Design, fabrication, and instrumentation of Automatic, Dynamic Videography Robot

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelors of Mechanical Engineering

by

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Graduation June 2023

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ABSTRACT

This is the report of research and fabrication of the automatic dynamic videography rolling robot which includes the exploration of dynamic design and appropriate material for the completion of the project and how this knowledge was utilized towards the fabrication of the project. This report further focuses on defining the need of the project and the valuable change it will create in developing the modern world.

ACKNOWLEDGMENTS

This project is indeed completed because of the timely input and guidance we got from our professors, lab in charges and friends. First, we would like to thank our project supervisor Dr. Usman Bhutta for accepting our proposal and taking us under his supervision. He regularly guides and directs us to work in order and to follow up the deadlines. Above all, his contribution to providing us the opportunity to work at the Aerial Robotics Lab for additive manufacturing is an invaluable addition to our project.

Special thanks to Dr. Mian Ashfaq Ali who helped us at a time when we were stuck in designing the shell of the project and his one advice played a crucial part in initiating the project fabrication. Lab Engineer Ali Hassan advised us in making an electronic circuit for the control of the project, Dr. Jawad Khan, our co-supervisor, who allowed us to work in the additive manufacturing facility at Aerial Robotics Lab at SINES.

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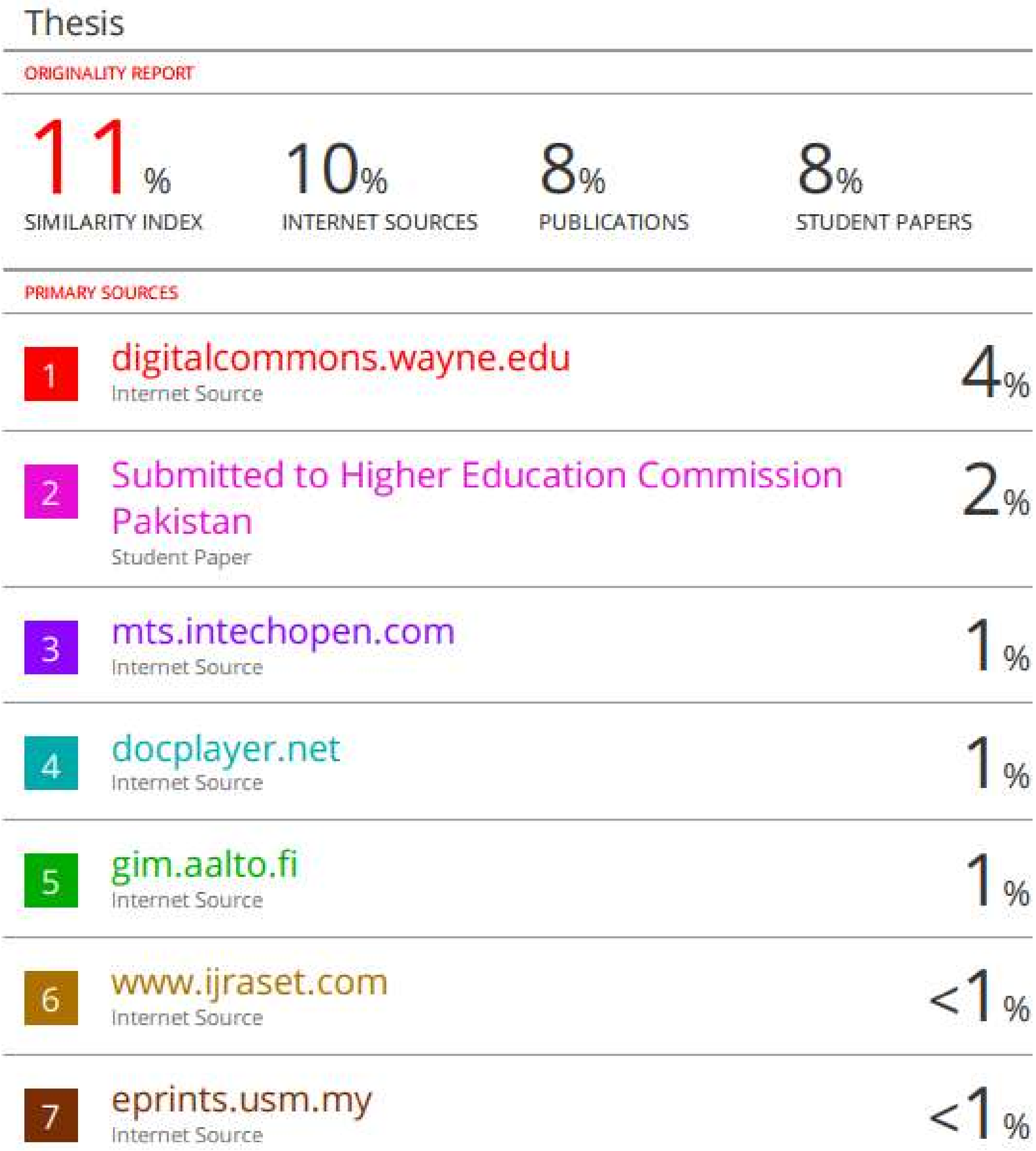
8266 to control servo motor. Last but not least, we want to thank our friends and family members for their moral support without which it was much difficult to walk on this tough road.

ORIGINALITY REPORT

The ideas and content presented in this report are authentic and it is our own creation. Where the content is outsourced, a proper reference is presented to acknowledge the contribution in the completion of this project.



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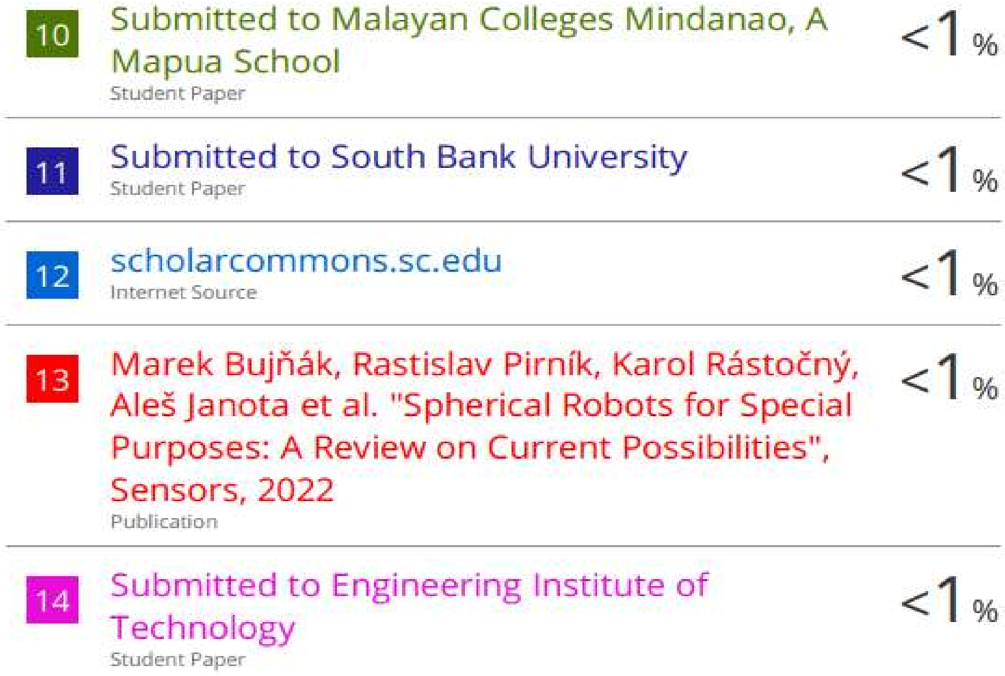

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CHAPTER 1: INTRODUCTION

Introduction

This is a remote controlled, ball shaped, rolling robot that has the capability to move on any surface by rolling and floating over water in the same manner. This robot serves multiple purposes in different domains like in surveillance for a military operation, guard bot in the security of homes and buildings, search, and rescue operations in disaster management like in case of floods and earthquake, and as a personal AI Robot.

Motivation of Work

The recent floods in Pakistan in 2022 which took thousands of lives along with it and a financial loss of billions of dollars was not an easy moment for the suffering nation. Likewise, the earthquakes in Balokot in 2005 and the stream of terrorism at different locations of the country has flabbergasted the whole nation. Incidents like these and the engineering background prompts us to develop such a project that will ultimately serve both purposes, the final year project in the domain of mechanical engineering and the contribution of our services for the betterment of society.

Problem Statement

There is a need for such a device that can move in two mediums covering land and water which has the system of self-aligning itself once it is toppled over. The device should be able to serve multiple purposes as per the requirement of society.

Objectives of the Project

The project has the following deliverables.

- It should be able to move in a straight-line path changing its direction of travel and speed of motion.
- It should be able to take the necessary turn in the right and left direction.
- It should be remote controlled over some distance.
- It should be able to provide video surveillance.
- It should be able to move on water.

CHAPTER 2: LITERATURE REVIEW

About Project:

This project is determined to produce an automatic, remote controlled, ball shaped device which serves as surveillance device or watch dog. This robot has the potential to move over any surface whether it is on the ground or above the water surface. It can be used to serve various purposes including:

- Providing mobile surveillance.
- Ability to move on any terrain.
- Ability to float and travel over water.
- Closed design provides safety for the components.
- Work as sensor to study remote areas like temperature, humidity, pressure, wind speed etc.

Introduction of spherical robots:

"The set of all points in three-dimensional space lying the same distance from a given point (the center)" is referred to as a sphere.

When a robotic device interacts with people, the shape of a sphere offers complete symmetry and a soft, safe, and friendly appearance without any sharp corners or protrusions. A spherical structure can freely rotate in any direction and is stable in all positions when it comes to robotics.

Since the propulsion system is inside the ball, it can be hermetically sealed to give the interior components the best possible shield. An important benefit of the spherical shape is that it maximizes internal volume relative to surface area and offers the best resistance to internal over- or under-pressure.

A spherical robot design has a lot of benefits. They are first and foremost very maneuverable. They can be made to move in any direction by being holonomic in design. By doing so, the robot has more options for navigating around objects and is less likely to become stuck in corners. Additionally, spherical robots cannot be turned over.

Robots with wheels typically can land upside-down and become useless. A spherical robot differs from this in several ways. Traditional robots struggle with obstacles like stairs and ledges, but a spherical robot can easily overcome these obstacles. They can be dropped or thrown as well thanks to this feature. They are very good at regaining control after hitting obstacles. This is beneficial for swarm applications etc.

History of Spherical Robots:

Initially, the first vehicles were small toys that were powered by springs and had a fixed axis of rotation. Patents at that time mainly focused on finding ways to store and convert spring energy using various mechanical solutions. One of the early challenges in the development of these toys was to add steering capabilities. In 1906, B. Shorthouse addressed this challenge by patenting a design that allowed the internal counterweight to be manually adjusted, resulting in the toy rolling along a curved trajectory instead of a straight line (U.S. Patent 819,609). Since then, various mechanisms have been patented to produce self-propelled balls with different rolling paths, some of which are irregular.

In 1957, J.M. Easterling patented a design that replaced the mechanical spring power source with a battery and an electric motor (U.S. Patent 2,949,696). This led to the introduction of electric motors, which used various mechanical solutions that had been previously used with spring-driven inventions. The addition of shock and attitude sensing using mercury switches allowed for the control of motor operation and rolling direction, as well as the addition of light and sound effects.

In 1974, McKeehan introduced an active second freedom for a motorized ball, which allowed the ball to change its axis of rotation upon impact with an obstacle, using additional motors (shown in Fig. 2, right). This paved the way for the development of radio-controlled ball robots (introduced in 1985 in U.S. Patent 4,541,814) and, eventually, computer-controlled ball robots.

As toy cars became more common in the mid-1980s, they were frequently incorporated into spherical robots to provide a fully steerable 2-degree-of-freedom rolling toy (U.S. Patent 4,438,588).

Spherical robots, also called spherical robots, have a relatively short history, with most research done in the last two decades. His one of the earliest spherical robots was developed in 1991 by Hirose and his team at the Tokyo Institute of Technology. Dubbed TITAN VII, the robot was a large spherical robot with his six legs and multiple cameras designed for exploration in difficult terrain.

Other researchers then began exploring the possibilities of spherical robots. 1998, Murata et al. We have developed a spherical robot called "Rolling Robot". It consisted of several modules that could be combined into different shapes. Rolling robots are designed to move in a variety of environments, such as stairs and uneven surfaces.

2005, Shimoyama et al. We have developed a spherical robot called "Puyu" which consists of three nested spheres. The innermost sphere contained the camera, and the two outer spheres were used for movement. Puyu is designed for use in hazardous environments such as nuclear power plants.

Another important development in the history of spherical robots is when Kuniyoshi et al. He developed a robot called "Spherical Drive System". The robot consisted of a spherical shell with multiple arms that could be extended to move the robot in different directions. The spherical drive system was developed for use in search and rescue missions.

In recent years, researchers have continued to develop new types of spherical robots for various applications. For example, in 2016, researchers at the University of California, Berkeley, developed a spherical robot called the Rolling Robot with Articulated Mechanisms (RRAM) designed to explore rough terrain. The robot had a flexible body that could adapt to its surroundings, allowing it to navigate obstacles smoothly.

Overall, the history of spherical robots is relatively short, but the development of this technology shows great potential for use in various applications such as exploration, search and rescue, and inspection of hazardous environments.

DIFFERENT DESIGN APPROACHES:

BARYCENTER OFFSET (BCO):

Barycenter Offset (BCO) refers to the displacement of the barycenter, or center of mass, of a system from its geometric center or centroid. The barycenter is the average position of all the mass in a system, and it is a crucial concept in many areas of physics and astronomy.

In robotics, Barycenter Offset can refer to the displacement of the center of mass of a robot from its geometrical center or base. The Barycenter Offset can have a significant impact on the stability and maneuverability of a robot. For instance, if the Barycenter Offset is too high, the robot may be unstable, making it difficult to balance or control. On the other hand, a lower Barycenter Offset can improve the stability of the robot, making it easier to control.

The Barycenter Offset is often considered in the design and control of robotic systems, particularly those that are mobile or have arms. The Barycenter Offset can be influenced by the mass distribution of the robot's components, including its body, sensors, and actuators.

In addition to robotic systems, Barycenter Offset is also considered in other fields, such as aerospace engineering, where it can impact the stability and maneuverability of spacecraft and satellites.

Overall, Barycenter Offset is an important concept in the design and control of robotic systems, as well as other areas of engineering and physics. Understanding and managing the Barycenter Offset can help improve the stability and maneuverability of a system, leading to better performance and efficiency.

It is further classified as following:

HAMSTER BALL:

An early iteration of a barycenter offset system is commonly known as the hamster ball design, aptly named for its resemblance to a hamster in a toy ball.

This design consists of a small-wheeled robot placed inside the ball, often a small remote-control car, which propels the robot forward using its weight. The shell of the ball is navigated by a non-holonomic ally, much like a car, with changes in the heading of the internal robot necessary to alter its direction of travel.

Single or multi-wheeled vehicles can be employed, with a four-wheeled differential-drive vehicle producing distinct motion curves from a single-wheeled one. A four-wheel drive system can act as a differential drive, providing the robot with the ability to turn on the spot, adding holonomic characteristics to the vehicle. Additionally, this design is relatively straightforward to model, fabricate, and control, with control being relatively simple as it maneuvers like any basic remote-control car. One of the main drawbacks is that some slipping of the internal robot or driving mechanism typically occurs. However, this can be mitigated through a closed loop control system combined with appropriate internal tracking sensors to calculate slippage. Apart from energy loss and control issues resulting from friction, another drawback of this design is the behavior of the robot when it becomes airborne due to vibration or encountering bumps. When the internal vehicle becomes airborne, traction between the shell and the internal robot's wheels becomes zero, causing the shell to lose momentum. Moreover, positional tracking may be affected. While this issue can be somewhat managed with sensors and a proper control system, it is unacceptable in tasks where navigation accuracy is critical.

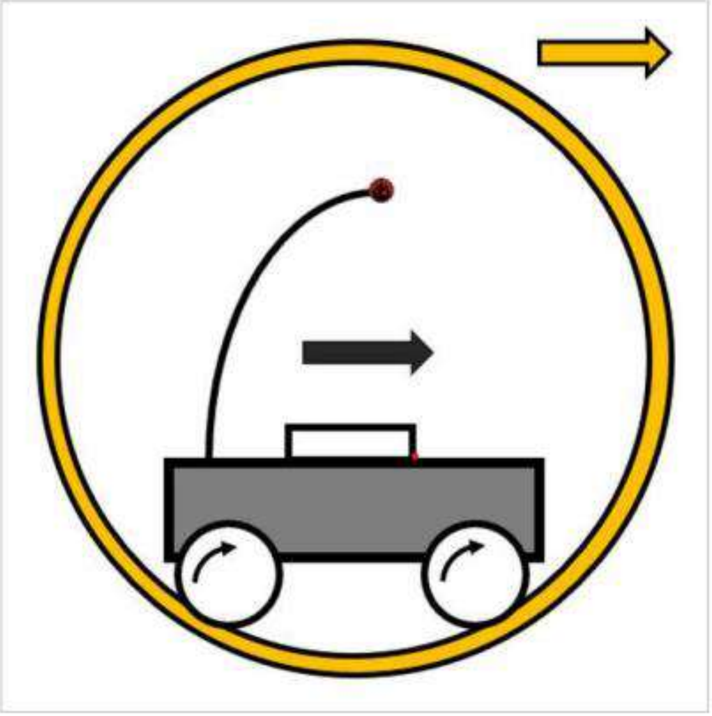


Figure 1: Principal sketch of a Hamster ball mechanism

INTERNAL DRIVE UNIT (IDU):

To address the issue of shifting in barycenter offset designs with internal robots, some designs have incorporated mechanisms that ensure constant contact between the robot's wheels and the outer shell. This can be achieved with a spring-loaded or fixed mechanism, where a rod and spring are attached to the top of the internal robot to press it against the shell. A 3-degree-of-freedom ball bearing is also attached on top of the spring to allow it to travel with low friction on the inner shell's surface.

The advantage of having constant contact between the wheelbase and shell is that mean ball speed can be easily controlled by the motor wheel speed. The IDU is responsible for moving the robot in any direction, and most commonly utilizes either a single wheel or multiple wheels arranged in a holonomic configuration. This configuration enables the robot to move in any direction and rotate around any axis, making it highly maneuverable.

The IDU also includes sensors for measuring the robot's orientation, velocity, and acceleration, which are crucial for maintaining stable and accurate control. Some spherical robots utilize internal flywheels or gyroscopes for stability and balance, which also helps to mitigate any unwanted movements or vibrations.

The IDU system also allows for a sealed or honeycomb outer shell design if the wheels are larger than the holes in the outer shell. However, at high speeds, the heading of an IDU-based robot can be difficult to control, and slippage between the wheels and the shell may occur. Adjusting the tension between the spring-loaded system and the internal robot can minimize slippage, but it also results in higher friction forces. Additionally, an IDU system cannot use stored momentum and must use power to keep its wheels spinning to move down small inclines. Rolling down steep inclines without controlled power can also cause unpredictable movement. Designers must also ensure that the IDU system is well-balanced to avoid unwanted patterns of movement.

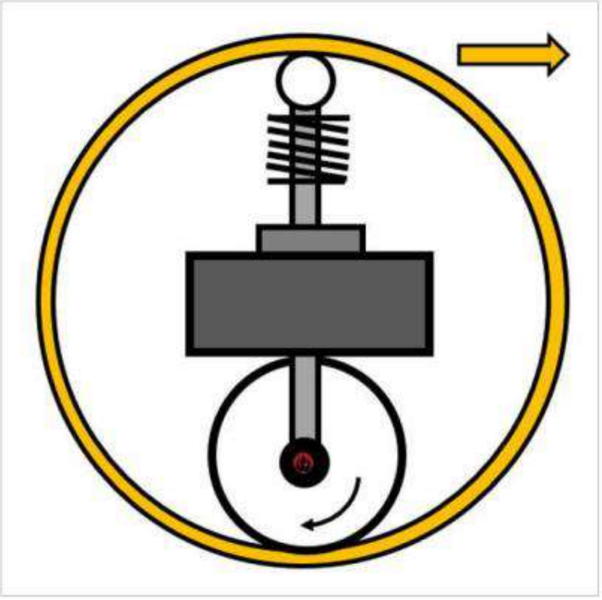


Figure 2: IDU system sketch

One of the main challenges in designing and implementing IDUs in spherical robots is minimizing their size and weight while still maintaining sufficient power and torque to move the robot effectively. This is particularly important for small or micro spherical robots, where space and weight are at a premium.

In addition, the IDU must be able to withstand the rigors of movement and operate reliably over extended periods of time. This requires careful selection of materials and components, as well as thorough testing and validation of the design.

Overall, the IDU is a critical component of spherical robots and plays a key role in their mobility and control. Advances in IDU technology are likely to have significant impacts on the capabilities and applications of spherical robots in a variety of fields, including exploration, inspection, and surveillance.

UNIVERSAL WHEEL:

The Universal Wheel (UW) mechanism is a popular design for spherical robots due to its increased maneuverability compared to other barycenter offset designs. The UW system utilizes three omni-directional wheels with axes that meet at a single point, forming an equilateral triangle. This configuration allows the robot to move in any direction while keeping the center of the robot in the same location. The UW system can also make use of stored momentum, allowing the robot to roll down inclines without using any power.

To control the direction of travel, the UW system uses a differential drive, where two wheels are rotated at different speeds to achieve the desired direction. The third wheel remains stationary during normal movement but can be utilized for additional control in certain situations, such as turning on the spot. The UW system can also utilize holonomic control, where all three wheels can be independently controlled for precise movement.

One of the main advantages of the UW system is its ability to navigate smoothly over uneven surfaces, such as steps or bumps. The three omni-directional wheels can move independently, allowing the robot to adjust to changes in surface height or angle. Additionally, the UW system is less affected by the shifting issue associated with internal robots since the wheels are always in contact with the ground.

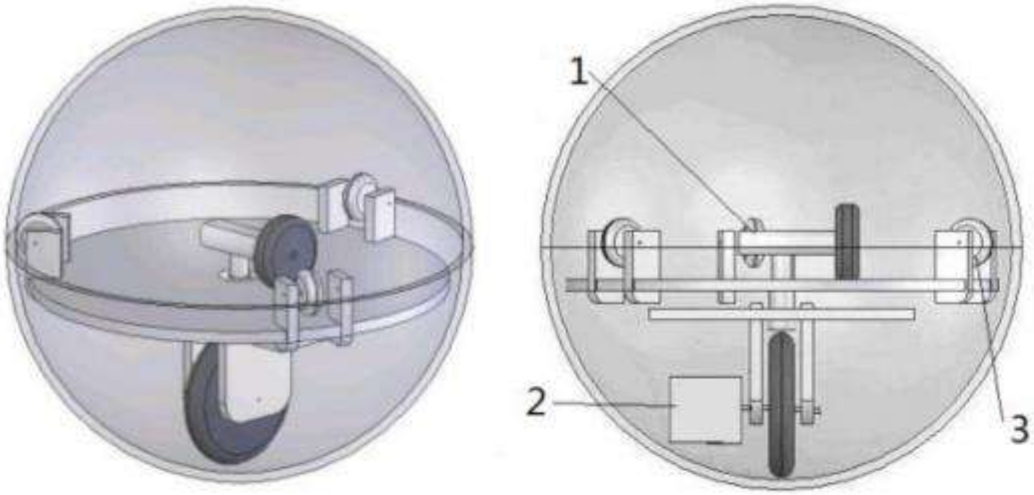


Figure 3: Universal wheel mechanism

However, the UW system does have some limitations. Due to the three-wheel configuration, the robot is less stable compared to other designs, which can be problematic in certain applications. Additionally, the UW system is more complex to design, and manufacture compared to simpler designs like the IDU. Despite these limitations, the UW system is still a popular choice for spherical robot design due to its increased maneuverability and versatility.

PENDULUM DRIVEN:

A common design used in industry and academia is the pendulum-driven design. The pendulum model consists of a fixed shaft that runs through the center of the robot's shell and a sphere that rotates around the pendulum and shaft. As the pendulum rotates, the center of gravity moves outward from the center and the shell begins to roll. Moving the pendulum left or right along the equator moves the center of gravity left or right, and the robot begins to rotate in the corresponding direction.

As Bob's weight increases, so does the torque that can drive the robot. However, if Bob is heavy, then the robot is heavy. The most notable drawback of this design is its inability to climb steep grades. Placing the bob where most of the system's weight is borne allows the robot to climb steep hills. But in practice, well-designed spherical robots can usually only go up Inclination of about 30 degrees. Spherical robots that can traverse slopes greater than 30 degrees may require commercially or economically impractical construction techniques. Pendulum drives have some limitations but are low-power designs that are easy to implement and can be sealed in enclosures. Rotundos can roll and hover in snow, ice, mud, and sand at speeds of up to 10 km/h. Additionally, it can carry a payload of 1.81kg.

Figure 4: Pendulum Driven Mechanism

A drawback of this design is that the shell movement is not holonomic.

A turning radius is associated with that movement. As with all other center of gravity offset designs, the center of mass cannot be moved beyond the extent of the shell. It is also important to consider that output torque increases as shell radius increases and pendulum weight increases. However, as these objects grow, so does the energy required to move them. There is a delicate design balance when considering the material composition and physical size of the internal elements.

Conceived as a children's toy, Roball is a pendulum-based spherical robot with the addition of a tilt mechanism that allows it to rotate. The robot was developed for unlimited operations, minimizing cost and complexity. Onboard sensors allow the robot to navigate its environment autonomously. All elements are placed on the robot's plateau (equator) and steering is provided by counterweights. In this model the counterweight is the battery.

The counterweight is designed to stay on the bottom of the shell, allowing the shell to move around it to create propulsion. In the previous example, the internal mass moves inside the hull and is designed to roll and balance the robot.

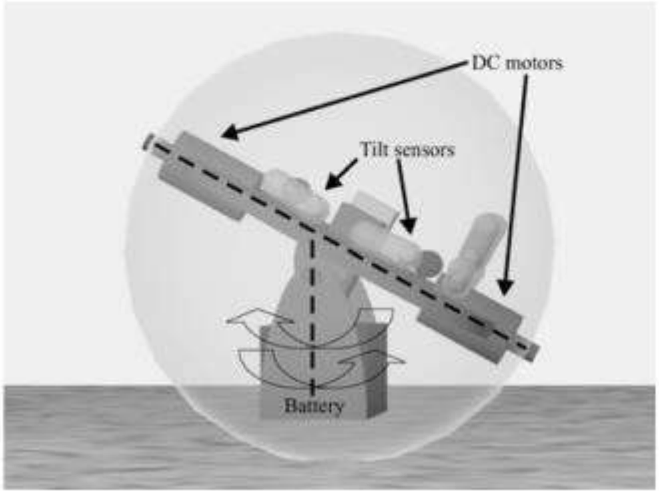


Figure 5: Advanced Pendulum driven mechanism

DOUBLE PENDULUM:

Double pendulum driven spherical robots are a type of barycentrically driven robot that use two pendulums to generate motion. In this design, the inner pendulum is attached to the center of the robot and the outer pendulum is attached to the inner pendulum. Both pendulums are free to swing in two directions [15]. When the inner pendulum swings back and forth, it transfers energy to the outer pendulum, causing it to swing as well. As the outer pendulum swings, it causes the robot to roll in the direction of the pendulum's swing.

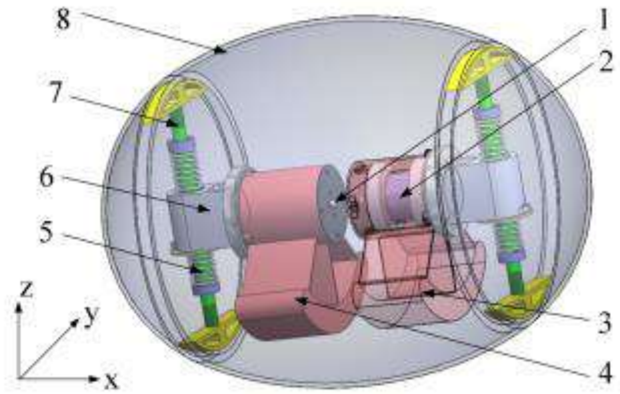


Figure 6: Double pendulum driven mechanism

The motion generated by the double pendulum system is chaotic, which can make controlling the robot difficult. However, this unpredictability can also make the robot more versatile in certain situations. The robot can easily traverse rough terrain, and its movement can be used to explore complex environments.

One challenge of the double pendulum design is maintaining control over the robot's movement. Because the motion is chaotic, the robot's trajectory is difficult to predict. Additionally, the robot's motion is highly dependent on the length of the pendulums and the force applied to the pendulum. This makes it challenging to control the robot's movement with precision.

Despite these challenges, double pendulum driven spherical robots have been successfully used in a variety of applications. They have been used for exploration in environments that are difficult to access, such as underwater or in outer space. They have also been used for search and rescue missions in disaster zones. Additionally, their unique movement has made them popular for artistic displays and performances.

Material Selection of Body

While selecting material for the body of our robot, we considered various options like carbon fiber, PLA, TPU etc. Each of these options have unique properties and contribute to different functions. They have the following properties which make them unique.

CARBON FIBER:

Carbon fiber is a composite material that is widely recognized for its exceptional strength, lightweight nature, and high stiffness. This material is composed of thin fibers made primarily of carbon atoms that are firmly bound together by a polymer matrix, typically epoxy resin. One of the most significant properties of carbon fiber is its high strength-to-weight ratio, which allows for the construction of strong and durable structures without adding excessive weight. Carbon fiber also exhibits high stiffness or rigidity, making it suitable for applications where stability and resistance to bending or flexing are required. Additionally, its excellent chemical resistance, electrical conductivity, and low thermal conductivity make it an attractive material for a wide range of applications. The unique combination of properties possessed by carbon fiber can be tailored to specific requirements by adjusting the fiber orientation, fiber volume fraction, and resin matrix.

Now we will discuss the advantages and disadvantages of using this as material to manufacture the outer body of our robot.

Advantages:

- Carbon fiber is known for its low weight, which allows for the construction of a lightweight spherical robot. This enables enhanced maneuverability, reduced energy consumption, and improved overall performance.
- Despite its lightweight nature, carbon fiber offers exceptional strength. It provides a high strength-to-weight ratio, ensuring that the outer body of the spherical robot can withstand external impacts and loads without sacrificing structural integrity.

- Carbon fiber exhibits high stiffness or rigidity. This property enables the spherical robot to maintain its shape and stability during movement, ensuring accurate and precise motion control.
- Carbon fiber is highly resistant to corrosion, making it suitable for use in various environments. The outer body of the spherical robot made from carbon fiber will remain durable and unaffected by exposure to moisture, chemicals, or corrosive substances.
- Carbon fiber composites have excellent impact resistance compared to many other materials. The outer body of the spherical robot will be better able to withstand accidental collisions and impacts, providing protection to internal components.
- Carbon fiber can be molded into complex shapes, allowing for intricate and custom designs. This enables engineers to create a unique and aesthetically appealing outer body for the spherical robot.
- Carbon fiber composites have inherent vibration damping properties. They can absorb and dampen vibrations, reducing noise and enhancing the stability and performance of the spherical robot.

Disadvantages:

- Carbon fiber is generally more expensive compared to traditional materials like steel or aluminum. The higher cost of carbon fiber can pose a challenge for projects with budget constraints.
- Working with carbon fiber requires specialized manufacturing techniques and equipment. Processes such as molding, curing, and post-processing are more complex and time-consuming compared to conventional materials, potentially increasing production costs.
- While carbon fiber composites have good impact resistance, they can still be susceptible to damage from high-energy impacts or concentrated point loads. The outer body of the spherical robot may require additional protective measures or reinforcement in areas prone to impacts.
- Carbon fiber composites can exhibit a relatively brittle behavior compared to metals. While carbon fiber is strong under tension, it may be more prone to catastrophic failure under excessive bending or impact loads, as it lack1s the ductility and toughness of metals.
- While carbon fiber is electrically conductive, it may not offer the same level of electrical conductivity as metals. In some applications, additional measures or conductive coatings may be required to ensure efficient electrical grounding or integration of electronic components.

- Repairing carbon fiber composites can be challenging compared to metals. Damage to the outer body of the spherical robot may require specialized repair techniques, making maintenance and repairs more complex and potentially costly.

PLA:

PLA, also known as polylactic acid, is a renewable and biodegradable thermoplastic polymer. It is derived from plant-based materials like corn starch and sugarcane. PLA has become a popular choice due to its eco-friendliness and unique properties. It is biodegradable and can be broken down by microorganisms, reducing plastic waste. PLA is also easy to process and can be used in various manufacturing techniques such as injection molding and 3D printing. It has excellent transparency, rigidity, and low toxicity. However, PLA has limited heat and UV resistance, moisture sensitivity, and moderate chemical resistance, so it's important to consider these limitations when choosing it for specific applications.

Now, we will discuss the advantages and disadvantages of selecting this in our scenario.

Advantages:

- PLA is a biodegradable material, which means it can break down naturally in the environment, reducing its impact on pollution and waste. Using PLA for the outer body of a spherical robot promotes sustainability and eco-friendliness.
- PLA is derived from renewable resources, such as corn starch or sugarcane, making it a more sustainable choice compared to petroleum-based plastics. It helps reduce reliance on fossil fuels and promotes the use of renewable materials.
- PLA is relatively easy to process using various manufacturing techniques, including injection molding and 3D printing. Its low melting point and good flow characteristics make it suitable for complex shapes and customization.
- PLA is low in toxicity and is generally safe for use in applications that involve direct contact with food or the human body. This makes it suitable for applications where safety and non-toxicity are important.
- PLA offers good transparency and can be produced with a glossy finish, providing an aesthetically pleasing outer body for the spherical robot. It allows for easy visual inspection and can enhance the overall design appeal.

- PLA is generally more affordable compared to some other biodegradable polymers or specialty materials. Its cost-effectiveness makes it accessible for various applications, including the outer body of a spherical robot.

Disadvantages:

- PLA has a relatively low heat resistance compared to other engineering plastics. It starts to soften and deform around temperatures of 60-65°C (140-149°F), which may limit its use in applications where high temperatures are expected.
- While PLA offers sufficient rigidity and strength for many applications, it may not have the same level of mechanical strength as some other plastics or composites. The outer body of the spherical robot may require additional reinforcement or design considerations to withstand impacts or loads.
- PLA is sensitive to moisture absorption, which can affect its mechanical properties and dimensional stability over time. Exposure to high humidity or water may cause the material to degrade or weaken, requiring careful storage and protection.

- PLA has moderate chemical resistance and may degrade or swell when exposed to certain chemicals or solvents. Compatibility with specific chemicals in the robot's operating environment should be considered to ensure the material's integrity.
- prone to damage or fractures under severe impacts or collisions.

CHAPTER 3: METHODOLOGY

For the fabrication of our ball, we went through these steps.

- Finalizing the material of the shell
- Devising an optimum design for the linear motion of the ball
- Devising an optimum design for the turning mechanism of the ball
- Finite Element Analysis of the Material
- Tensile and Impact Test
- Devising a mechanism to install cameras in the robot.
- Devising a mechanism to make the robot waterproof.
- Devising balancing on water.
- Devising a remote-controlled system to control the robot.

Material Selection and its fabrication

Poly Lactic Acid is used for the fabrication of the shell and other components used for the compilation of the project.

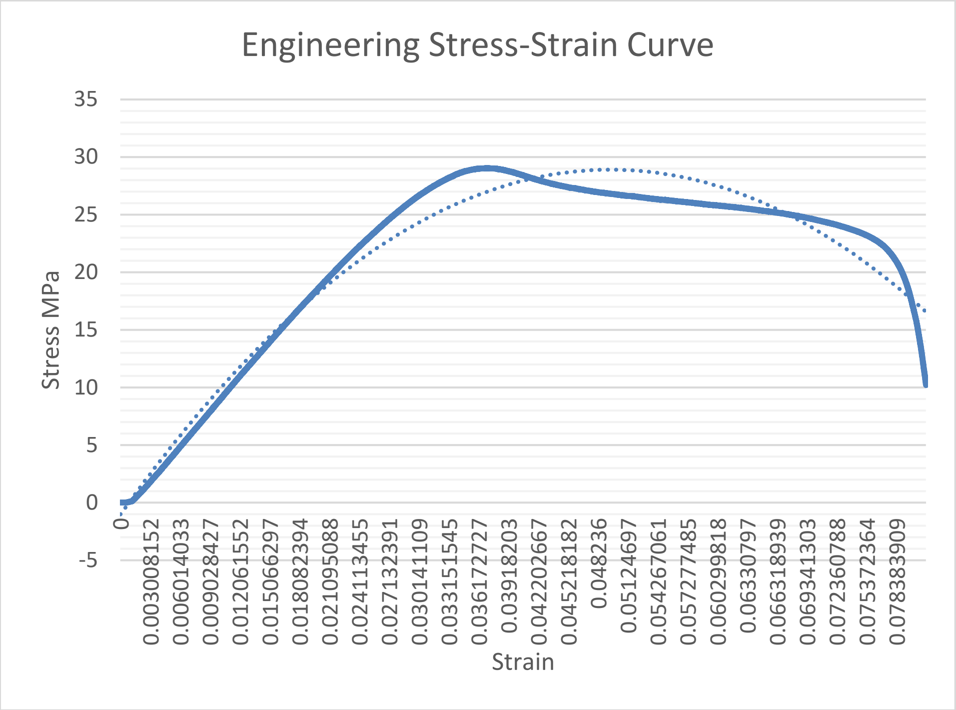
Method of Manufacturing

All the necessary parts are made through additive manufacturing.

Material Properties Tests

Tensile and Impact tests were conducted to find out the tensile strength, plastic behavior, and behavior under impact loading.

Yield Strength is 28 MPa and Elastic Modulus is 980 MPa.



Designs of the Ball

Multiple designs were taken under consideration to reach the deliverables of the project. The designs are listed below based on the purpose it serves.

Design for linear motion of the robot.

- Bary Center offset design.
- Inertia mass design

Designs to make a turn.

- Pendulum design
- Pinion and rack design

BARY CENTER OFFSET

In this mechanism the center of gravity of the ball is shifted forwards or backwards to roll the ball forward or backward. DC geared motors are mounted on the opposite faces of the ball with their shafts facing inside of the ball. The shafts of both motors are connected to a common pendulum that rotates with the rotation of the motor shafts. The design is shown below.

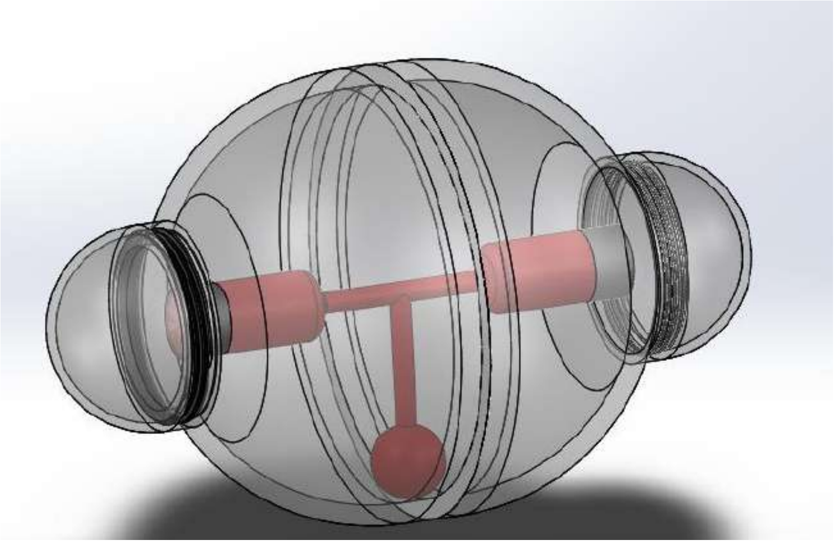


Figure 7: First prototype model

After the successful completion of the first prototype, necessary analysis was done on the dynamics of robot. These are the highlighting features of the design.

- As the motor is turned on, the robot vibrates to and for some 2 or 3 seconds before starting to get push in the forward direction. It is because the pendulum was taking a full revolution and hence when the pendulum is at the front the body moves to front and when the pendulum went back after 180 deg of rotation the body moves back.

- Even when it started getting pushed in the forward direction the problem of these vibrations was still there.
- The design was very unstable since the center of gravity of the body was shifting continuously.
- There was dynamic unbalancing also because we must mount all the electronic circuits on the rotating shell, and it was an almost impossible at the initial stage to balance all the mounted components on the rotating body.

INERTIA MASS DESIGN

In this design a mass is suspended with the excel to provide inertia for the motors body. In other words, the mass holds or clutches the motors that are rotating the shell of the ball. Since the motors require the clutching torque necessary to rotate a load so the hanging mass provides that. The design of the system is shown below.

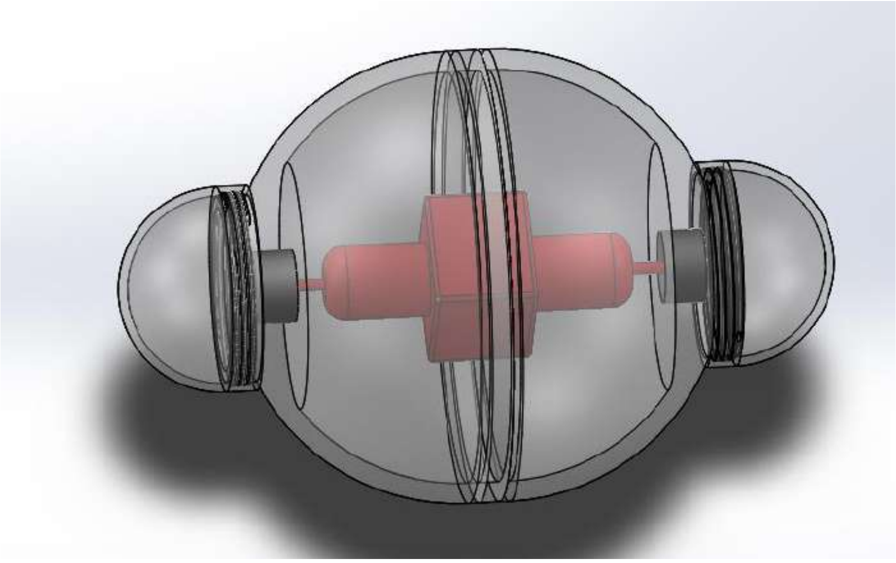


Figure 8: Second Prototype model

After the completion of the second prototype, we came up with the following results.

- The movement of the ball was quite controlled, and the vibrations were reduced to a significant amount.
- The dynamic unbalancing was eliminated since the rotating shell bears no supplementary components.
- The startup motion was smooth and quick.
- It provides better speed and control.
- It was easier to assemble and disassemble.

Turning of the Ball

To make the ball able to turn there is only one good solution to it and that is sifting the center of gravity of ball either in right or left side to make it able to turn. For this reason, two designs are taken into consideration.

Pendulum Design for Turning

In this design a pendulum will be suspended in the middle of the ball with the stationary shaft. The mass will be turned using servo motor at the desired angle. In this way, making a turn is possible.

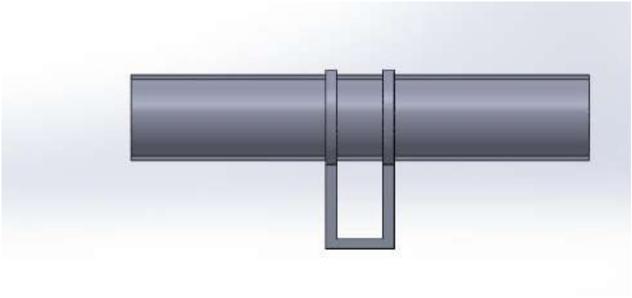


Figure 9: Pendulum design internal mechanism

Pinion and Rack Design

In this design, a system of pinion and rack is used to move the sliding mass in right or left side of the ball. In this way turning can be achieved.

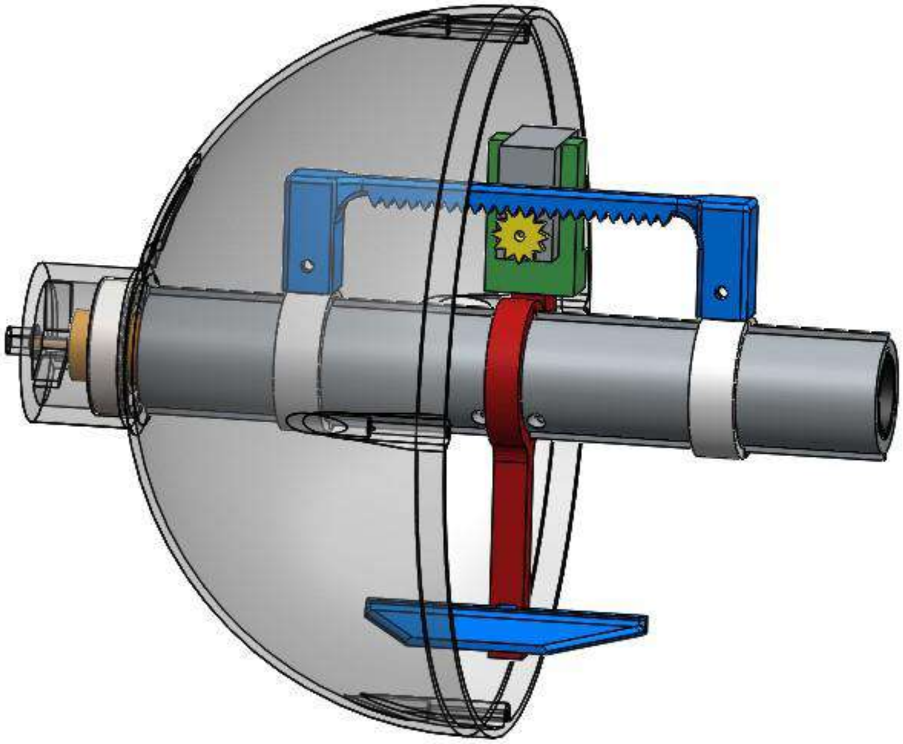
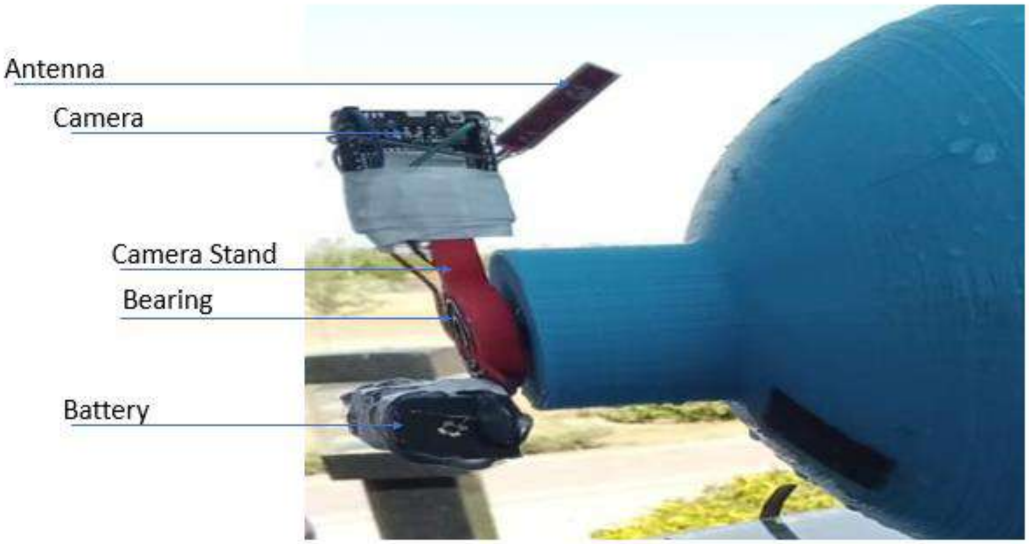


Figure 10:Rack and pinion design

Installation of Cameras

Installing cameras is a big challenge since the body of the robot is rolling and we need a stationary point to support the camera and we cannot afford for the camera to roll along with the body. For this reason, there is a need for such a joint in which the camera stays stationary with respect to the moving ball. To overcome this problem a bearing is used to suspend the cameras with the heavy weight. The weight must be able to slide over the surface of the rolling ball and in this way the camera can stay stationary.



Making the Ball Waterproof

To make the ball waterproof, there is need of sealing all the potential joints where there is risk of water leakage. To serve this purpose silicon glue is used to seal all the potential joints from there is even a slight chance of water leakage.

Devising the Balancing on Water

While driving the robot on land, the robot is self-capable of aligning itself when toppled over. While in the case of water, there is no surety that the robot will come to its original position once it is disturbed unless the system is designed in which the center of buoyancy is kept higher than the center of gravity of the ball.

Electronic Control of the Robot

To control the robot remotely, a system of Wi-Fi module was used to control it with the controller that was made using an html code to operate it form the phone.

Finite Element Analysis of the Ball

The finite element analysis is done using Solid works software in which a drop test simulation was done to study the behavior of the body and material after impact loading on the rigid surface. The results are shown below.

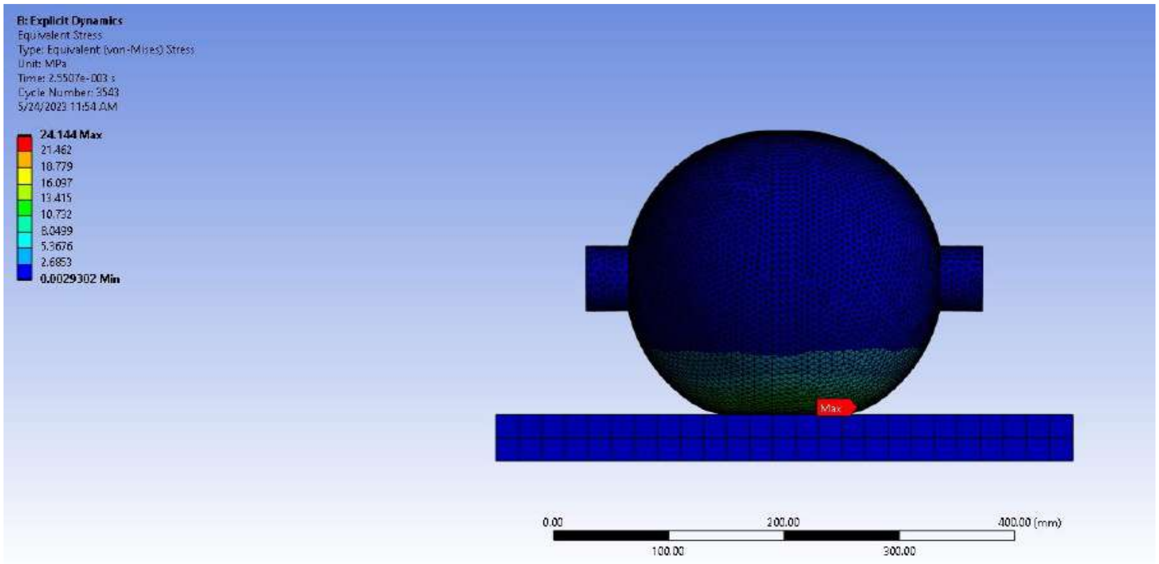


Figure 11: FEA Stress Analysis drop test

CHAPTER 4: RESULTS AND DISCUSSIONS

As our project is a commercial device that was first manufactured in 2018 by an American company named Guard Bot. First, we started working on its design and its internal mechanism. We found several different mechanisms by which we will be able to move this device. The two mechanism that we shortlisted and started working are as follow:

- Barycenter offset mechanism.
- Central suspended mass mechanism

Barycenter offset mechanism:

The distance between a spherical robot's geometric center and its center of mass (barycenter) is referred to as the barycenter offset. The location where the robot's total mass can be concentrated is known as the barycenter. The distribution of mass throughout the robot affects it. On the other hand, the geometric center is the point that is equally far from every other point on the robot's surface. The barycenter and geometric center of a robot with perfect symmetry would be at the same place. The mass of the robot is typically distributed unevenly, which causes a barycenter offset. The spherical robot's stability and maneuverability may be impacted by the barycenter offset. The robot may be unstable and have trouble maintaining equilibrium if the geometric center and barycenter are sufficiently far from one another. The offset can also lead the robot to roll or pitch against its intended direction, which makes it challenging to control. Engineers may change the robot's mass distribution or add more parts to balance the weight distribution to make up for the barycenter offset. This can increase the robot's stability and control, enabling it to maneuver through its environment more successfully.

Central suspended mass mechanism:

Rolling robots frequently use a center suspended mass as a design element to increase their stability and control. It describes a mass or weight that is suspended above the robot's center, usually above the rolling mechanism. A central suspended mass can be used to decrease and stabilize the robot's center of gravity by positioning it above the rolling mechanism. This is so that the robot doesn't topple over, as the suspended mass produces a downward force that balances out other forces. Additionally, the mass adds to the robot's inertia, making it more difficult to push or tip it over. A center suspended mass can aid maneuverability while simultaneously enhancing stability. The robot can quickly turn or change direction by changing its center of gravity by moving or shifting the mass. However, using a center suspended mass in rolling robots comes with several difficulties. The greater weight may put more strain on the rolling mechanism, which over time may result in increased wear and tear. Mass can also make the robot more difficult to move about or transfer in small locations. In general, rolling robots, especially those built for stability and control, benefit from the use of a center suspended mass. To make sure that the robot is practical, dependable, and simple to operate, it should be carefully balanced with other design factors. Preferred mechanism and why:

We prefer the central suspended mass mechanism because this mechanism is more stable and allows the device to move on slope of higher angle than the other mechanism. It is easier to balance the device working on this mechanism because the jerk of pendulum is eliminated from this mechanism.

Some useful calculations for roll ball:

RADIUS CALCULATIONS:

We selected the radius of the ball to be 12.5 cm and we did all our calculations keeping in mind this value of radius.

MOTOR:

We are using 2 (two) 12v motors as the main power source.

For each motor:

$$\text{Maximum motor Power}=14\tau s \omega_{\text{no load}}$$

$$P_{max}=5.647\text{W}$$

Torque supplied by motor at this maximum power is = 5kgcm

$$\tau max=0.4903\text{Nm}$$

$$\text{Angular velocity at maximum power} = 12\ \omega_{\text{no load}}$$

$$\mathrm{Ɯ}_{max}=11.515\text{ rad/s}$$

Consider robot as hollow sphere because its thickness is small as compared to its diameter.

Mass of Sphere = 0.7 Kg

Torque required to roll a sphere is unknown.

$$\text{Radius of Gyration}=\sqrt{\frac{2}{3}}R=\sqrt{\frac{2}{3}}(0.125)=0.102\text{m}$$

$$\text{Moment of inertia of hollow sphere}=\frac{2}{3}MR^2=\frac{2}{3}(0.5)(0.102)^2=0.00346\text{kg-m}^2$$

Moment of inertia of Single outer cylinder$=\frac{1}{2}M(r_2^2+r_1^2)=\frac{1}{2}(0.066\text{kg})(0.064^2+0.047^2)=0.000205\text{kg-m}^2$

$$\text{For two cylinders}=0.00041\text{ kg-m}^2$$

Moment of inertia of Single Bearing$=\frac{1}{2}M(r_2^2+r_1^2)=\frac{1}{2}(0.073)(0.047^2+0.0232^2)$

$=0.000099$ kg-m^2, for two bearings= 0.000198 kg-m^2

Total inertia=0.00346 + 0.00042 + 0.000198 =0.004068 kg-m^2

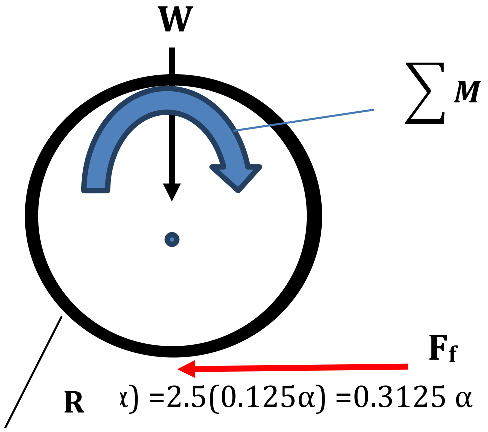


Figure 12: Inertia Calculation

Equations of Motions:

$F_x = ma_x$ α) =2.5(0.125α) =0.3125 α

$F_y = ma_y$ N

Moment applied by both motors is= τ = 1 Nm

So, M=Iα; $\tau - F_x(r) = 0.004068\alpha$ ➔

1-0.3125(α)(0.125)= 0.004068 kg-m2

α =25.5 rad/s2

Fx=7.97N a=3.186 m/s^2 NA = 24.5N

Now to verify no slip condition: $F_x \leq \mu_s N$ $\mu_s = .4$

$7.97 \leq 9.8$ (So, no slip condition is verified.)

Verify the movement of shell:

- Moment of inertia of suspended mass calculated using Solid works = I_w = 0.01077444 Kg-m^2
- Moment of inertia of outer shell, Cylinders, Bearing = 0.004068 kg-m^2
- Torque requires to roll the inside mass with an angular acceleration of 25.5rad/s = τ_w= 0.01077444*25.5 = 0.2747 N-m
- Torque requires to roll the outside shell including disk and bearing with an angular acceleration of 25.5rad/s = τ_w= 0.004068 *25.5 = 0.1037 N-m
- Friction produces a counter torque:

Frictional torque = τ_f = 0.01*9.8*2.5*0.125 = 0.032625 N-m

If $\tau_w > \tau_f + \tau_s$ (then shell will rotate and inside weight remain stationary)

$0.2747 > 0.1343$

So, our condition is satisfied, our ball will rotate without rotating the inside weight.

Table 1:Torque and Acceleration Table

S.no	**Applied torque (Nm)**	**Angular acceleration (rad/s2)**	**Linear acceleration (m/s2)**	**Fx (N)**
1	0.8	18.54	2.31	5.79
2	1	25.5	3.18	7.97
3	1.2	27.82	3.47	8.69

CALCULATION ABOVE WATER SURFACE:

We assume that 2/3 part of the sphere will be above the water, so we apply the second law on the ball such that sum of all the forces on the ball is equal to zero.

We calculated the volume of the ball and calculated the amount of mass present in the ball to completely submerge it in water and calculated the mass of ball to submerge it only 1/3rd of the complete ball. Results are attached below:

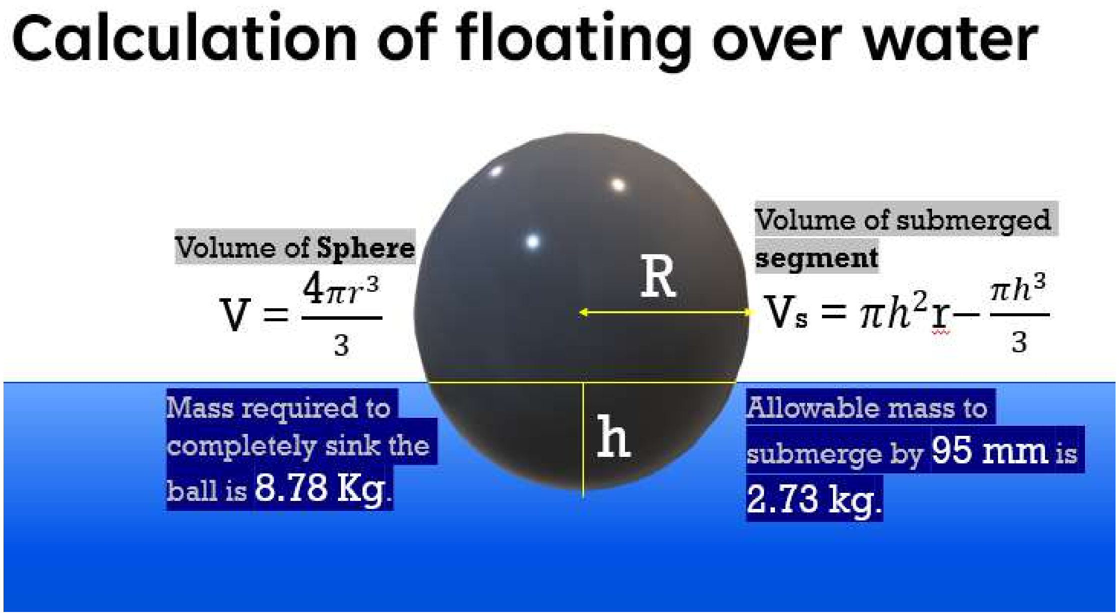


Figure 13: Floating calculation Results

To make the ball float over water it is necessary to consider the Archimedes' Principle in sight which states that the upthrust force on the object partially or fully submerged in a fluid is equal to the volume displaced by that fluid into the density of the fluid displaced. This principle provides us with the minimum amount of mass that is required to completely submerge the ball in the water.

COMPLETE SUBMERSION IN WATER

Volume of the Robot is = V = $\frac{4*\pi*r^3}{3}$ = $\frac{4*\pi*0.128^3}{3}$ = 0.00878 m^3

Minimum mass required to completely submerge the ball = m*g = D*V*g

m = D*V, m = 1000*0.00878, m = 8.78 Kg

CALCULATION OF TURNING RADIUS:

We calculated the radius of turn using the moment balance equation. We did moment balance by incorporating all the masses that are contributing to positive or negative moment on the axle. We found some interesting results that by increasing the mass that is sliding, the radius of turning reduces, which means we get sharp tur. Also, by increasing the displacement of the mass on the axle by sliding rings, radius of curvature reduces again. It is recommended from the literature to reduce the mass of body to float the body on the surface of water perfectly. That's why we keep the mass of our whole model equals 2.7 Kilograms.

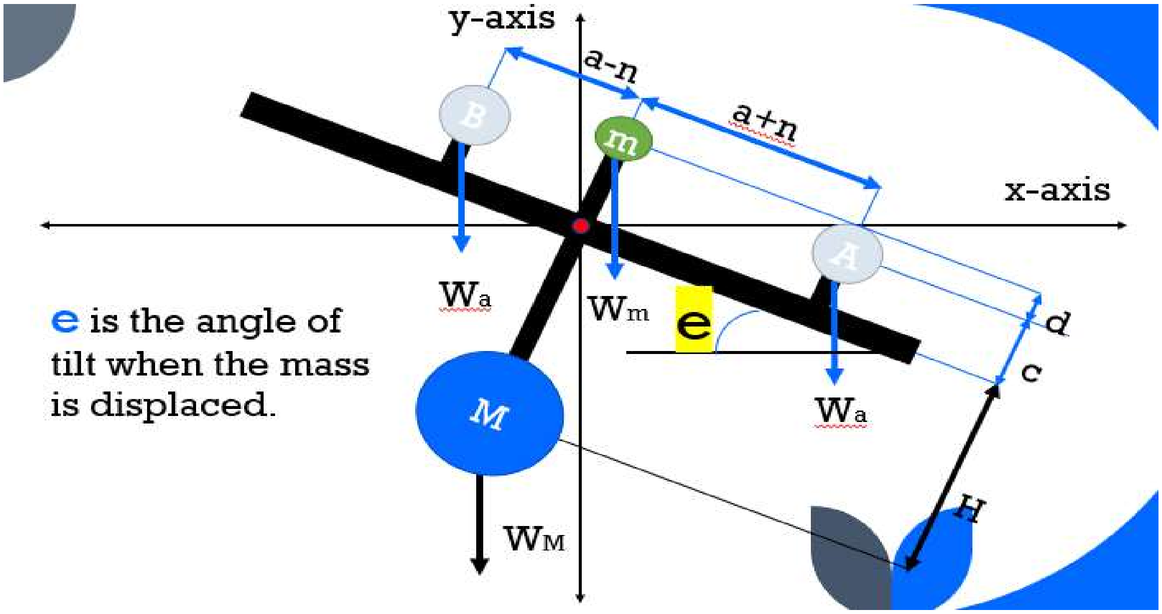


Figure 14: Turning mechanism analysis.

Consider the assembly pivoted at the red point in the diagram. Here A, B, m, M are the masses. Where A and B are the masses of the rings which are equal in this case and serving for the purpose to turn the ball. M is the mass of the rest of the components in which battery and other electronic components are present. Servo motor mass is represented by small m. The distances of these masses are shown in the diagram.

Now, let's say mass A has moved a distance 'n' towards the right side and since mass A and B are coupled with each other mass B also moves a distance 'n' towards the right side as shown. This causes the assembly to tilt by an angle 'e' as shown.

Let's find out that angle 'e' when we know all of the masses and distances.

Summing all the moments equal to zero.

$$W_M . H . \sin(e) + W_a . (a-n) . \cos(e) - W_a . (a+n) . \cos(e) - W_m . (c+d) . \sin(e)$$

$$+ W_a . c . \sin(e) - W_a . c . \sin(e) = 0$$

$$W_M . H . \sin(e) + W_a . \cos(e) . (a -n -a - n) - W_m . (c+d) . \sin(e) = 0$$

$$W_M . H . \sin(e) - W_a . \cos(e) . (2n) - W_m . (c+d) . \sin(e) = 0$$

$$(H.W_M - (c+d).W_m) . \sin(e) = 2nW_a . \cos(e)$$

$$\frac{Sin(e)}{Cos(e)} = \frac{2\mathrm{nWa}}{\mathrm{H.W} - (\mathrm{c+d}).\mathrm{Wm}},\ \tan(e) = \frac{2\mathrm{nWa}}{\mathrm{H.W} - (\mathrm{c+d}).\mathrm{Wm}}$$

$$e = \tan^{-1}\left(\frac{2nWa}{H.W - (c+d).Wm}\right)$$

Radius of Rotation

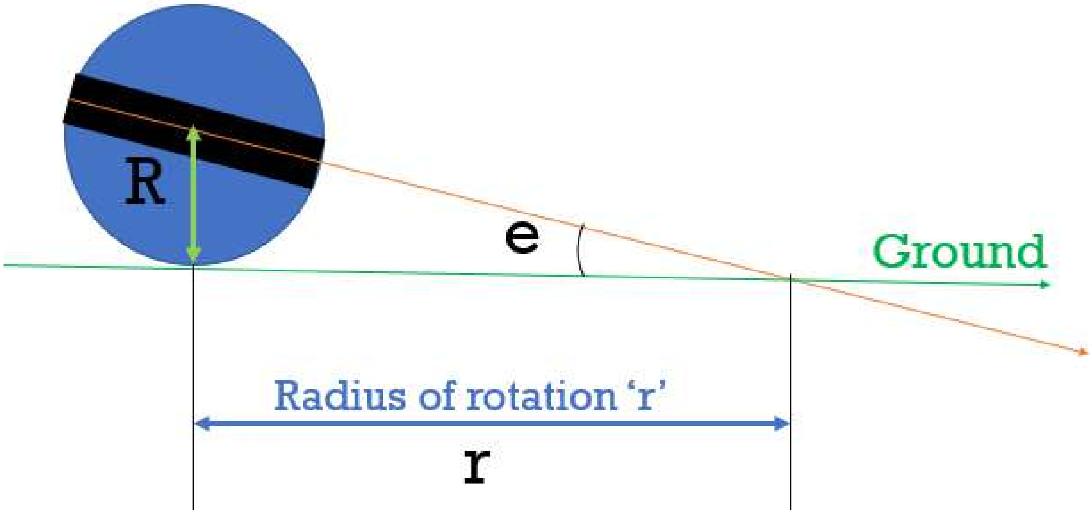


Figure 15: Radius of Rotation.

$\tan(e) = \frac{R}{r}$, substitute value of e, we get:

$$\frac{2nWa}{H.W - (c+d).Wm} = \frac{R}{r}, \qquad r = \frac{(H.W - (c+d).Wm).R}{2nWa}$$

Complete internal design:

The complete internal design of the ball is shown in the below figure. It has an axle, two geared DC motors for movement in forward and backward direction. It has two moving rings on the axle that has some added weight (200 grams) on both rings. These rings slide on the axle and help in the right and left turning of the shell. This added weight is sliding with the help of servo motor, which is attached with the rings using rack and pinion mechanism.

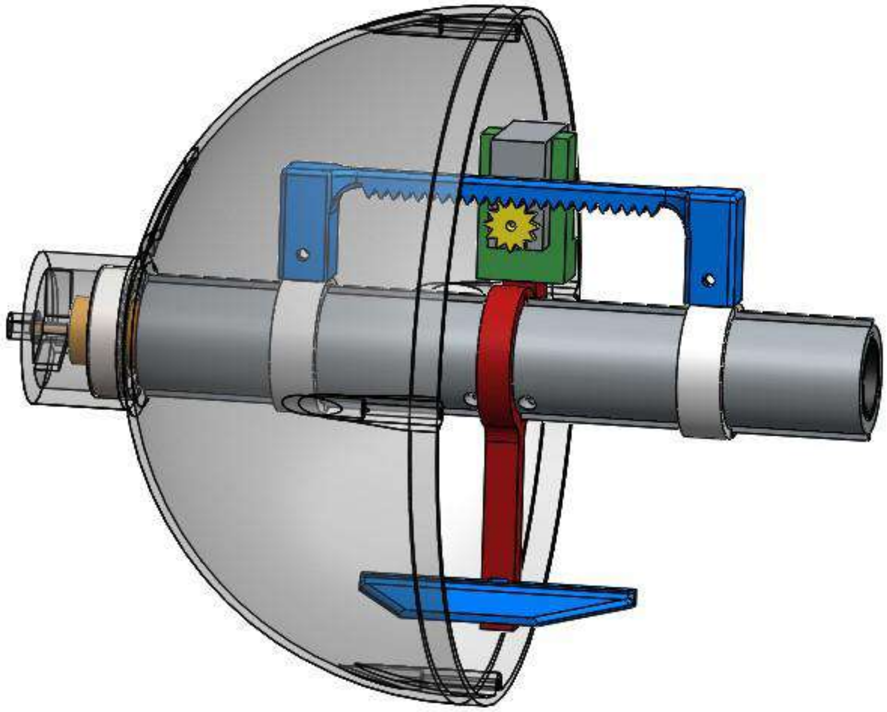


Figure 16: Internal Design

Results of UTS Test on PLA Material:

We completed the UTS test on our selected material. We get Yield strength of 29 MPa, and young modulus of 2 GPa. Results are attached below. We get the yield stress by noting the point on the curve from which curve start declining, or in other words, strain is increasing, and stress is reducing. We got the young's modulus by calculating the slope of the linear portion of the curve. We got a bit different result from the literature suggested results because these results depend upon the quality of the sample. As we used 3d-printed samples of PLA, so results also depend upon the quality of the 3d-printed part quality. Good quality gives better results.

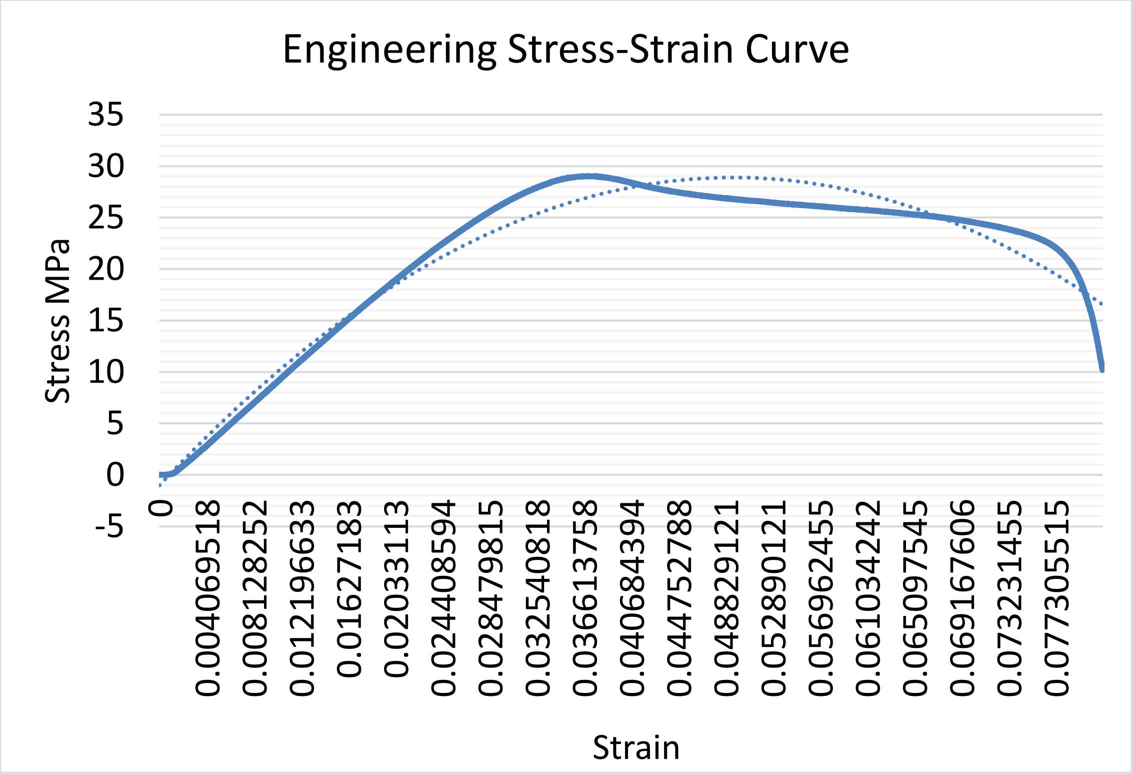
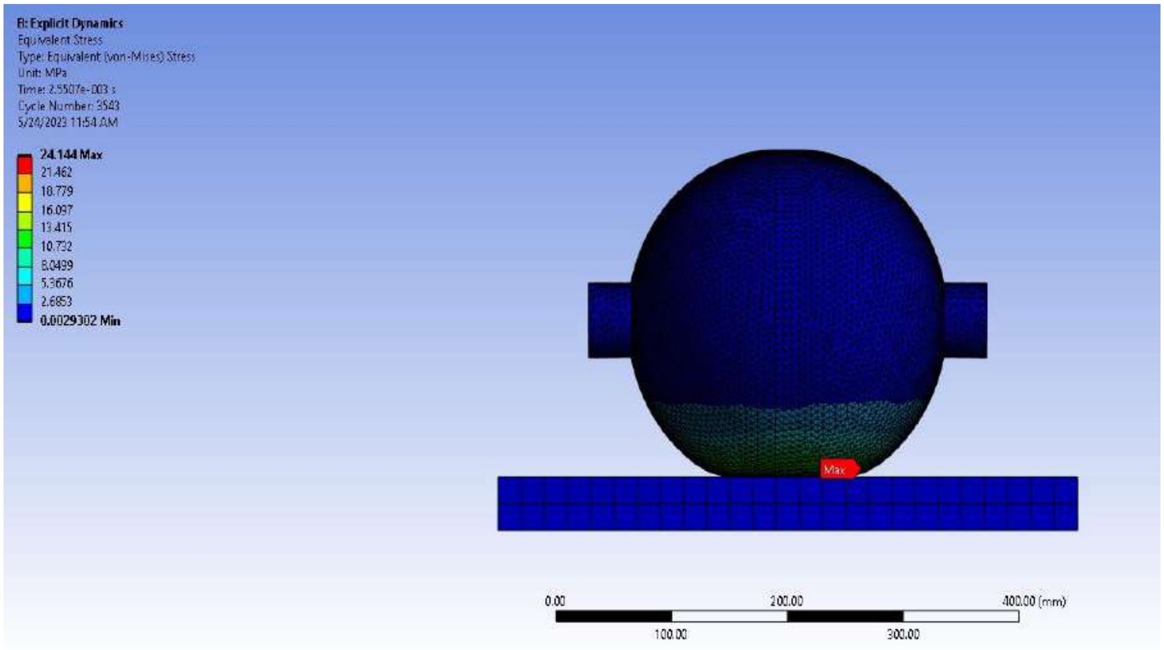


Figure 17: UTS Results

Finite Element result of Drop test in ANSYS:

We calculated the maximum stress in the shell using ANSYS by using the assumption that we are dropping the ball from the height of 2 meters. After the analysis we found the maximum stress in the shell to be 24.14 MPa, which is less than the yield stress calculated from the UTS test. This means that our selected thickness of shell, which is 3mm, is safe and correct.



B: Explicit Dynamics
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 2.5507e-003 s
Cycle Number: 3543
5/24/2023 11:54 AM

Figure 18: FEA Results

Some important results that deduced from the discussion are:

- Diameter of ball.
- Displacement of sliding ring for turning.
- Maximum mass that ball contain to float on water surface.

- Results deduced from UTS test.
- Experimental measurement of speed, velocity, acceleration.
- Finite Element Analysis results for maximum stress.
- Moment of inertia calculation for shell and internal mechanism.

This section discusses every result in complete detail. Every requirement to develop a complete working model is clearly discussed in this section.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In conclusion, we would like to share that this project is selected for security and rescue purposes. So, its application is very broad in these departments but also have some applications in commercial sector as house security robot. The basic purpose of this robot is to deliver live videos and images of the area in which this robot is present. Its durability and applications depend upon its size, increasing its size will increase its capability to surpass the obstacles that came in its way and for big size robot, it is easy to roll on rocky land easily.

This robot project is a noteworthy development in robotics and has the potential to completely alter security and surveillance methods. A notable accomplishment is the creation of a spherical, amphibious robot that can move through many settings and terrains. This robot offers unmatched adaptability in its use thanks to its capacity to travel over land, water, and even snow.

The project's main goal of improving security protocols has been accomplished quite successfully. This Robot sturdy construction and sophisticated sensor capabilities enable effective monitoring and detection of possible threats across a variety of settings. This robot has been shown to be an excellent deterrent against unauthorized access and suspicious activity, whether installed in public areas, commercial buildings, or remote locations.

This robot can also perform real-time surveillance thanks to its remote monitoring capabilities, which lowers the need for human intervention and boosts operational effectiveness. Security professionals can make educated decisions and act swiftly in response to developing circumstances thanks to its capability to communicate live video footage and sensor data to a central control system.

The Robot project has also proven beneficial in situations involving disaster relief. Due to its amphibious characteristics, it may enter locations that are inaccessible to humans, like flooded areas or challenging terrain. Rescue and relief efforts can be accelerated by using these kinds of robots in these circumstances, potentially saving lives, and lessening the effects of natural disasters.

Future developments in autonomous navigation and artificial intelligence may significantly improve the capability of these robots. These robots may be better able to adapt to changing settings and recognize potential dangers if advanced decision-making systems and machine learning algorithms are used.

The videography robot project opens new opportunities for protecting public safety and addressing issues that traditional security measures struggle to overcome, even though there may be some ethical concerns regarding the use of robotics in surveillance and security. The videography robot project paves the way for a future where intelligent robots work alongside humans to build safer and more secure settings by establishing a balance between technological innovation and ethical implementation.

This robot project has shown promise in several other areas in addition to security and surveillance. It is suitable for jobs like environmental monitoring, observing wildlife, and even exploring dangerous or inaccessible locations because to its distinctive appearance and maneuverability. This robot can help with data collection for scientific study and conservation activities by being given specialized sensors and tools. The project's accomplishment also acts as a testament to robotics' potential and an inspiration for further advancement in the industry. The robot project has established a solid framework for the creation of increasingly more sophisticated and adaptable robotic systems as technology progresses.

To conclude the report, we would like to say that we went for research as our first approach to understanding the basics of the project in the mission of completing the project within the dedicated deadline. Different designs were explored and analyzed in the initial stage and screened by passing through the test of performance, manufacturability, cost, and reliability. Then the selected designs were prototyped to study further their pros and cons. Based on the performance of the fabricated prototype the final design was sorted out. We continue to keep this strategy till this point when we are in a state of ambivalence to finalize our schematic design for the turning system of the ball. Auxiliary tasks were performed to support the ball completion. For example, tensile testing of PLA specimen, impact testing and Finite Element Analysis were performed to enhance the efficiency of the project and to keep the professionalism of the engineering profession. We analyze all the results and if these results did not match the results from the literature, we did the analysis again and again, until the point we reach the optimized results. We used these results in our calculations of required parameters so that we get best results of our parameters.

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