compliance with desired specifications and safety standards. These results aid in verifying the wheel's reliability, enabling stakeholders to assess its performance and make informed decisions based on the analysis outcomes.

3.2.1.1 Static Structural Analysis

The static structural analysis of the wheel has been conducted, and the resulting outcomes are presented below. Static structural analysis involves examining the wheel's response to applied loads and forces while in a stationary position.

The analysis includes evaluating various parameters such as stress distribution, deformation, and safety factors. These measurements provide insights into the structural integrity and strength of the wheel, ensuring its ability to withstand the expected loads without experiencing failure or excessive deformation. By assessing the stress distribution, engineers can identify critical areas prone to high stress concentrations and make necessary design adjustments to enhance the wheel's performance and durability.

The results of the static structural analysis offer valuable information about the wheel's behavior under different loading conditions. They provide a quantitative assessment of the wheel's performance characteristics, enabling engineers to validate the design and identify any potential design flaws or weaknesses. This information is essential for ensuring the wheel's reliability and meeting the desired specifications and safety standards.

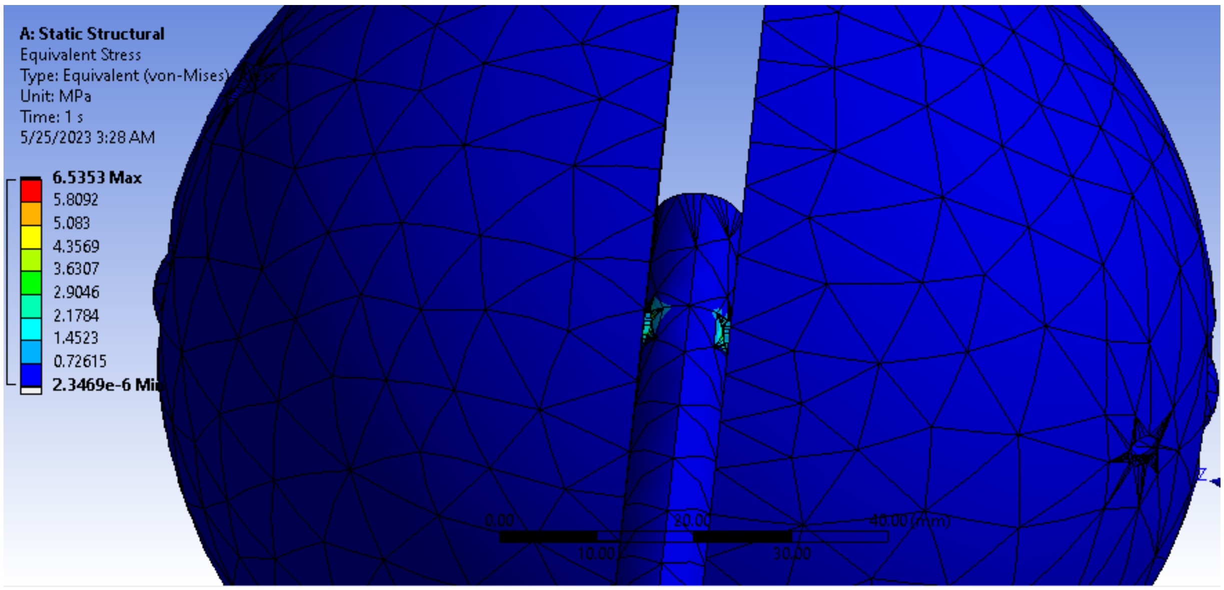


Figure 32. Static Structural Analysis of Wheel (Shaft)

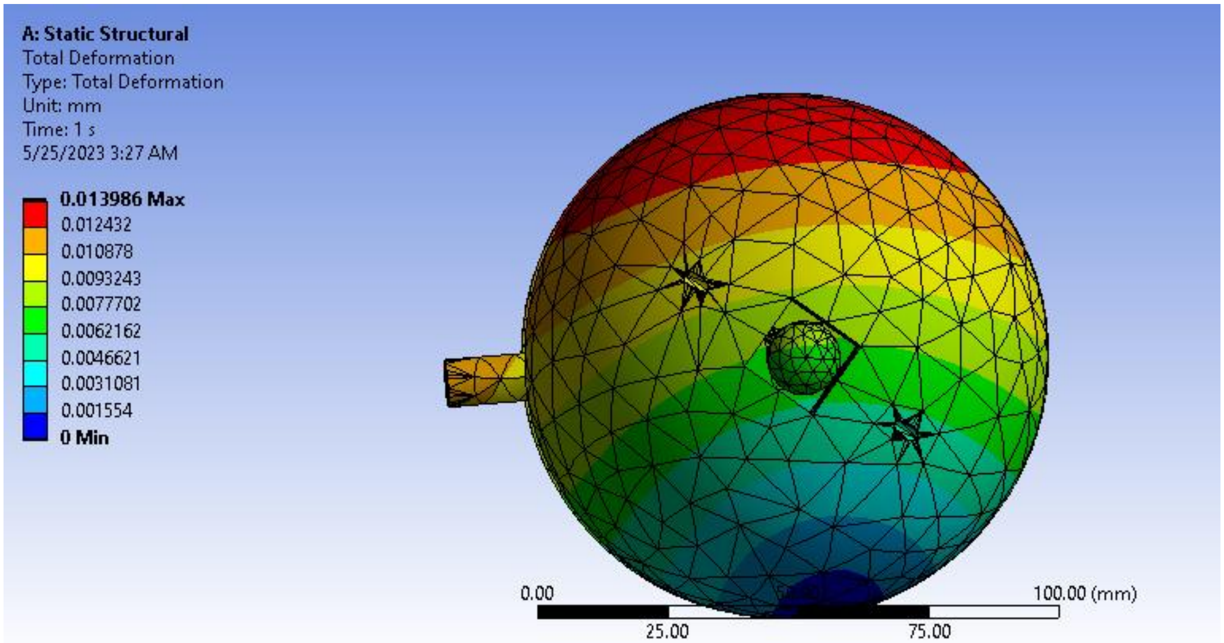


Figure 33. Static Structural Analysis of Wheel

3.2.1.2 Dynamic Analysis

Dynamic analysis is a critical engineering process that centers on investigating the dynamic behavior of the wheel during motion. This analysis considers significant factors such as rotational forces, vibrations, and impact loads. By simulating real-world operating conditions, dynamic analysis enables engineers to gain insights into how the wheel responds to dynamic forces and evaluate its durability and performance under various dynamic scenarios.

During dynamic analysis, the rotational forces acting on the wheel are thoroughly examined. These forces are essential to understand the wheel's rotational motion and its interaction with other components of the system. Vibrations, another crucial aspect, are assessed to determine their effect on the wheel's performance and structural integrity. By comprehensively studying these vibrations, engineers can identify potential issues that may arise due to resonance or excessive oscillations, allowing for necessary design modifications.

Additionally, dynamic analysis takes into consideration the impact loads that the wheel may experience during operation. These loads can result from uneven terrain, sudden shocks, or collisions. By subjecting the wheel to simulated impact scenarios, engineers can assess its ability to withstand and absorb these external forces without compromising its structural integrity or impairing its overall performance.

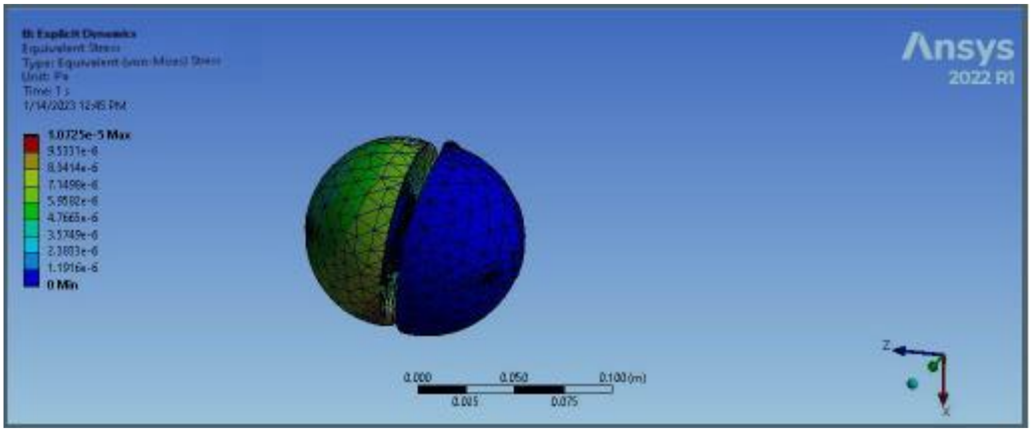


Figure 34. Explicit Dynamic Analysis of Wheel (Horizontally)

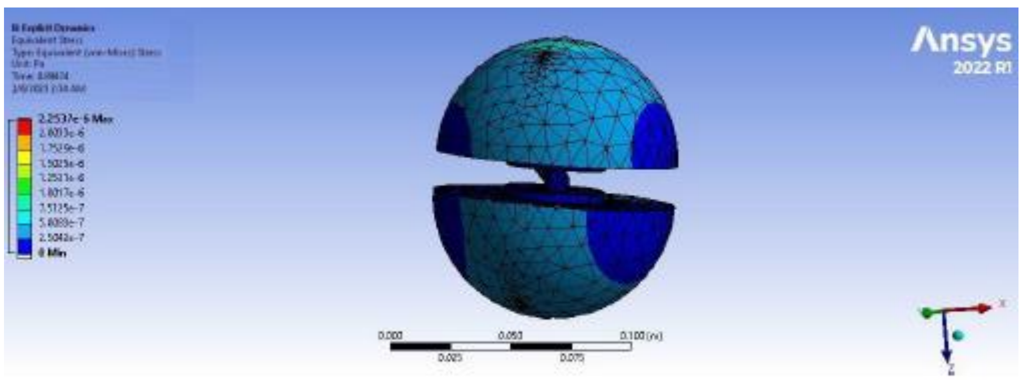


Figure 35. Explicit Dynamic Analysis of Wheel (Vertically)

3.1.2 Body Analysis

The completed body model undergoes a series of comprehensive analyses to evaluate its performance and characteristics. These analyses encompass various aspects, including structural integrity, stress distribution, deformation, and relevant parameters. The obtained results are presented below, providing valuable insights into the body's performance and suitability for its intended application.

The analyses conducted on the body model are crucial for verifying its structural integrity. Factors such as stress distribution and deformation are assessed to determine if the body can withstand expected loads and forces without failure or excessive deformation. This information is vital for ensuring the body's durability and reliability during operation.

In addition to structural integrity, other performance parameters are evaluated. These can include tolerance levels, maximum weight capacity, and other factors impacting the body's functionality. Analyzing these aspects helps engineers understand the body's performance limits and determine its suitability for specific use cases.

The presented results provide a clear understanding of the body's performance characteristics. They serve as evidence for stakeholders, decision-makers, and end-users to evaluate the body's capabilities and make informed decisions regarding its implementation. The results demonstrate the body's performance, facilitating the assessment of its effectiveness and informing potential design improvements.

Overall, the analysis results are a crucial resource for evaluating and validating the final body model. They provide quantitative data and visual representations of the body's performance under different conditions. This information supports informed decision-making, enhances the body's design and functionality, and ensures compliance with desired specifications and requirements.

3.1.2.1 Static Structural Analysis

The results obtained from static structural analysis play a pivotal role in the design process, facilitating informed decision-making and optimization of structural performance. These outcomes offer insights into areas of potential vulnerability, enabling the identification of design enhancements and ensuring compliance with safety regulations and performance requirements.

By simulating the behavior of the structure under different static loading conditions, static structural analysis aids in determining its capacity to withstand forces without undergoing failure or excessive deformation. The analysis considers factors such as material strength, stiffness, and the applied loads to accurately predict the distribution of stresses and deformations within the structure.

The information derived from static structural analysis guides engineers in refining the design, improving structural integrity, and enhancing overall performance. The results for analysis are attached as follows.

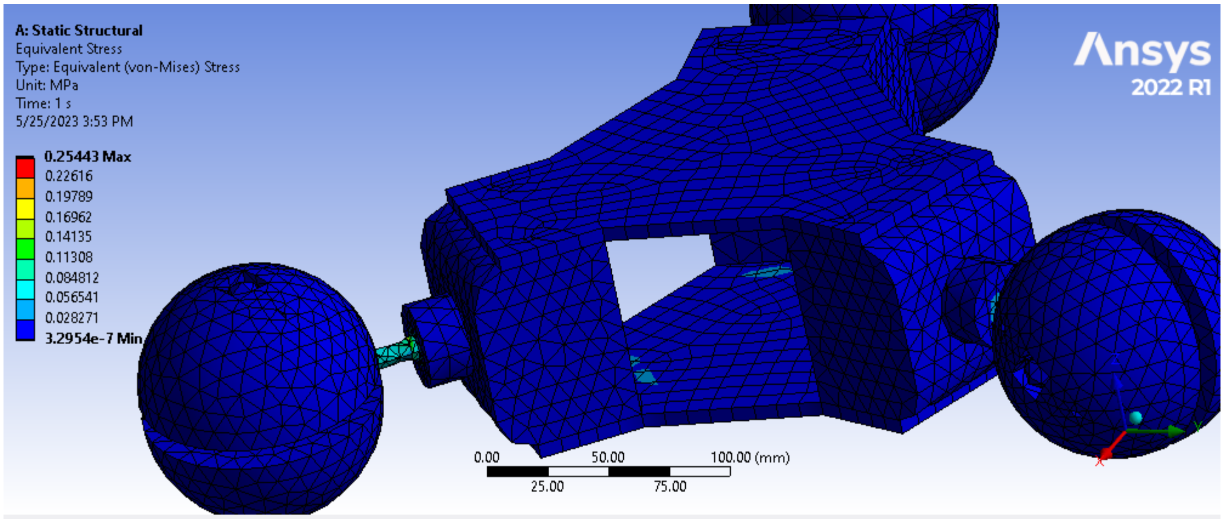


Figure 36. Static Structural Analysis of Body (Top)

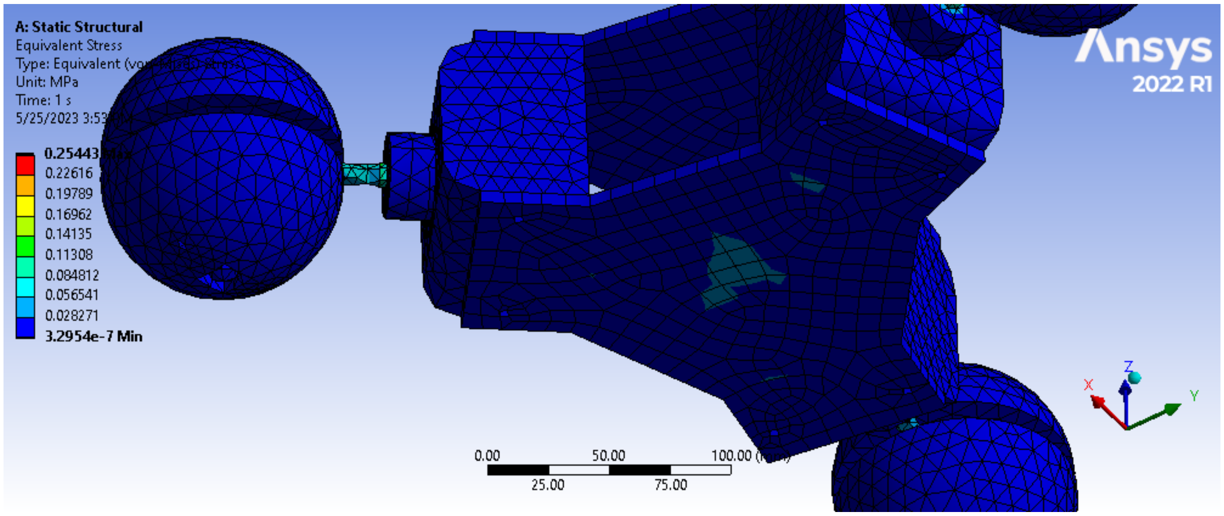


Figure 37. Static Structural Analysis of Body (bottom)

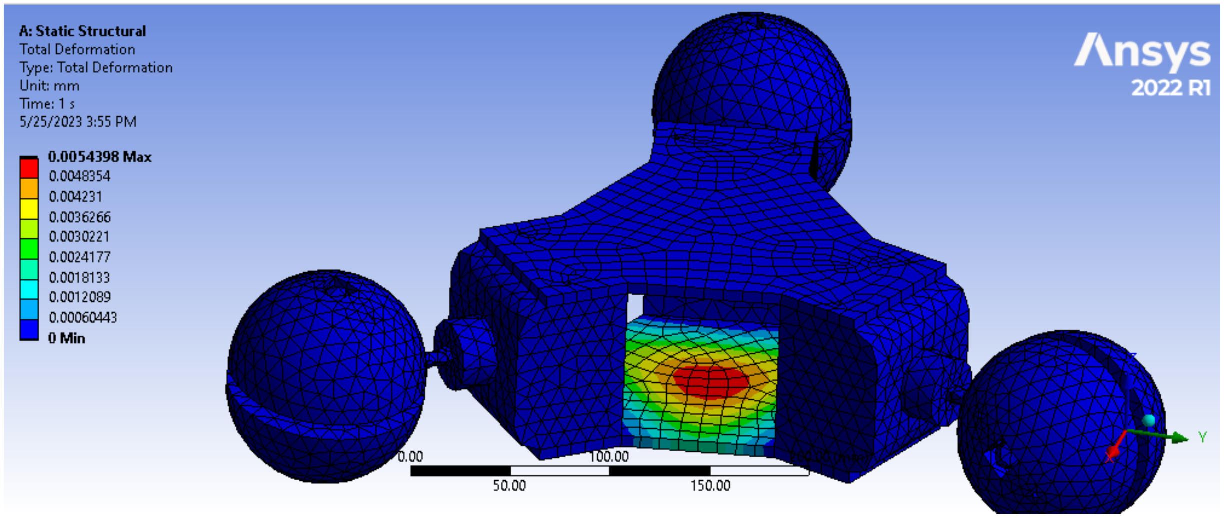


Figure 38. Static Structural Analysis of Body (base)

3.1.2.2 Dynamic Analysis

The entire assembly has undergone a comprehensive dynamic analysis, and the obtained results are provided below. Dynamic analysis involves evaluating the behavior and response of the complete assembly under varying dynamic loads, forces, and operating conditions.

During the dynamic analysis, various factors such as rotational forces, impact loads, vibrations, and fluid flow are taken into consideration. These factors simulate the real-world operating conditions and interactions that the assembly may experience during its intended use. The analysis aims to assess the assembly's ability to withstand dynamic forces, maintain stability, and ensure optimal performance.

Utilizing advanced mathematical models, computer simulations, and numerical techniques, the dynamic analysis predicts and characterizes the assembly's dynamic behavior over time. It enables engineers to understand phenomena such as resonance, natural frequencies, damping effects, and dynamic response characteristics.

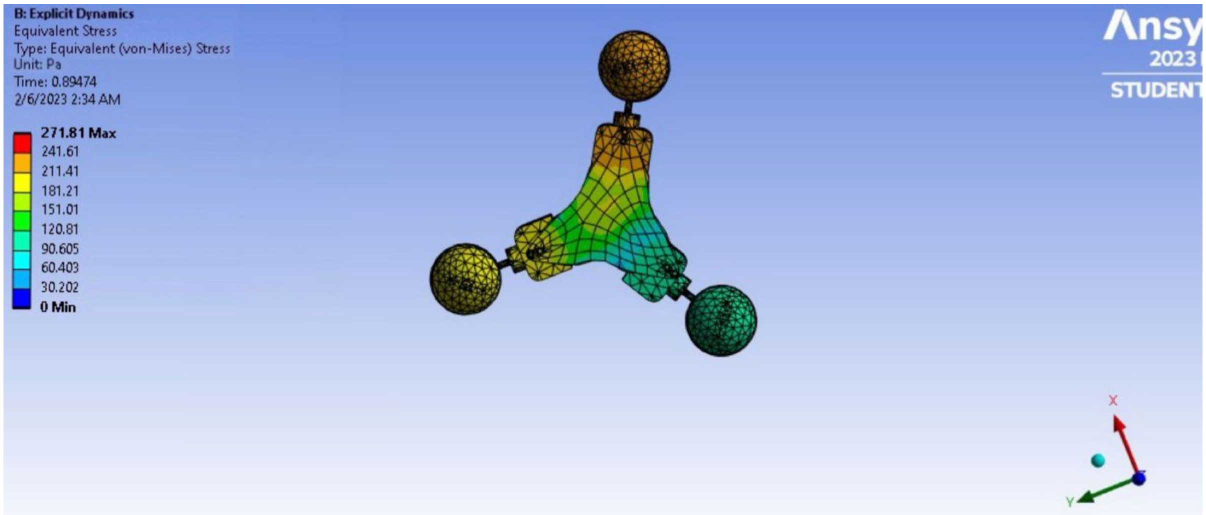


Figure 39. Explicit Dynamic Analysis of Body (top)

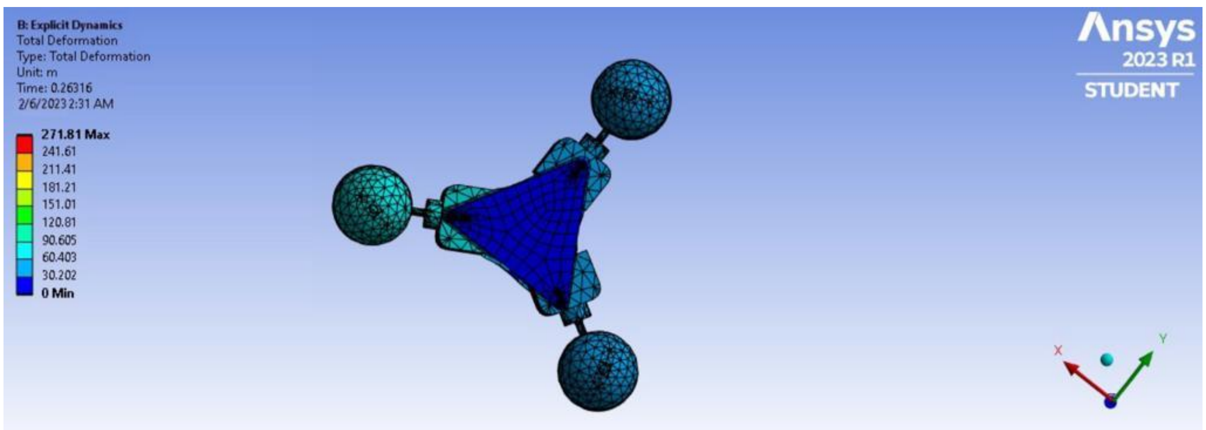


Figure 40. Explicit Dynamic Analysis of Body (bottom)

3.3 Manufacturing and Assembly

The manufacturing process for UGVs entails intricate procedures that demand specialized expertise across multiple domains, encompassing mechanical engineering, electrical engineering, and computer science. Commencing with the UGV design phase, meticulous consideration is given to the selection of suitable sensors, equipment, and materials. Prototyping and rigorous testing follow suit to ascertain adherence to the design specifications. Upon finalization of the design, the manufacturing process initiates, entailing a series of distinct stages. These stages typically involve fabricating the chassis, integrating sensors and equipment, and harmonizing computing hardware and software components. Thorough testing ensues to validate compliance with predetermined specifications and to assess the UGV's capability in executing its designated tasks.

3.3.1 Wheel Manufacturing and Assembly

For the manufacturing of the wheel, Polylactic Acid (PLA) is selected as the preferred filament for 3D printing the wheel components. PLA is a popular choice due to its favorable properties such as biodegradability, ease of printing, and reasonable strength. The wheel parts are printed using 3D printers that employ the PLA filament, ensuring precise and accurate fabrication.

Once the printed parts are obtained, the assembly process begins. Multiple screws and suitable resins are utilized to securely fasten and connect the printed components, creating the desired wheel assembly. The selection of screws and resins depends on factors such as the intended use, load requirements, and compatibility with PLA material. The assembly process ensures that the individual printed parts come together seamlessly, forming a functional and robust wheel structure. The use of screws and resins provides stability, strength, and integrity to the assembly, enabling it to withstand the anticipated loads and forces during operation.

Overall, the combination of PLA filament for 3D printing and the assembly using screws and resins allows for the efficient and reliable manufacturing of the wheel. This approach leverages the benefits of 3D printing technology while ensuring the structural integrity and performance of the final wheel assembly.

3.3.1.1 Fabrication of Prototype I

The drawing of the prototype's main parts has been attached for reference. However, the final shape of the wheel did not meet the required standards, leading to the decision to discard this prototype.

The attached drawing serves as a visual representation of the initial design concept and provides insights into the intended form and structure of the wheel. Despite the efforts put into creating the prototype, it fell short of meeting the desired specifications and performance criteria.

Discarding the prototype is a necessary step in the design and development process, as it allows for further improvements and iterations to achieve the desired outcome. The lessons learned from this discarded prototype will inform future design revisions, ensuring that the final product meets the necessary standards of functionality, aesthetics, and performance.

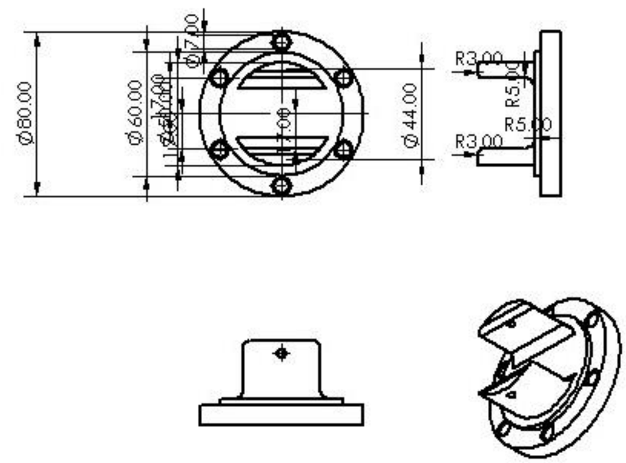


Figure 41. 2D Drawing of Prototype I Wheel Side

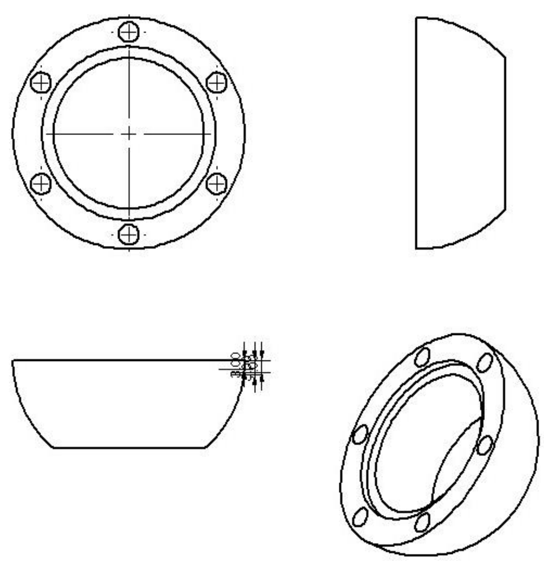


Figure 42. 2D Drawing of Prototype I Hemisphere

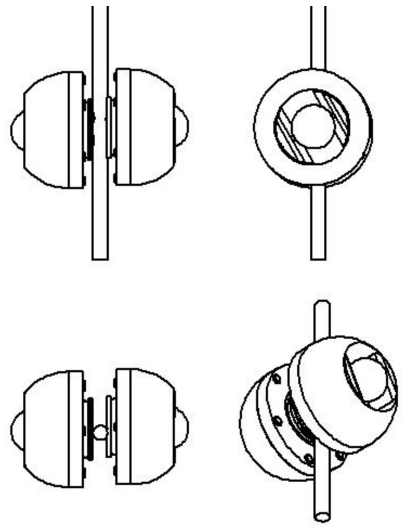


Figure 43. 2D Drawing of Prototype I Assembly

3.3.1.1 Fabrication of Prototype II

Prototype II has been successfully fabricated using the same material, Polylactic Acid (PLA), for 3D printing its parts. Following the printing process, the individual parts are meticulously assembled using screws and an appropriate epoxy adhesive. To enhance the functionality and performance of the wheel, it incorporates two bearings, with one placed in each hemisphere. Additionally, a connecting shaft is integrated to link the two hemispheres of the wheel.

The use of PLA as the material for 3D printing offers several advantages, including its biodegradability, light weightiness, ease of printing, and reasonable strength. These properties make PLA an optimal choice for creating the parts of the prototype, ensuring accurate and precise fabrication. The assembly process involves securely fastening the printed parts using screws and epoxy adhesive. This combination ensures structural integrity, stability, and durability, enabling the prototype to withstand the anticipated loads and forces during operation.

The incorporation of bearings in each hemisphere of the wheel allows for smooth rotation and reduced friction. These bearings facilitate the efficient transfer of loads and provide improved performance during operation. Furthermore, the connecting shaft plays a crucial role in connecting and synchronizing the two hemispheres of the wheel. It enables coordinated movement and enhances the overall stability and functionality of the prototype. By utilizing these design elements and materials, Prototype II aims to address the limitations identified in the previous iteration. It represents a step forward in achieving the desired outcome and serves as a basis for further evaluation, testing, and refinement.

Multiple views of the Prototype II are illustrated as follows for reference.

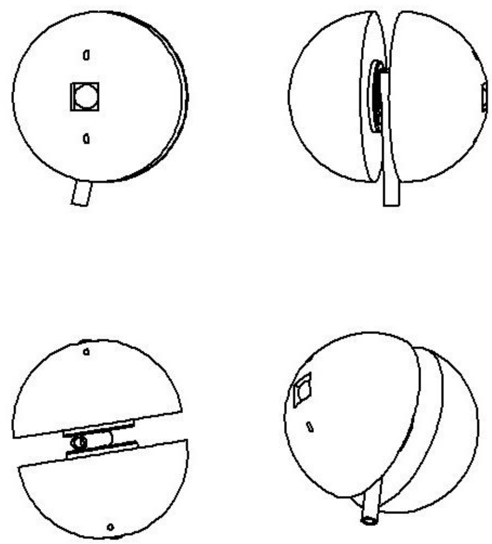


Figure 44. 2D Drawing of Prototype II Assembly

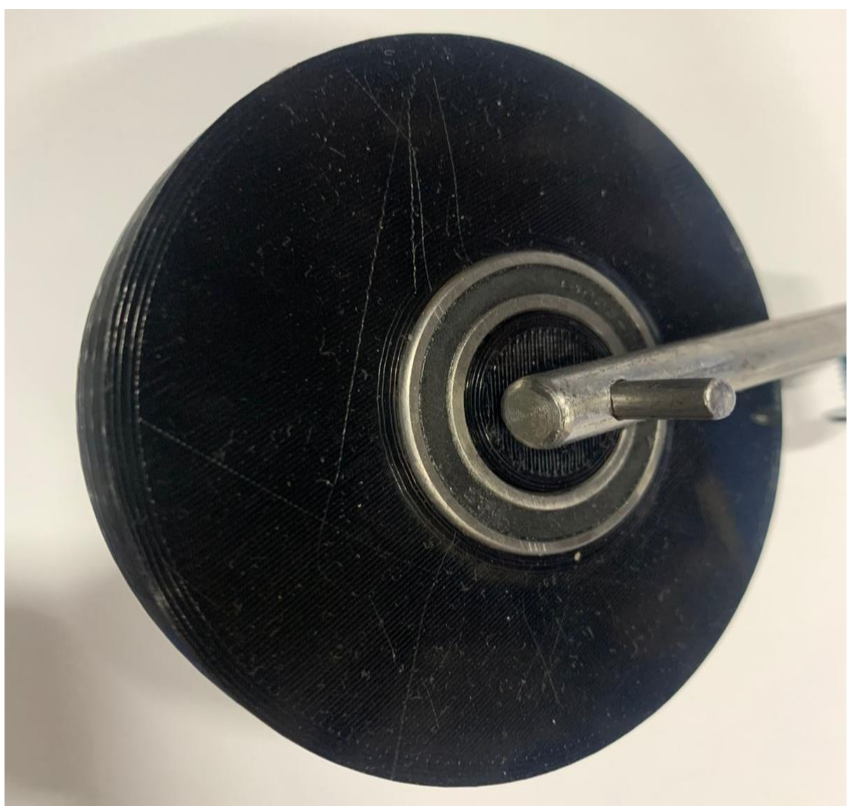


Figure 45. Prototype II, Cross-section Wheel

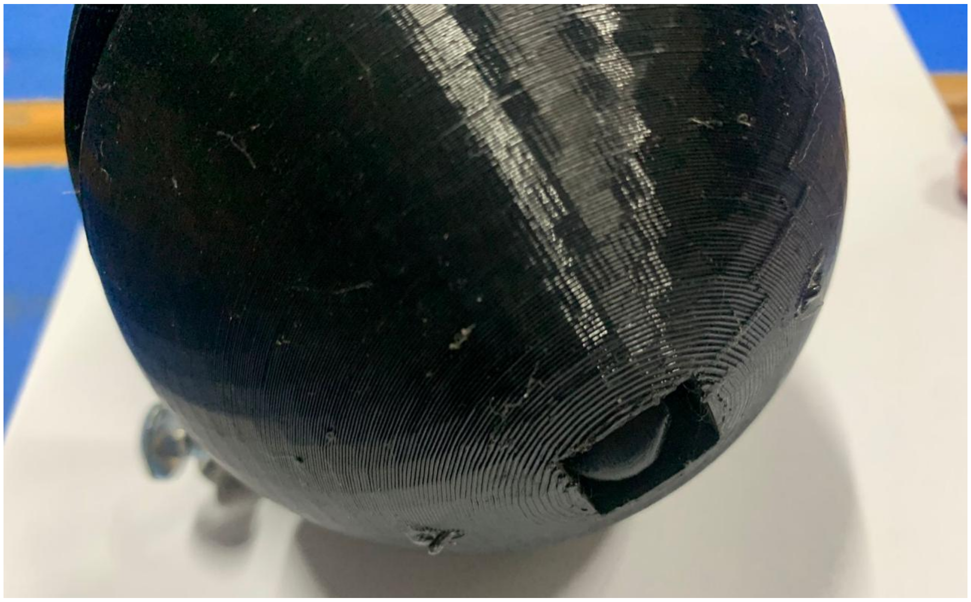


Figure 46. Prototype II (Top View)

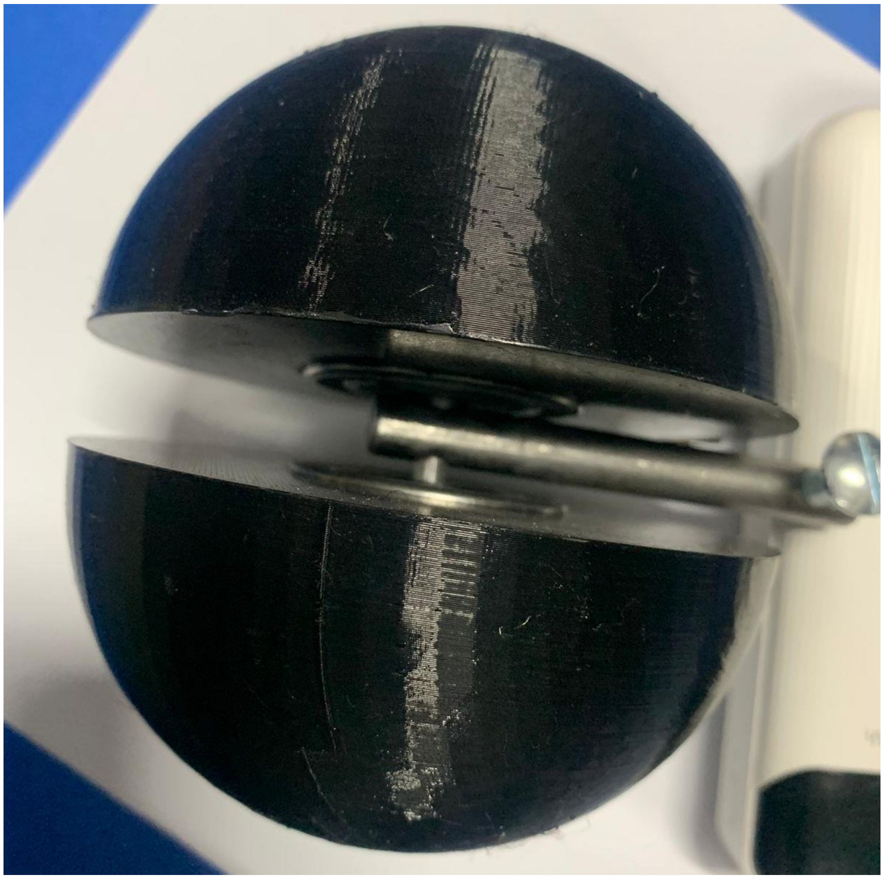


Figure 47. Prototype II, Complete Assembly

3.3.2 Body Manufacturing and Assembly

The manufacturing and assembly processes occur concurrently, involving the fabrication of multiple parts followed by their assembly into the body of the robot.

During the manufacturing phase, various parts of the robot are produced using appropriate manufacturing techniques such as machining, molding, or 3D printing. These parts are created based on precise design specifications, ensuring dimensional accuracy and adherence to functional requirements. The manufacturing process may involve different materials depending on the specific component's characteristics and performance criteria.

Simultaneously, the assembly process takes place, where the manufactured parts are joined together to form the complete body of the robot. This involves carefully aligning and connecting the individual components according to the assembly instructions and design specifications. Fasteners, such as screws, bolts, or adhesive agents, are utilized to secure the parts and ensure their stability and structural integrity.

Concurrent manufacturing and assembly offer several benefits, including streamlined production timelines and efficient resource utilization. This approach minimizes delays and allows for continuous progress throughout the manufacturing and assembly stages.

The completed assembly represents the culmination of the manufacturing and assembly processes, resulting in a fully functional robot body ready for further integration with other system components. It serves as the foundation for subsequent testing, programming, and integration of additional features to bring the robot to life and fulfill its intended purpose.

3.3.2.1 Fabrication of Motor Holders

The motor holders have been meticulously designed to securely house the motors and serve as a critical connection between the electronics and the wheel shafts. These holders play a crucial role in achieving proper alignment and integration of the motors within the larger robot assembly. In order to achieve a combination of lightweight construction and durability, the motor holders are crafted using Polylactic Acid (PLA) via the process of 3D printing. PLA possesses the advantage of being lightweight, making it an ideal choice for minimizing the overall weight of the robot while ensuring structural strength and integrity.

The utilization of 3D printing enables the precise and customizable production of the motor holders, ensuring an impeccable fit for the motors and other associated components. This approach allows for flexibility in design iterations and modifications, enabling swift prototyping and reducing manufacturing time. By employing PLA as the material for 3D printing, the motor holders strike a balance between weight reduction and mechanical resilience. This ensures that the motor holders can effectively withstand the loads and forces encountered during the robot's operation while contributing to an overall lightweight design philosophy.

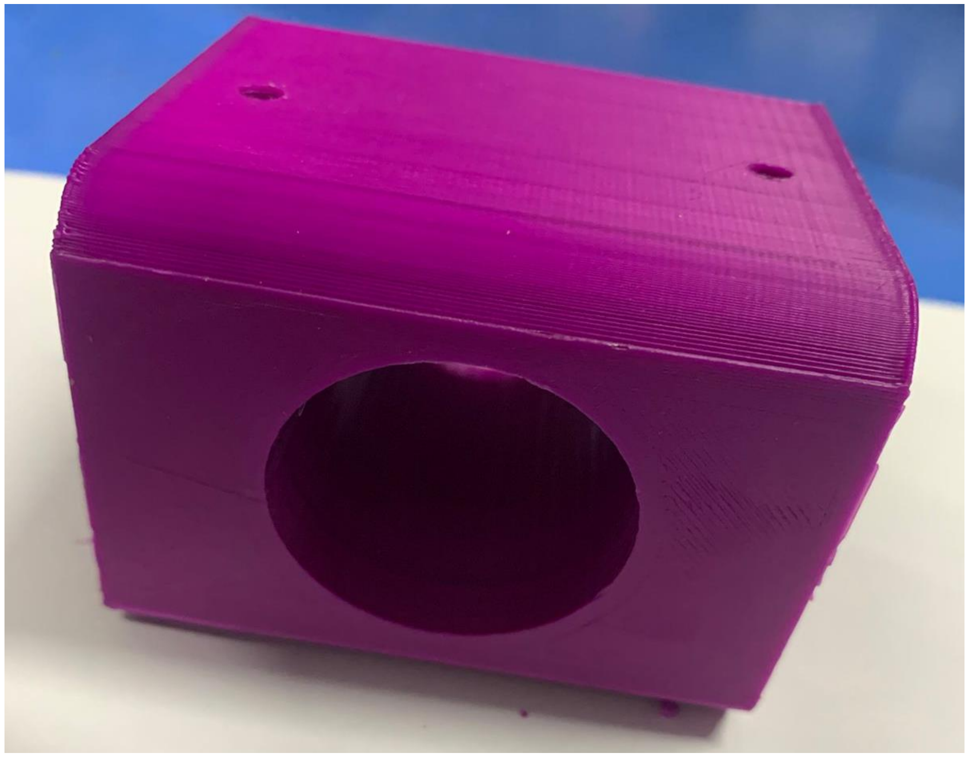


Figure 48. Motor Holder (Side View)

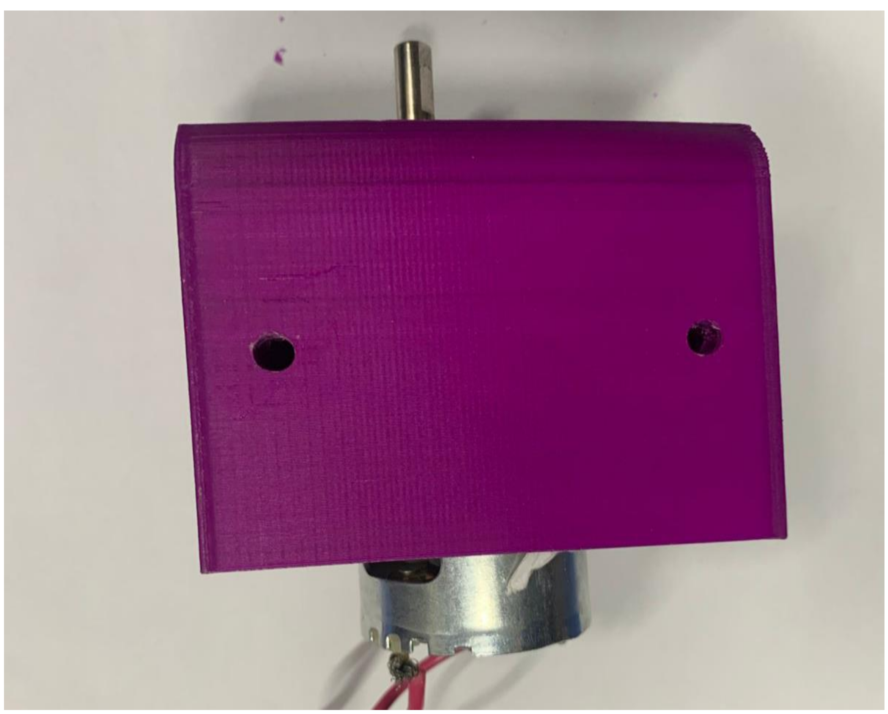


Figure 49. Motor Holder with Motor Assembly (Side View)

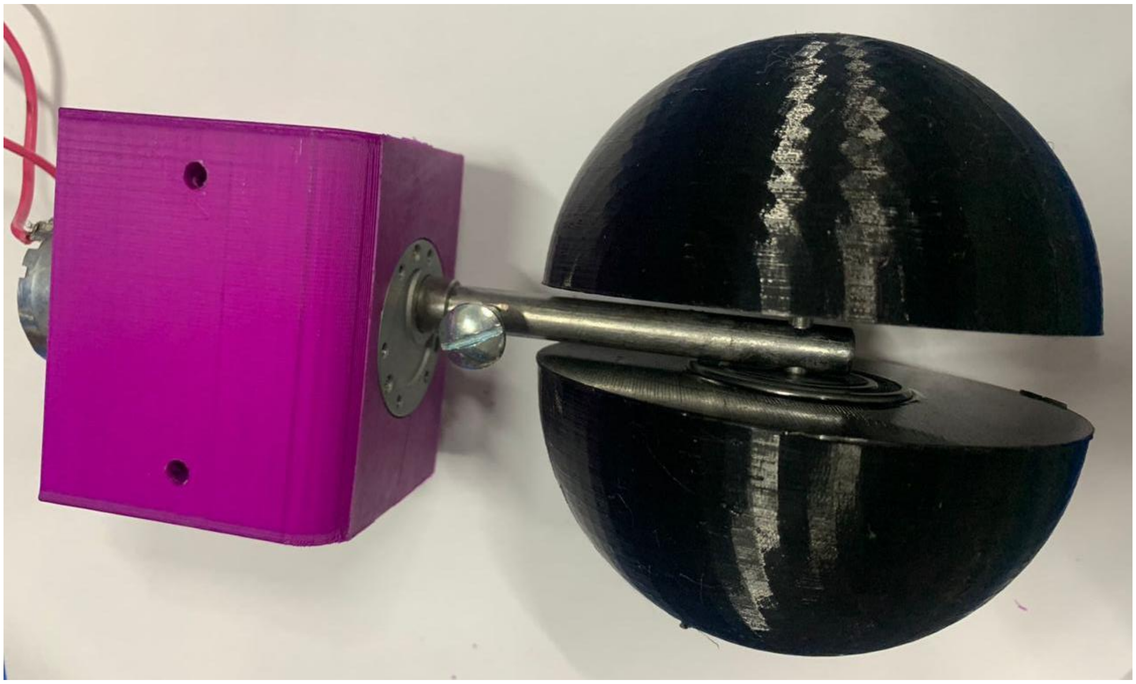


Figure 50. Motor Holder with Motor and Wheel Assembly (Side View)

3.3.2.2 Fabrication of Connecting Shafts

In the initial prototype of the wheel, the shafts were fabricated using 3D printing technology. However, this approach proved to be inadequate as the 3D printed shafts exhibited a tendency to break easily even under relatively low stress applications. Recognizing this flaw, measures were taken to rectify the issue in subsequent iterations. To address the weakness observed in the previous prototype, the decision was made to manufacture the shafts of the current module using carbon steel. Carbon-steel, renowned for its exceptional strength-to-weight ratio, was chosen due to its remarkable properties such as high tensile strength, flexibility, and widespread availability.

By using carbon steel for the shafts, the objective is to enhance the structural integrity and durability of the wheel assembly. It possesses superior strength characteristics compared to the previously used 3D printed materials, making it capable of withstanding higher stress levels and loads without failure or deformation. This ensures a robust and reliable performance of the wheel module, even in demanding operating conditions. Moreover, carbon-steel's malleability allows for easy customization and shaping of the shafts to suit the specific requirements of the wheel assembly. This flexibility enables engineers to precisely tailor the dimensions and design of the shafts, optimizing their performance and compatibility within the overall system. Additionally, the availability of the material is advantageous in terms of sourcing and cost-effectiveness. Its wide availability in the market ensures a readily accessible supply, reducing manufacturing lead times and associated expenses. By adopting carbon-steel as the material for the shafts, the lessons learned from the shortcomings of the previous prototype are effectively addressed. This modification demonstrates a commitment to improving the design and ensuring the functionality and reliability of the wheel module.

Overall, the use of steel for the shafts in the current module represents a strategic decision aimed at overcoming the fragility of the previous prototype. The integration of carbon's strength, malleability, and availability provides a solution to enhance the performance and longevity of the wheel assembly, ensuring a more resilient and efficient operation.

Table 8. Properties of Carbon Steel

Properties	Carbon steel
Carbon component	0.60-1.0
Ultimate tensile strength (MPa)	685
Density (kg/m3)	7840
Young’s modulus (GPa)	190-215

Figure 51. Connecting Shaft, Screw, and Hemisphere connector

Figure 52. Connecting Shaft, Screw, and Hemisphere connector Assembly

3.1.2.3 Acrylic Plates

To construct the outer walls of the body, acrylic plates are employed for both the top and bottom sections. These plates play a crucial role in providing structural support and housing for the electronics and holders within their designated positions.

Acrylic is selected as the material of choice due to its advantageous characteristics. One key benefit is its lightweight nature, which helps to minimize the overall weight of the body, making the robot more agile and efficient in its movements. Additionally, acrylic exhibits considerable strength, ensuring that the external walls can withstand various forces and maintain their integrity during operation. Compared to other materials that may be excessively heavy or prone to bending under the weight, acrylic offers a favorable combination of weight reduction and structural robustness. It strikes a balance between durability and weight, ensuring that the body remains sturdy while avoiding unnecessary additional mass that could hinder the robot's performance. Moreover, acrylic is readily available and cost-effective, making it a practical choice for manufacturing the external walls. Its versatility allows for easy fabrication and customization to meet the specific design requirements of the body.

By utilizing acrylic plates, the external walls provide an ideal enclosure for the electronics and holders, offering both protection and stability. The use of acrylic enhances the overall performance of the robot by optimizing weight, maintaining structural integrity, and ensuring the secure placement of crucial components.

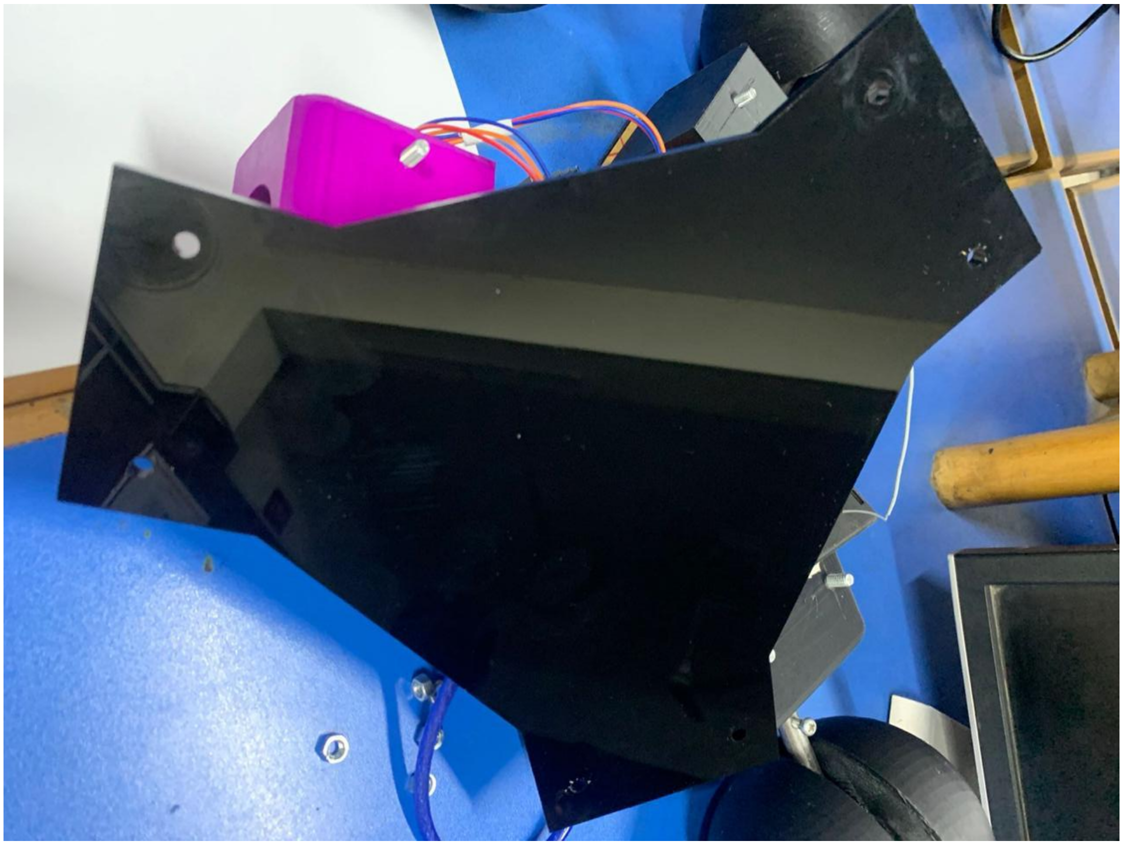


Figure 53. Acrylic Plates

3.1.2.4 Complete Assembly

Upon completion of the manufacturing phase, the individual components are methodically assembled in accordance with the predetermined specifications. This assembly procedure entails the utilization of a variety of screws and bolts to establish secure connections between the motor holders, acrylic plates, and other internal elements.

The motor holders serve a critical function by facilitating the integration of motors into the overall structure, ensuring precise alignment and optimal operational performance. Through the use of screws, the holders are firmly affixed to their designated positions, imparting stability and structural support to the motors. Likewise, the acrylic plates are meticulously joined together to form the external walls of the prototype. The screws and bolts are instrumental in creating robust and dependable attachments between the plates, thereby upholding the structural integrity of the body.

By employing appropriate fastening mechanisms, the assembled prototype achieves the desired configuration and resilience. This meticulous assembly process guarantees secure interconnections between all components, mitigating the risk of potential dislodgment or detrimental movement that could compromise the prototype's functionality and reliability. The application of screws and bolts enables the prototype to be disassembled and reassembled as necessary for subsequent adjustments, repairs, or enhancements. This facilitates iterative design iterations, streamlines maintenance efforts, and accommodates future modifications with ease.

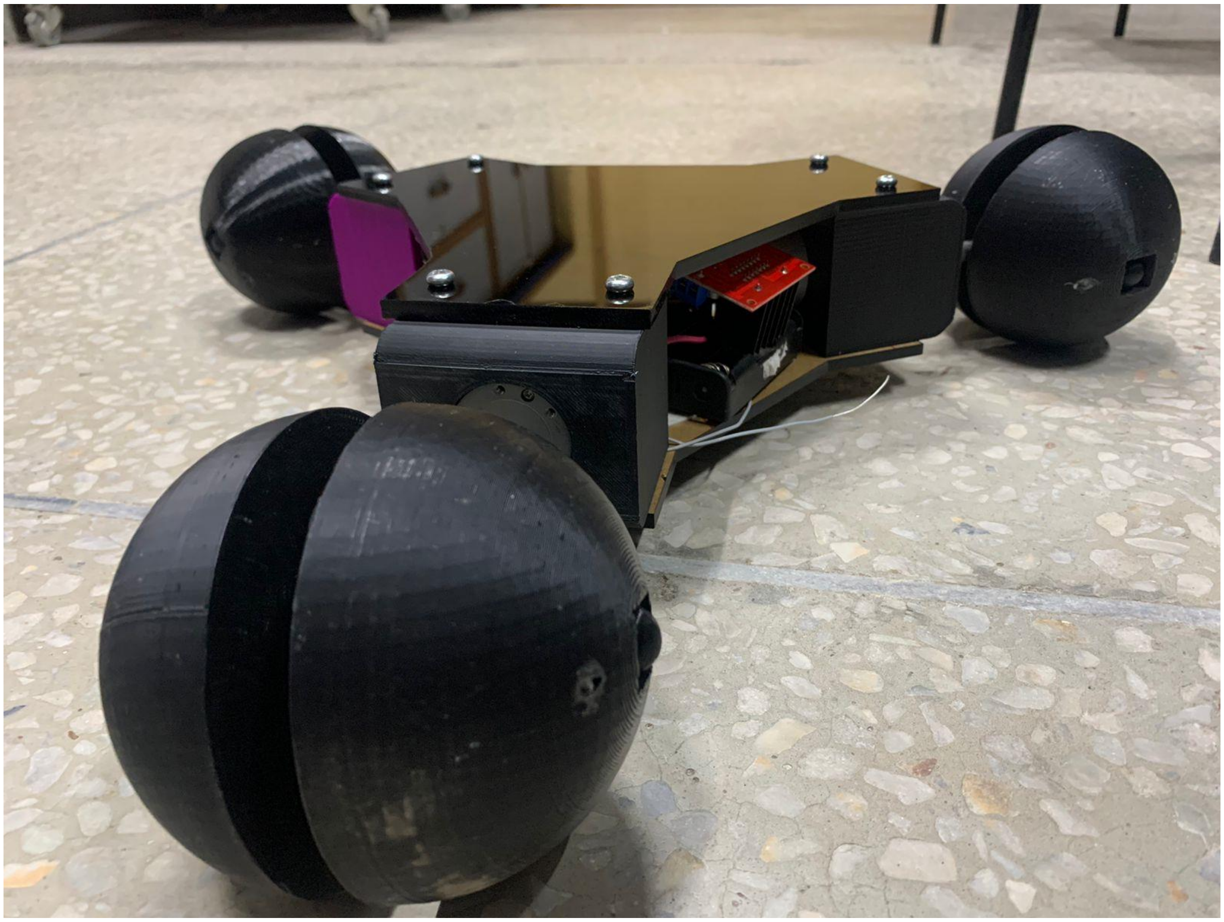


Figure 54. Complete Assembly (Side View)

Figure 55. Complete Assembly (Top View)

When embarking upon UGV design, cost of production emerges as a critical factor, as failure to withstand hazardous environments incurs substantial financial implications. Furthermore, UGVs must exhibit affordability to facilitate widespread adoption across diverse industries. To mitigate costs, numerous UGV manufacturers leverage off-the-shelf components and open-source software, thereby effectuating significant reductions in development expenses.

3.4 Electronics Section

The electronics portion consists of multiple components such as enlisted below:

- LGM37- 550, High Torque Metal Gear Motors
- Rechargeable Battery
- L298N Motor Drivers
- RC Transmitter FS-16X
- RF Reciever FS-LA6B
- Arduino UNO Controller

3.4.1 LGM37- 550, High Torque DC Geared Motors

The motors have an essential role in the mobility of the vehicle and provide necessary force for the locomotion. Each motor is tested for following parameters before final selection for the UGV:

- Torque
- Speed
- Dimensions
- Weight

After considerations the motor finalized for the UGV is LGM37- 550, a high torque metal DC geared motor with the following specifications:

Table 9. Specifications of DC Motor

Parameters	**Specifications**
Rated Voltage	12 V
Gear Ratio	60.1:1
Speed	720 RPM
Max continuous torque	0.325 Nm
Dimensions	3.75 x 1.5 x 1.5 in

Table 10. Parameters of DC Motor

VOLTAGES	**NO LOAD**		**STALL**						
NOMINAL	**SPEED**	**CURRENT**	**SPEED**	**CURRENT**	**OUTPUT**	**TORQUE**		**CURRENT**	
V	rpm	A	Rpm	A	mN.m	W	mN.m	Kg.cm	A
12	450	0.3	380	0.83	130	5.34	294	3.00	4.3
12	150	0.3	126	0.83	360	4.78	588	6.00	4.3

12	90	0.3	76	0.83	530	4.28	1470	15.00	4.3
12	64	0.3	54	0.83	760	4.32	1470	15.00	4.3
12	50	0.3	42	0.83	784	4.3	1470	15.00	4.3

3.4.2 Rechargeable Battery

The battery selected for this application consists of 18650 lithium-ion cells. Each cell provides a voltage of 3.7 V and has a capacity of 3800mAh. To achieve the desired voltage level, four cells are connected in series. This configuration ensures that the required voltage is met for the intended operation. The capacity of 3800mAh per cell is sufficient to power the system for a runtime of approximately 30 minutes. This capacity ensures an adequate supply of energy to support the desired duration of operation. The specifications are incorporated below:

Table 11. Specifications of Rechargeable Battery

Parameters	Specifications per cell	Specifications after merging
Voltage	3.7 V	14.8 V
Capacity	3800mah	3800mah
Diameter/ width	18 mm diameter	36 mm total width
Length	65 mm	130 mm

3.4.3 L298N Motor Driver

The motor driver used for DC motor is L298N. It is capable of running two motors at a time. Motor drivers perform the task of h-bridge and reverse the directions of motor where required. They also act as regulators to provide constant voltage to motors. This specific driver has a current rating of 2 Amps. It has four inputs and outputs, with two PWM enable pins. The figure is attached below along with specifications.

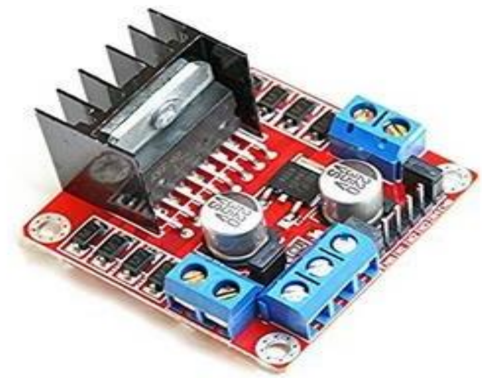


Figure 56. L298N Motor Driver

Table 12. Specifications of L298N DC Motor Driver

Parameters	Specifications
Supply voltage (max)	46 V
Supply current (max)	2 A
Driver Voltage	5 – 35 V
Driver Current	2 A
Logic Current	0 – 36 mA
Maximum Power	25 Watts

3.4.4 RC Transmitter FS-16X

RC transmitter is used to transmit signals to receiver to act. Motors would be connected to the receiver and would be controlled by the transmitter. FS-i6x is a six to ten channel transmitter. Three motors are connected to channel 2,3 and 4 simultaneously. Range of the transmitter is 2.4- GHz. The figure of transmitter is shown below:

Figure 57. FS-16X Transmitter

Table 13. FX-16X Specifications

Parameters	**Specifications**
Channels	6 – 10 channels
RF Range	2.408-2.475 GHz
RF power	< 20dBm
RF Channel	135
Bandwidth	500KHz
Low Voltage warning	<4.2V
DSC Port	PS/2 Port PPM
Weight	392g
Chargeable	No
Antenna length	26mm
Power	6V DC 1.5AA*4
Size	174 x 89 x 190mm

Online update	Yes
Color	Black

3.4.5 RF Reciever FS-LA6B

FS-IA6B is a six-channel receiver. Range of receiver is 2.4 GHz. Operating voltage is 4 to 8.4V. It weighs only 14.9 grams. Motors will be connected to the receiver through Arduino nano it will receive signals from the receiver. Channels 1 and 2 will be connected with motors. Figure and specifications are given below:

Figure 58. FS-LA6B Receiver

Table 14. FS-LA6B Specifications

Parameters	**Specifications**
Channels	6
Frequency Range	2.4055 – 2.475GHz
Weight	14.9 grams
Input voltage	4 to 8.4V
Transmitting power	< 20dbm
RF receiver sensitivity	-105dbm
I-bus interface	Yes
Antenna length	26mm * 2 (dual antenna)
Dimensions	47x26.2x15mm
Color	Black

3.4.6 Arduino UNO

The microcontroller used is an Arduino UNO. It is a development board that is based on the ATmega328P microcontroller. It consists of 14 digital input/output pins (out of which 6 can be used as PWM outputs), 6 analog input pins, a USB connection, A Power barrel jack, an ICSP header and a reset button. The figure is given below:

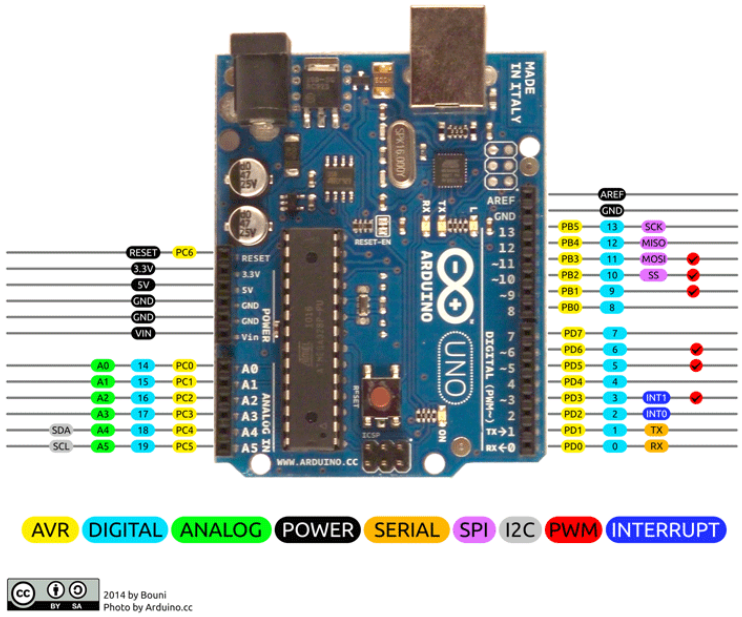


Figure 59. Arduino UNO

Table 8 Arduino UNO Specifications

Microcontroller	**ATmega328P – 8-bit AVR family microcontroller**
Operating Voltage	5V
Recommended Input Voltage	7-12V
Input Voltage Limits	6-20V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
Flash Memory	32 KB (0.5 KB is used for Bootloader)
SRAM	2 KB
EEPROM	1 KB
Frequency (Clock Speed)	16 MHz

3.4.7 Electronics Circuitory

The circuit for the control system applies to three L298N drivers, three motors, an Arduino UNO and the flysky controller package. The circuit is designed as a basic motor control system with each motor having a respective motor driver. Even though these drivers are able to run two motors simultaneously, testing has shown that if the motor specifications are too high, motor drivers are unable to supply ample amount of current to each motor. To counteract this issue, three motor drivers are utilized.

The Arduino pins are used as follows; nine digital pins are given to the motors with each motor driver taking three apiece. Three more digital pins are associated to the 3 channels used from the flysky controller. Finally, the ground pin of the Arduino is connected in common with both the motor drivers and the receiver.

Figure of designed circuit is given below:

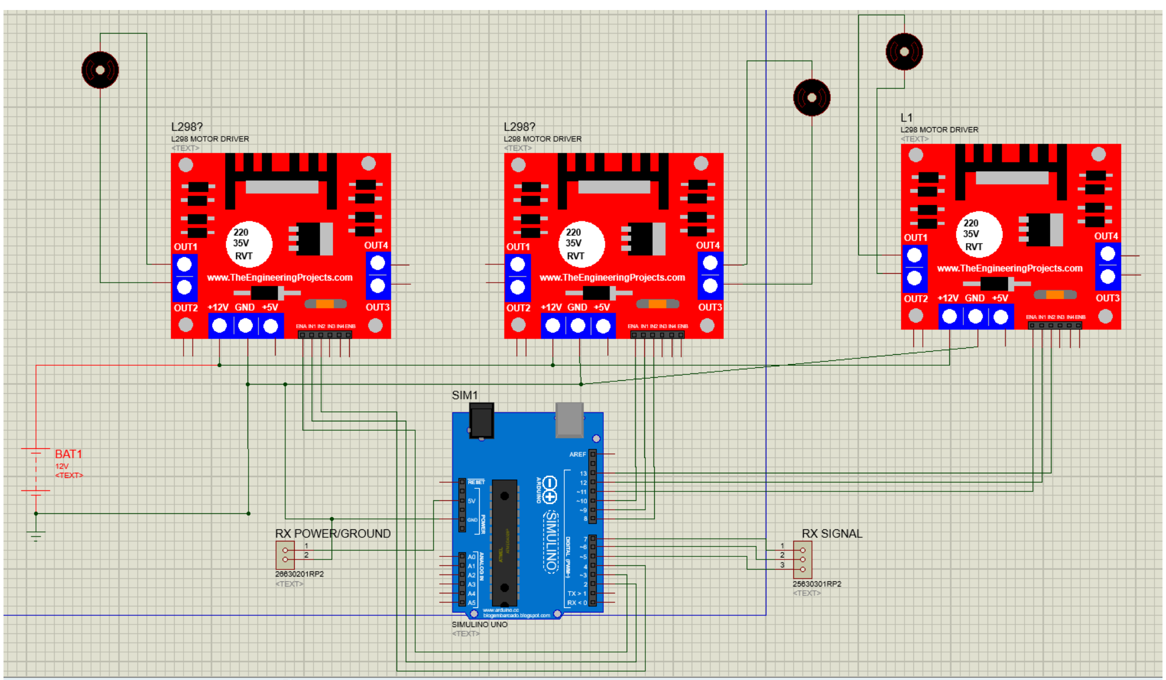


Figure 60. Controls Circuit

Chapter 4 – CONTROLS AND PROGRAMMING

4.1 Controls

The controls of a three-wheeler robot are very different from a normal two-wheeler or four-wheeler robotic base. The problem lies in the orientation and setting of the wheels. The three wheels are placed at an angle of 120 to each other. However, one major advantage of such an orientation is the ability of the robot to rotate clockwise and anticlockwise. So now we have six possible movements of the robot: forward, backward, left, right, clockwise rotation and anti-clockwise rotation.

When we have to move the robot forward, motor1 and motor2 will be actuated in right and left direction respectively, this will enable the active rotation of wheel1 and wheel2. The third motor, however, will be at halt and its wheel will be in passive rotation, that is, only the outer hemisphere will rotate. The same methodology will be used in backward direction with only the direction of the motors reversed.

When we need to rotate the base clockwise, all three motors will be actuated in the right direction and vice versa for the anticlockwise direction. This actuation of motors in triangular configuration will enable the robot to rotate about its axis.

The left and right movements involve some mathematics because here all three motors need to be actuated however with different speeds. When we consider the left movement, motor1 and motor2 will be actuated in left direction and the third motor will move in right direction. The placement angle of the motors and their speeds will accumulatively allow the base to move in x-axis. The mathematical equations are as shown below.

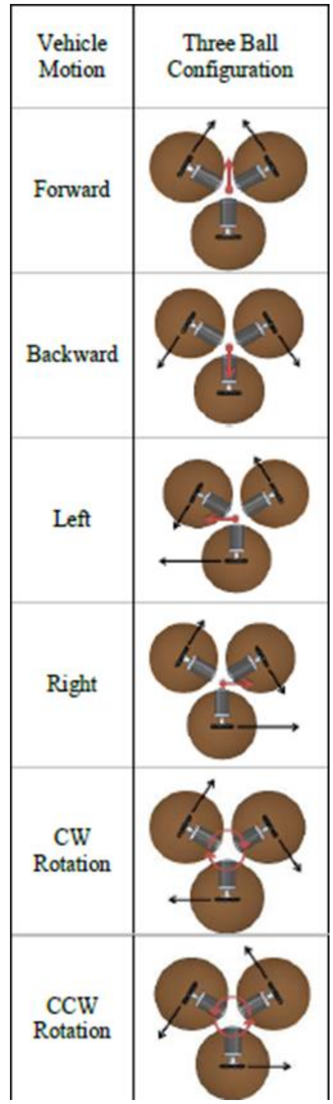


Figure 61. Controls Representation

4.1.1 Controls Calculations

Motor 1 (M1): 30+ 120 +90 =240
Motor 2 (M2): 30 + 90 = 120
Motor 3 (M3): 0

F_x= Cos (240) * M1+ Cos (120) * M2+ Cos (0) * M3
F_y= Sin (240) * M1+ Sin (120) * M2+ Sin (0) * M3
F_W= 1 * M1+ 1 * M2+ 1 * M3

$$\begin{bmatrix} F_x \\ F_y \\ F_\omega \end{bmatrix} = \begin{bmatrix} \cos 240 & \cos 120 & \cos 0 \\ \sin 240 & \sin 120 & \sin 0 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} M1 \\ M2 \\ M3 \end{bmatrix}$$

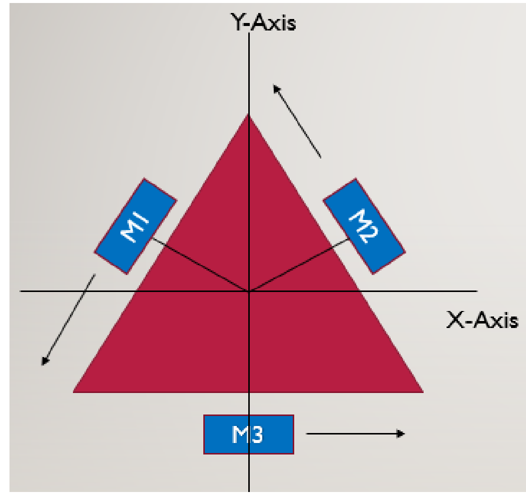


Figure 62. Controls Implementation on UGV

4.2 Programming

The controller which is Arduino UNO receives signal from the transmitter FS-16X. the pulse from the transmitter is then mapped onto numerical values which are further used to make decisions about the movement of the robot.

To control the movements of the robot, channels 2, 3 and 4 are used. Channel 2 determines the right and left direction of the robot. Channel 3 determines the forward and backward direction and channel 4 determines the clockwise and anti-clockwise direction.

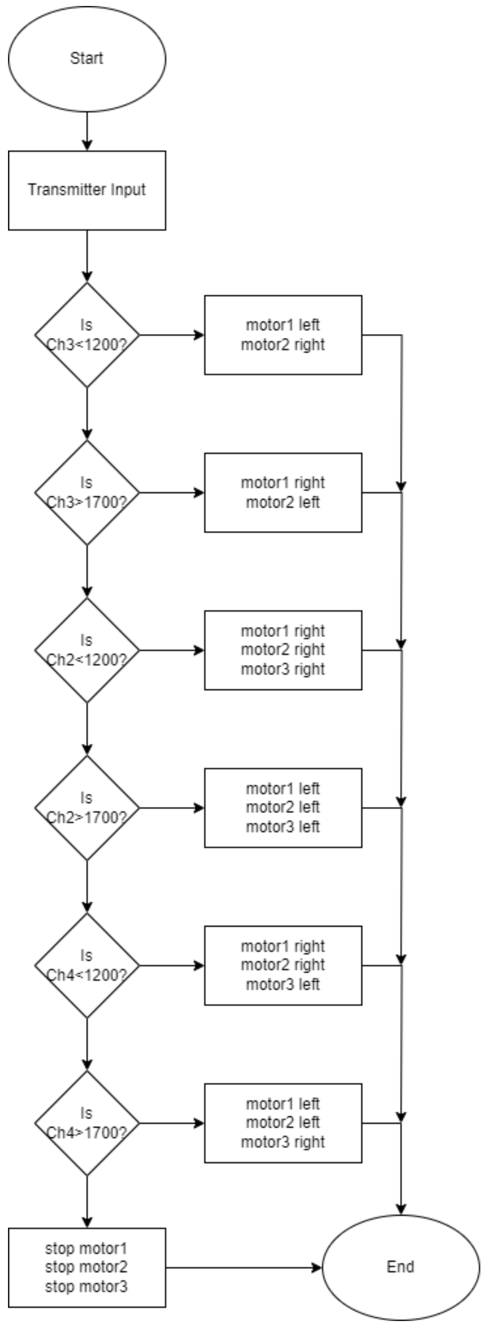


Figure 63. Programming Flowchart

Chapter 5 – MATERIAL FOR FABRICATION

The final deliverable of this project was to recommend a material for the future fabrication of the Unmanned Ground Vehicle (UGV) that possesses the necessary characteristics to withstand the stresses associated with being thrown from a height of 7 feet. The goal was to identify the best materials available in the local market that strike a balance between durability, sustainability, and affordability in terms of craftsmanship.

Extensive research and analysis were conducted to evaluate various material options and their suitability for this specific application. Factors such as strength, impact resistance, weight, and cost were taken into consideration. The material needed to have the ability to endure the significant forces and potential impacts encountered when the UGV is thrown. In addition, sustainability and cost-effectiveness were key considerations to ensure the long-term viability and economic feasibility of the fabrication process. The material had to be readily available in the local market, making it easily accessible for manufacturing purposes, while also being affordable within the project's budget constraints. Through a thorough assessment, a material was identified that meets all the necessary criteria. This material provides the required durability to withstand the stresses associated with throwing the UGV from a 7-foot height. It also offers sustainability in terms of sourcing and production, as well as being economically viable.

The recommendation for this material considers the project's goals of durability, sustainability, and cost-effectiveness, ensuring that the UGV can be fabricated with a material that meets the specified requirements while also being practical and feasible for future production.

5.1 Wheel Material

In the production of unmanned ground vehicles (UGVs), comprehensive research and testing of components play a critical role. Particularly in wheel manufacturing, a thorough examination and evaluation of multiple materials are essential to verify their properties against specified requirements. This research encompasses meticulous comparison of material properties to identify the optimal choice for integration into the UGV. By undertaking this rigorous process, the UGV's wheels can be fabricated using materials that meet the required criteria, ultimately enhancing the vehicle's overall performance and functionality. These efforts ensure that the selected materials align with the desired specifications, optimizing the UGV's operation in various conditions and supporting its intended tasks. Some of the materials selected for research are as follow:

- Vulcanized Rubber
- Polyurethane
- TPU
- PCTPE

5.1.1 Vulcanized Rubber

Vulcanized rubber is a type of elastomer that is undergone chemical treatment to enhance its mechanical properties. By heating the raw rubber compound with sulfur and other additives, the polymer chains within the material form cross-links. This process results in improved strength, durability, and elasticity, making the rubber more resistant to deformation, wear, and tear. Vulcanized rubber finds extensive use in industrial settings that demand high-performance materials, including tires, conveyor belts, seals, gaskets, and shoe soles. Its exceptional combination of characteristics makes it a favored option for challenging environments where reliability and long-lasting performance are crucial.

Vulcanized rubber is an excellent material for crafting throwable military-grade Unmanned Ground Vehicles (UGVs). Despite higher manufacturing costs, it provides exceptional durability, resilience, and the ability to withstand impacts and rough handling. These qualities make vulcanized rubber UGVs well-suited for demanding military operations. The enhanced mechanical properties of strength and elasticity further contribute to their reliability and performance. In summary, vulcanized rubber is a top choice for building long-lasting and rugged UGVs that can be thrown.

Ansys analysis for wheel made with vulcanized rubber is shown as follows.

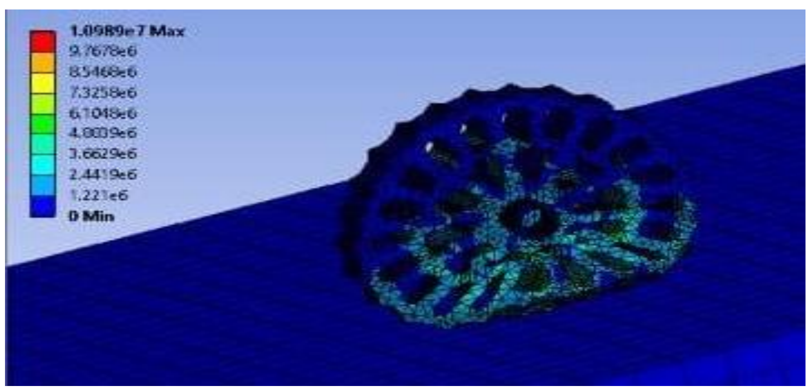


Figure 64. Ansys Analysis for wheel made with Vulcanized Rubber

5.1.2 Polyurethane

Polyurethane is a type of polymer that exhibits a broad range of properties, making it highly versatile and widely used in many industries. It is formed through the reaction of polyols and isocyanates, resulting in a material with exceptional characteristics. Polyurethane's versatility, ranging from soft foams to rigid plastics, combined with its desirable properties, makes it a valuable material in numerous industries for various applications.

The polymer is not a suitable material for throwable wheel design because of its softness that results in over-damping and damaging the body of the vehicle.

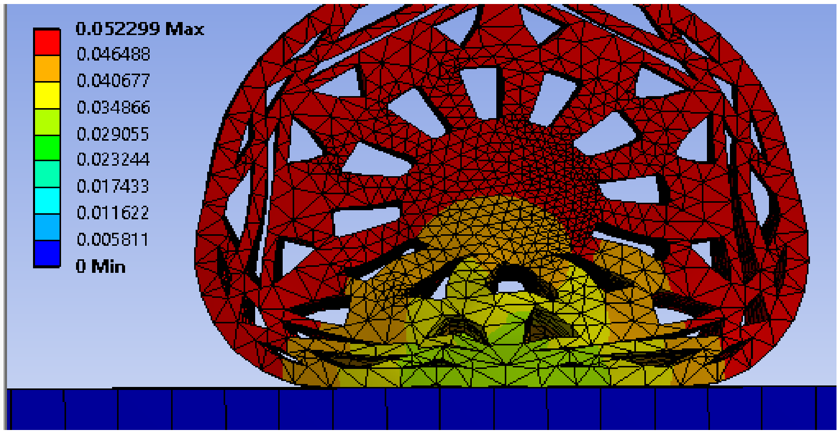


Figure 65. Ansys Analysis for wheel made with Polyurethane.

5.1.3 TPU

Thermoplastic polyurethane (TPU) is an elastomeric material formed by reacting diisocyanatos with polyols. It exhibits a unique blend of rubber-like elasticity and plastic-like properties. TPU offers exceptional mechanical performance, including high flexibility, strength, and chemical resistance. Its versatility extends to the field of 3D printing, where it is utilized for producing resilient and durable components with flexibility. With its desirable combination of characteristics, TPU finds extensive use in various industries for diverse applications, showcasing its suitability for a wide range of products.

TPU is as soft as polyurethane hence making it a good shock absorbent, damaging the UGV body in return. The Ansys results for TPU are almost similar to polyurethane.

5.1.4 PCTPE

PCTPE, or Plasticized Copolyamide TPE, represents a thermoplastic elastomer within the copolyamide material family. This material blend combines the properties of nylon and thermoplastic elastomers. The production process involves compounding a nylon polymer with plasticizers and additional additives to augment its flexibility and elasticity. PCTPE finds widespread application in the creation of flexible components, gaskets, seals, grips, and functional prototypes where an equilibrium between flexibility and mechanical strength is required. Its versatility makes it an optimal choice for various industries seeking resilient and pliable materials.

PCTPE, a chemical co-polymer of nylon and TPE, combines the rigidity and strength of nylon with the softness and flexibility of TPE. It exhibits remarkable load-bearing capabilities, withstanding significant loads without breaking. While it may deform under load, it readily regains its original shape once the load is removed. This unique property makes PCTPE an excellent choice for our manufacturing needs, providing a cost-effective alternative to vulcanized rubber.

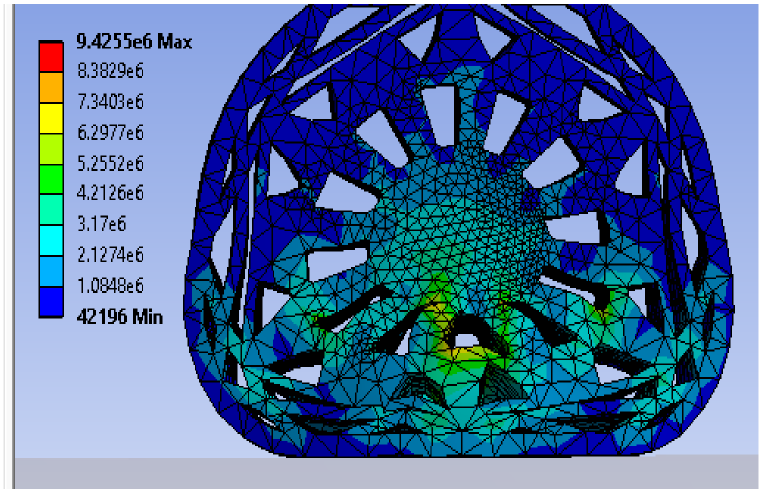


Figure 66. Ansys Analysis for wheel made with PCTPE.

5.2 Body Material

In the realm of unmanned ground vehicles (UGVs), the selection of materials for the vehicle's body is a crucial undertaking that directly influences its overall performance and durability. As UGVs continue to push the boundaries of autonomous exploration, surveillance, and industrial applications, the choice of materials becomes even more pivotal. Striking a delicate balance between weight, strength, corrosion resistance, and cost-effectiveness, the selection process demands meticulous evaluation of various materials and their respective properties. From advanced composites to lightweight alloys and innovative polymers, each option presents its own advantages and challenges. In this endeavor, precision and foresight are paramount to ensure the creation of a robust and efficient UGV body capable of enduring the rigors of demanding terrains and operational conditions. Some of the materials selected for research are as follow:

- Carbon Fiber
- Kevlar
- Fiber Glass
- Polycarbonate

5.2.1 Carbon Fiber

Carbon fiber is a widely utilized and efficient material in various commercial applications due to its exceptional properties. It possesses high stiffness, tensile strength, and a favorable strength-to-weight ratio, making it highly desirable. Additionally, carbon fiber exhibits excellent chemical resistance, can withstand high temperatures, and has low thermal expansion. These advantageous attributes have led to its rapid integration across multiple industries, including sports, automation, aerospace, military, construction, and electronics. The carbon-carbon bonding within the parallel layers of carbon fiber sheets, typically coated with organic materials like polyethylene oxide (PEO) or polyvinyl alcohol (PVA), contributes to its overall structure and performance. However, it should be noted that carbon fiber is relatively costly compared to alternative materials employed in these industries. Nonetheless, its long-term benefits and advantages make it a preferred choice despite the higher initial investment.

5.2.2 Kevlar

Kevlar, a para-aramid synthetic fiber, possesses remarkable strength, heat resistance, and durability. Similar to carbon fiber, Kevlar exhibits high stiffness, tensile strength, strength-to-weight ratio, chemical resistance, temperature tolerance, and low thermal expansion, making it a valuable component in various commercial products. With a tensile strength of approximately 3,620 MPa (525,000 psi) and a relative density of 1380 kg/m3, Kevlar offers exceptional performance. Its structure is composed of rigid molecules that tend to form planar sheet-like structures, resembling silk protein. This inherent brittleness provides Kevlar with its nearly indestructible nature, rendering the material resistant to alteration or modification after manufacturing. While this characteristic can be advantageous in applications requiring unparalleled strength, it can also pose challenges when post-manufacturing processes such as drilling or cutting are necessary. Nevertheless, Kevlar finds extensive use in military and other fields where its indestructible nature is highly desirable.

5.2.3 Fiberglass

Fiberglass is a type of fiber-reinforced plastic produced through the pultrusion process. It is available in different variants, such as C-class, E-class, and S-class, each offering distinct properties. With a density of 2000 kg/m3 and a tensile strength of 1000 MPa, fiberglass demonstrates remarkable versatility across a wide range of applications. Compared to carbon fiber, it is more cost-effective and flexible while outperforming many metals in terms of strength-to-weight ratio. Additionally, fiberglass exhibits non-magnetic and non-conductive properties, allows for transparent electromagnetic radiation, can be shaped into complex forms, and remains chemically inert under various environmental conditions. Its extensive use spans industries including aerospace, marine, automotive, construction, and recreation. Fiberglass finds applications in aircraft, boats, vehicles, baths, enclosures, pools, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, sporting goods, surfboards, and door skins. The combination of its strength, flexibility, and unique attributes positions fiberglass as a favored material across diverse sectors.

5.2.4 Polycarbonate

Polycarbonates are a group of carbonate polymers characterized by their OC(OC)2 bonding. They are valued for their exceptional properties, such as temperature resistance, impact resistance, and optical clarity. With a tensile strength ranging from 55 to 75 MPa and a density of 1200-1220 kg/m3, they offer a viable alternative to metallic composites. Although polycarbonate can be brittle at room temperature, it exhibits high impact resistance, making it highly durable in various applications.

The versatility of polycarbonate has led to its extensive use across multiple industries. It is commonly employed in the manufacturing of DVDs, cellphones, bottles, and medical equipment due to its favorable combination of strength, clarity, and resistance to temperature variations. The optical properties of polycarbonate, including its transparency and light transmission capabilities, make it suitable for applications requiring optical clarity, such as eyewear lenses and automotive components.

Furthermore, polycarbonates are known for their ease of processing and compatibility with various fabrication techniques, including injection molding and extrusion. This makes them a preferred choice in industries that demand efficient and cost-effective production methods. Overall, polycarbonates' unique properties and wide range of applications contribute to their significance in numerous industries.

Table 16. Comparison of Materials

Material	**Density (kg/m3)**	**Tensile strength MPa**
Carbon fiber	1750	3500
Kevlar	1380	3620
Fiberglass	2000	1000
NylonX	1000	100
Polycarbonate	1200-1220	55-75

Chapter 6 – CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

The primary objective of this project entailed the redesigning and fabrication of an omni-directional Unmanned Ground Vehicle (UGV) by leveraging novel spherical wheel technology. The project team set out to develop a lightweight, portable, and invertible vehicle, allowing it to be projectile launched (to make it throwable) for potential future applications. The design phase involved the generation of Computer-Aided Design (CAD) models utilizing SOLIDWORKS software, followed by performing structural and dynamic analysis using ANSYS. The analysis primarily focused on assessing the static characteristics of the body and wheel designs. Furthermore, ANSYS analysis was employed to recommend optimal materials for the UGV based on meticulous research.

6.2 Future Work

This project has encompassed extensive research to identify and propose suitable materials for the fabrication of a throwable prototype vehicle. The primary objective is to engineer a robot that can withstand the impact of being thrown while maintaining its structural integrity and functionality. Thorough analysis has been conducted to assess the material properties, including durability, lightweight characteristics, and impact resistance. The research findings lay a strong foundation for subsequent engineering teams to further advance the project. By leveraging the proposed materials and incorporating necessary design modifications, future groups can proceed with the development of the throwable prototype vehicle. These modifications may entail structural adjustments, shape refinements, or component enhancements to optimize the vehicle's overall performance and functionality.

The outcomes of this research provide a valuable starting point, enabling engineering teams to streamline the prototyping process and focus on the implementation of the proposed materials and design alterations. This approach ensures an efficient and effective progression towards the realization of a throwable vehicle that meets the project's objectives of robustness, lightweight design, and minimal impact susceptibility when thrown.

By capitalizing on the insights gained from this research, future engineering teams can expedite the development cycle and concentrate on the practical realization of the prototype. This collaborative approach will pave the way for the successful engineering of a throwable vehicle, aligning with the desired goals of structural integrity, weight optimization, and impact resistance during operational deployment.

REFERENCES

[1] Z. Miao, J. Mo, G. Li, Y. Ning, and B. Li, "Wheeled hopping robot with combustion-powered actuator," *Int J Adv Robot Syst*, vol. 15, no. 1, pp. 1–14, Jan. 2018, doi: 10.1177/1729881417745608.

[2] Nexter Group, "NERVA LG Mini Unmanned Ground Vehicle (UGV)," *Army Technology*, Jan. 2016.

[3] Nexter Group, "NERVA-S_Brochure website," *https://www.epequip.com/wp-content/uploads/2017/04/NERVA-S_Brochure_EN_2017T1_EPE-Branded.compressed.pdf*, pp. 1–2.

[4] K. Tadakuma and R. Tadakuma, "Fig. 2: Example of Conventional Wheels for Omnidirectional mobility," Scottsdale,Arizona, Sep. 2007.

[5] K. Tadakuma *et al.*, "Throwable tetrahedral robot with transformation capability," in *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2009*, Dec. 2009, pp. 2801–2808. doi: 10.1109/IROS.2009.5354196.

[6] G. I. R. K. Galgamuwa, L. K. G. Liyanage, M. P. B. Ekanayake, and B. G. L. T. Samaranayake, "Simplified controller for three wheeled omni directional mobile robot," in *2015 IEEE 10th International Conference on Industrial and Information Systems, ICIIS 2015 - Conference Proceedings*, Feb. 2016, pp. 314–319. doi: 10.1109/ICIINFS.2015.7399030.

[7] C. Irvin, S. Leo, and J.-H. Kim, "GunBot: Design Concept of a Semi-Autonomous UGV with Omni-directional Mobility and Auto-Target Tracking," Boca Raton, Florida, May 2012.

[8] J. J. Parmar and C. v Savant, "Selection of Wheels in Robotics," *Int J Sci Eng Res*, vol. 5, no. 10, pp. 1–5, Oct. 2014, [Online]. Available: http://www.ijser.org

[9] G. Cawood, "Summary of Omni-Directional Drive Choices," Port Elizabeth, Nov. 2012.

[10] K. Shabalina, A. Sagitov, and E. Magid, "Comparative analysis of mobile robot wheels design," in *Proceedings - International Conference on Developments in eSystems Engineering, DeSE*, Feb. 2019, vol. 2018-September, pp. 175–179. doi: 10.1109/DeSE.2018.00041.

[11] The Role of Autonomous Unmanned Ground Vehicle Technologies in Defense Applications. (*https://www.mobilityengineeringtech.com/component/content/article/adt/pub/features/articles/37888*)

[12] Wang, X., Deng, Z., Peng, H., Lu, C., Peng, Z. "Autonomous docking trajectory optimization for unmanned surface vehicle: A hierarchical method", 2023, Journal of Marine Science and Engineering

[13] Zhu, M., Xiao, C., Gu, S., Du, Z., Wen, Y. "A circle grid-based approach for obstacle avoidance motion planning of unmanned surface vehicles.", 2023, Journal of Marine Science and Engineering

[14] Chunhui Zhou, Shangding Gu, Yuanqiao Wen, Zhe Du, Changshi Xiao, Liang Huang, Man Zhu "The review unmanned surface vehicle path planning: Based on multi-modality constraint."

[15] Noor Amira Ilyanie Ruslan, Noor Hafizah Amer, Khisbullah Hudha, Zulkiffli Abdul Kadir, Saiddi Ali Firdaus Mohamed Ishak, Syed Mohd Fairuz Syed Dardin "Modelling and control strategies in path tracking control for autonomous tracked vehicles: A review of state of the art and challenges"

[16] David Glade, Lt Col, USAF "Unmanned Aerial Vehicles: Implications for Military Operations", Air University Press Maxwell AFB, AL 36112-6615, July 2000

[17] 7 Pros and Cons of Drones and Unmanned Aerial Vehicles, May 11, 2021 (*https://onlinemasters.ohio.edu/blog/the-pros-and-cons-of-unmanned-aerial-vehicles-uavs/*)

[18] Abdelhafid Bouhraoua, Necar Merah, Mansour Aldajani, Moustafa Elsahafei "Design and implementation of an unmanned ground vehicle for security applications", January 2010

[19] Dr. Sanur Sharma "Unmanned Ground Vehicles: Global Developments and Future Battlefield", Jul 2022 (*http://www.indiandefencereview.com/spotlights/unmanned-ground-vehicles-global-developments-and-future-battlefield/*)

ANNEXTURE A

```
//Code for Motors:
int Ch3, Ch2, Ch4;
#define ch2 10
#define ch3 9
#define ch4 8
#define pwm1 5
#define a1 6
#define b1 7
#define pwm2 3
#define a2 2
#define b2 4
#define pwm3 11
#define a3 12
#define b3 13

int mspeed = 255;

void setup() {
 pinMode(ch3, INPUT);
 pinMode(ch2, INPUT);
 pinMode(ch4, INPUT);
 pinMode(pwm1, OUTPUT);
 pinMode(a1, OUTPUT);
 pinMode(b1, OUTPUT);
 pinMode(pwm2, OUTPUT);
```

```
 pinMode(a2, OUTPUT);
 pinMode(b2, OUTPUT);
 pinMode(pwm3, OUTPUT);
 pinMode(a3, OUTPUT);
 pinMode(b3, OUTPUT);
 Serial.begin(9600);

}

void loop() {
 Ch3 = pulseIn(ch3, HIGH);
 Ch2 = pulseIn(ch2, HIGH);
 Ch4 = pulseIn(ch4, HIGH);
 Serial.println("Remote Controller");
 Serial.print("Value Ch3 = ");
 Serial.println(Ch3);
 Serial.print("Value Ch2 = ");
 Serial.println(Ch2);
 Serial.print("Value Ch4 = ");
 Serial.println(Ch4);
 Serial.println(digitalRead(pwm3));
 delay(500);
 if((Ch3<1200)) //backward
 {
 analogWrite(pwm1, mspeed); // motor1 left
  digitalWrite(a1, HIGH);
  digitalWrite(b1, LOW);
```

```
analogWrite(pwm2, mspeed); //motor2 right
digitalWrite(a2, LOW);
digitalWrite(b2, HIGH);
}
else if((Ch3>1700)) //forward
{
analogWrite(pwm1, mspeed); //motor1 right
digitalWrite(a1, LOW);
digitalWrite(b1, HIGH);
analogWrite(pwm2, mspeed); //motor2 left
digitalWrite(a2, HIGH);
digitalWrite(b2, LOW);
}
else if ((Ch2<1200)) //Right
{
analogWrite(pwm1, mspeed); //motor1 right
digitalWrite(a1, LOW);
digitalWrite(b1, HIGH);
analogWrite(pwm2, mspeed); //motor2 right
digitalWrite(a2, LOW);
digitalWrite(b2, HIGH);
analogWrite(pwm3, mspeed); //motor3 right
digitalWrite(a2, LOW);
digitalWrite(b2, HIGH);
}
else if ((Ch2>1700)) //Left
{
```

```
analogWrite(pwm1, mspeed); //motor1 left
digitalWrite(a1, HIGH);
digitalWrite(b1, LOW);
analogWrite(pwm2, mspeed); //motor2 left
digitalWrite(a2, HIGH);
digitalWrite(b2, LOW);
analogWrite(pwm3, mspeed); //motor3 left
digitalWrite(a2, HIGH);
digitalWrite(b2, LOW); }
else if((Ch4<1200)) //CW
{
analogWrite(pwm1, mspeed); //motor1 right
digitalWrite(a1, LOW);
digitalWrite(b1, HIGH);
analogWrite(pwm2, mspeed); //motor2 right
digitalWrite(a2, LOW);
digitalWrite(b2, HIGH);
analogWrite(pwm3, mspeed); //motor3 left
digitalWrite(a2, HIGH);
digitalWrite(b2, LOW); }
else if ((Ch4>1700)) //CCW
{
 analogWrite(pwm1, mspeed); //motor1 left
digitalWrite(a1, HIGH);
digitalWrite(b1, LOW);
analogWrite(pwm2, mspeed); //motor2 left
digitalWrite(a2, HIGH);
```

```
  digitalWrite(b2, LOW);
  analogWrite(pwm3, mspeed); //motor3 right
  digitalWrite(a2, LOW);
  digitalWrite(b2, HIGH);
  }
  else
  {
   analogWrite(pwm2, 0);
  analogWrite(pwm1, 0);
  analogWrite(pwm3, 0);}

}
```