A SINGLE UNIT CONCEPT AND DESIGN OF A HIGH MANEUVERABILITY MOBILE ROBOT

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DECLARATION

I hereby declare that I have conducted, completed research project and written the dissertation entitled “A Single Unit Concept And Design Of A High Maneuverability Mobile Robot”. I also declare that it has not been previously submitted for the award or any degree or other similar title of this for any examining body or University.

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Date :

Witness by

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Date :

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LIST OF ABBREVIATION

BCO	Barycenter Offset
CAD	Computer Aided Design
IDU	Internal Drive Unit
DC	Direct Current
COAM	Conservation of Angular Momentum
CMGs	Control Moment Gyroscopes
ABS	Acrylonitrile Butadiene Styrene

LIST OF SYMBOLS

n	Count of selection criteria
w_n	Weight of *n*th criteria
d_n	Rating of the *n*th criteria

ABSTRAK

Terdapat pelbagai jenis robot yang mempunyai kemampuan bergerak mudah alih yang tinggi. Salah satu daripadanya ialah robot sfera. Robot sfera menggunakan sistem pergerakan secara semula jadi dengan menggantikan pusat graviti untuk menghasilkan tork dan putaran. Penyelidik telah menghasilkan pelbagai mekanisma. Setiap mekanisma yang dhasilkan mempunyai reka bentuk yang berbeza. Reka bentuk tersebut mempunyai kelebihan dan kekurangan yang tersendiri. Oleh hal yang demikian, satu konsep dan reka bentuk unit tunggal robot sfera telah dihasilkan dalam projek akhir tahun ini. Robot sfera ini direka dan dilukis dengan menggunakan perisian yang dikenali sebagai "SolidWorks". Setiap perincian dan pemilihan bagi reka bentuk dan bahan bagi setiap komponen dibuat berdasarkan keperluan dan kriteria yang dikehendaki. Selain itu, ujian telah dilaksanakan bagi mengkaji prestasi robot sfera. Pemprograman dibuat dengan menggunakan perisian "Arduino IDE'. Seterusnya, ujian turut dilakukan ke atas robot sfera bagi mengkaji prestasi robot tersebut. Ujian Pra Set dan ujian Pergerakan Bebas dibuat. Berdasarkan pemerhatian, semasa ujian-ujian tersebut, robot sfera mampu untuk begerak ke hadapan dan ke belakang. Namun begitu, robot tersebut tidak mampu untuk mengenalpasti dan mengelak dari sebarang halangan di kawasan sekitar dengan baik. Antara faktor yang menyebabkan kegagalan ini adalah reka bentuk dan struktur dalaman selain posisi dan gangguan pada sensor ultrasonik. Akhir sekali, untuk menghasilkan robot sfera yang mampu berfungsi dgn baik, penambahbaikan hendaklah dilaksanakan. Hal ini termasuklah mereka semula bentuk casis untuk bahagian dalaman robot. Seterusnya, sensor ultrasonik hendaklah digantikan dengan kamera dan 'bluetooth". Oleh hal yang demikian, prestasi robot sfera yang mempunyai kemampuan bergerak mudah alih boleh ditingkatkan.

ABSTRACT

There are various types of high maneuverability mobile robot. One of it is spherical robot. Spherical robot utilizes an original locomotion system by displacing its center of gravity in order to generate torque and rotate itself. There are various principles developed by the researchers. Each of the principles has different designs. Moreover, the designs have its own advantages and disadvantages. Hence, in this final year project, a single unit concept and design of a high maneuverability spherical robot is developed. The spherical robot was designed using Conceptual Aided Design (CAD) software, known as SolidWorks. The selection of the design and materials done by considering the required needs or criteria. Apart from that, the programming was formed using Arduino Software. Next, to study the performance of the robot, the testing had been carried out. Pre Set Test and Free Style Test were conducted. Based on the result, the spherical robot able to move in a forward and backward direction. However, it did not able to detect and avoid obstacle well. The factors of failure are improper construction of internal chassis, positions, and interruption on ultrasonic sensor. Lastly, the future works for this project includes redesigning the internal chassis and replacing the ultrasonic sensor. Consequently, better performance of a high maneuverable spherical robot able to be obtained.

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Robots are the combination of science and technology. It consists of control systems, manipulators, power supplies, sensors and software that works together in order to perform certain tasks [1]. Nowadays, robot plays an important role as it contributes many benefits in human life. Robots are widely used in industry because it able to replace any repetitive, strenuous and potentially dangerous task. However, these benefits are limited to only specialized environment.

In addition, the robot has a few characteristics. For instance, sensing, movement, energy and intelligence. Firstly, the robot can sense the surrounding if it provided with sensors. These include light sensors, touch and pressure sensors, chemical sensors, hearing sensors and taste sensors. Secondly, the robot moves around the environment by walking on legs or propelling by thruster and rolling on wheels [1]. There are many types of robot designed by the researchers. One of the most common and influential robots is mobile robot.

Mobile robot is an automatic machine that gain convincing attention from the robotic community due to the challenges in navigating [2]. The most in demand applications for mobile robot are surveillance, transportation, industrial environment, medical, exploration and security systems. Apart from that, human uses mobile robot in hazardous environment, as they cannot reach a certain position. Hence, various locomotion mechanisms for mobile robots been designed and studied. Those mechanisms designed based on the requirements of each application. As a result, spherical robot was developed. It offers an efficient locomotion technique and natural geometry.

Moreover, the main component of the spherical robot is its spherical shell. The angular velocity may produce by one or more auxiliary components. It moves by rolling over surfaces. Next, it is the same as other robot because it operates as autonomous or remotely controlled robots. Spherical robot able to reach any point in space with ease, speed and accuracy. This is due to its capability to move in three-dimensional spaces easily. Hence, spherical robot is very suitable to be used in unfriendly or harsh environments such as outer fields. Furthermore, sometimes the operators are unable to reach or pass through any limited spaces. Equally important, the durability of its spherical design. This spherical design protects the sensitive electrical components in the robot as its body is fully covered.

Figure 1.1: Existing prototype of a spherical robot.

1.2 PROBLEM STATEMENT

Different kinds of mechanisms developed in order to develop a high maneuverable spherical robot. Each mechanism requires different design. However, those designs have their own limitations. Moreover, designing a maneuverable robot is a difficult task due to the difficulty for the robot to balance and stabilize itself. This is because, it is hard for the robot to balance and maintain its own stability. As for spherical robot, it may lose its stability when moving. It will keep on rolling and hard to stop at the right time, especially when the velocity is not controlled well. Not only velocity, the external factor from the surrounding such as the wind may cause the spherical shell to continue moving or turning to different direction.

Most of the existing spherical robots have a complicated design and mechanisms. Besides, the price is quite expensive. Hence, a spherical robot with a high maneuverability is fabricated with a lower cost and simple design compared to the existing design. In addition, a fabricated spherical robot expects to serve the same function as other mobile robots available in the market, which is avoiding obstacle around it.

Avoiding obstacle is an important task for the spherical robot. Furthermore, it helps our community when there is a need of searching or rescuing in hazardous environment. However, the action of the spherical robot after sensing the obstacle and ways of making it moves in the other direction after avoiding the obstacle is an issue. Due to its spherical shape, it is hard for the spherical robot to stop at the right time. In short, the fabricated spherical robot has to move in the correct direction and able to stop without losing balance while moving.

1.3 OBJECTIVES

The objectives of this project are as follows:

i. To fabricate a high maneuverability spherical robot.
ii. To ensure that the spherical robot able to detect and avoid obstacles around it.

1.4 SCOPE OF WORK

This project focused on the development of a spherical robot. The scope of work includes identifying the problem, analysing existing spherical robot, study the working mechanisms and conceptual design of spherical robot. The conceptual design done by using basic CAD software such as SolidWorks. This followed by a fabrication of spherical robot, testing and analysing the results and future work. Firstly, identifying the problem. Some research being studied in order to understand more about the needs of the spherical robot. Furthermore, it is not a common robot and there are various elements under considerations.

Secondly, study and analyse the existing design. Many prototypes being developed and could be referenced. Every researcher had a different idea of designing the mechanism of the robot. Apart from that, few improvements implemented to each design of the spherical robot. Hence, through this project, future work for the spherical robot should be discovered.

Thirdly, study the current working principle or mechanism of the spherical robot. Internal part of the spherical robot is the most dominant part. Further, all of the electronic components placed inside the spherical shell. Hence, the most appropriate and suitable mechanism for the spherical robot need to be chosen.

Fourthly, conceptual design of spherical robot. CAD software, “SolidWorks” is used. Each component of the spherical robot sketched and designed before the real prototype fabricated. These drawings would be the references as all parameters for each component were stated. The components assembled to develop a complete of spherical robot. The material for each component is determined and assigned by considering its function and properties. These materials play an important role as it affects the durability and performance of the spherical robot.

Next, fabricating the prototype followed by experimentation and testing. A prototype of a spherical robot produced and Arduino UNO used as the microcontroller. The programming is done using Arduino Software. After all, result analysis and future work. The analysis of the results completed by investigating the performance of the prototype. In sum, the suggestions for the future work determined and discussed for the purpose of improvement and better learning process.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF SPHERICAL ROBOT

2.1.1 EARLY ONE DEGREE OF FREEDOM SPRING DRIVEN MODELS

A spherical vehicle known as "Toy" patented by J.L. Tate in 1893. This vehicle carries an internal one degree of freedom [3]. The elastic spring drives the counter mass as illustrated in Figure 2.1.1 (Top). Based on the figure, central axis (B) carried the counter mass (C) while the elastic spring and drum (D) wind the spring when it is manually rotated. Then, the spring unwind as the ball releases and it continue to rotate in the forward direction. There is a bouncing off external obstacles that responsible in allowing the ball to continue moving.

In 1906, another design being patented (U.S. Patent 819,609). The design enables the internal counterweight of the robot to be manually adjusted. This is to ensure the ball rolls along a curved trajectory and not only the straight path. Figure 2.1.1 (Middle) shows the details of the counter mass. The support (g) place at certain angle to the rolling axis (f). The rolling axis remains in a tilted position related to the horizontal [3].

More designs on the mechanisms that producing more or less irregular rolling paths for self-propelled balls presented [3]. Apart from that, in 1909, a ball with a counter mass moved in a circular path inside the sphere by means of a gear (U.S. Patent 933,623). This mechanical toy shown in Figure 2.1.1 (Bottom). Unfortunately, due to the internal motion of the counter mass, the rolling axle changed its attitude continuously. Thus, the ball proceeds along a 'zig-zag' path.

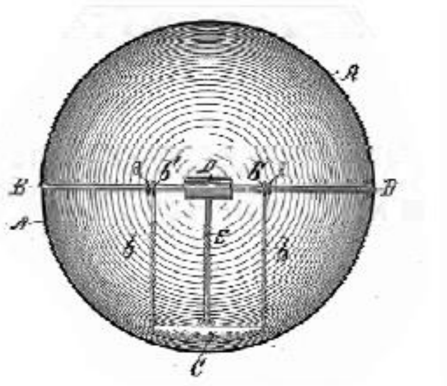


Figure 2.1.2 (Top): “Toy” by J.L. Tate. (U.S. Patent 508,558).

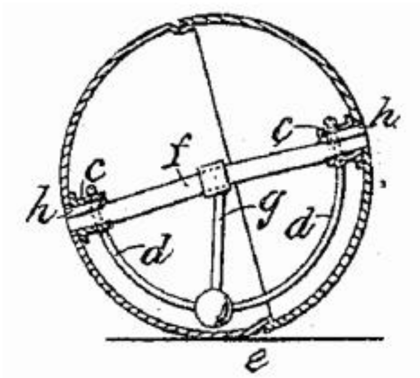


Figure 2.1.1 (Middle): Self-Propelling Device by B. Shorthouse. (U.S. Patent 819,609).

Figure 2.1.1 (Bottom): Mechanical Toy by E.E. Cecil. (U.S. Patent 933,623).

2.1.2 MAN-CARRYING MODELS

Spherical vehicles also developed for the purpose of marine applications and carry people. In 1889, this spherical vehicle produced by W. Henry (U.S. Patent 396,486). This spherical vehicle display in Figure 2.1.2 (Top). The working principle is the vehicle floated in the water with its passenger [3]. The mass of the ballast and the weight of the passenger provide stability to the spherical vehicle. The balanced mass inside ensure the movement of the vehicle itself and the same time the outer surface was rolling. Besides that, by tilting the axis of rotation, steering mechanism is developed. As the passenger mass inside the vehicle is moving, the axis of rotation would definitely tilted. This scenario is the same as the person runs on the treadmill. The structure could be inflatable and deflatable. The spherical structure, easy to be transported and stored.

Another spherical structure developed by S. E. Cloud [3]. Inside of the spherical structure accommodated by human being or vehicle and displayed in Figure 2.1.2 (Middle). However, the focus of this design is the ability of the spherical structure to be inflated and deflate. Next, Figure 2.1.2 (Bottom, Left). This figure presents different design as the spherical vehicle equipped with a pedal mechanism for use on land or water besides a seat is provided. Further development of design, illustrated in Figure 2.1.2 (Bottom, Right). It is being implemented as the spherical vehicle steered by relocating the centre of gravity in a very similar way to hang-gliders.

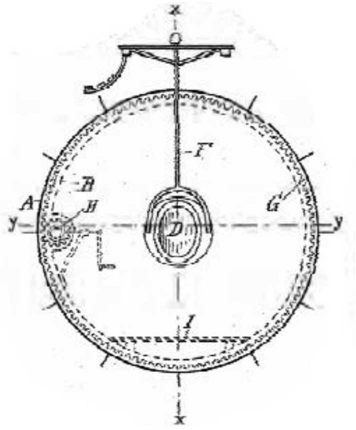


Figure 2.1.2 (Top): Marine vessel by W. Henry (U.S. Patent 396,486).

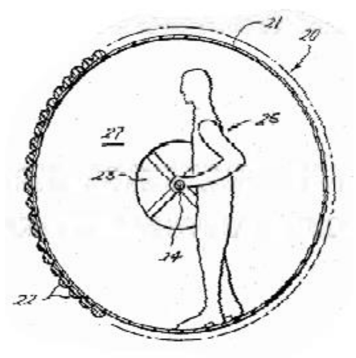


Figure 2.1.2 (Middle): Spherical vehicle by S. E. Cloud (U.S. Patent 3,428,015).

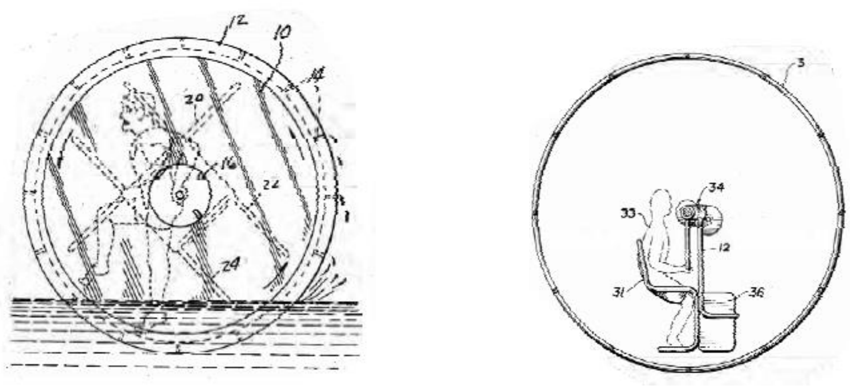


Figure 2.1.2 (Bottom): Spherical watercraft by W. E. Wilson (U.S. Patent 2,838,022) (left) and another spherical vehicle by L. R. Clark Jr. and H. P. Greene Jr. (U.S. Patent 4,501,569) (right).

2.1.3 ELECTRICAL ONE AND TWO DEGREE OF FREEDOM MODELS

The power source replaced by a battery and electric motor in two almost parallel patents. Figure 2.1.3 (Left) indicates one of the patents was developed by E. A. Glos (U.S. Patent 2,939,246, filed 1958). Secondly, J.M. Easterling (U.S. Patent 2,949,696, filed 1957) in Figure 2.1.3 (Right). The first designed was included a gravity-operated switch. This involves activation of the motor in required position. The motor's ability is to drive the counter mass over the upper dead centre when it is in contact with objects [3]. Hence, the ball autonomously reverse for a half-revolution. Moreover, the ball could change the direction of rolling.

There are many benefits of using the electric motor. Hence, electric motors applied in various mechanical solutions that were already at least partly familiar from earlier spring-driven inventions. Next, shock and attitude sensing introduced with mercury switches. It controlled the motor operation and rolling direction besides adding the light and sound effects to the ball [3].

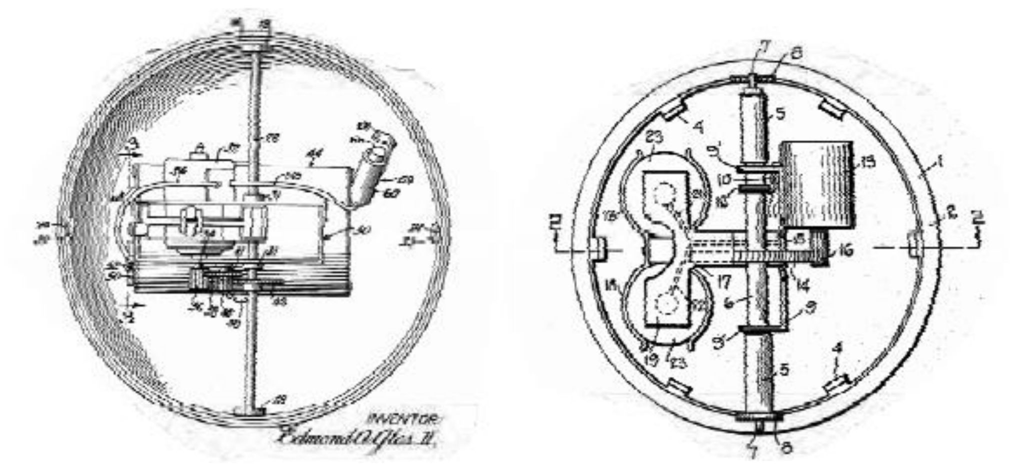


Figure 2.1.3: Toy ball by E. A. Glos (U.S. Patent 2,939,246) (left) and Toy by J. M. Easterling in 1957 (U.S. Patent 2,949,696) (right).

2.2 BARYCENTER OFFSET (BCO) PRINCIPLE

Barycenter offset is commonly used in spherical robots as it involves shifting of a center of mass to produce a desired motion [4]. The mass distribution of the ball will be shifted if the internal mechanisms moving. This cause the ball to roll to a new position of equilibrium. The robot can move properly through its environment if the timing and control methodology done in a correct way. A weighted bob of a given mass, swings on an armature about a support rod which positioned in the center axis of the robot. As the bob rotates, the center of mass rotates accordingly through the center axis of the robot. In Figure 2.2, a pendulum acts as the center of mass inside the sphere.

This kind of mechanism is simple and easy to be implemented as it only needs a load as the main component. However, the main limitation of this mechanism is the existence of a maximum output torque constrained. This happens because the center of gravity cannot be shifted outside of the shell.

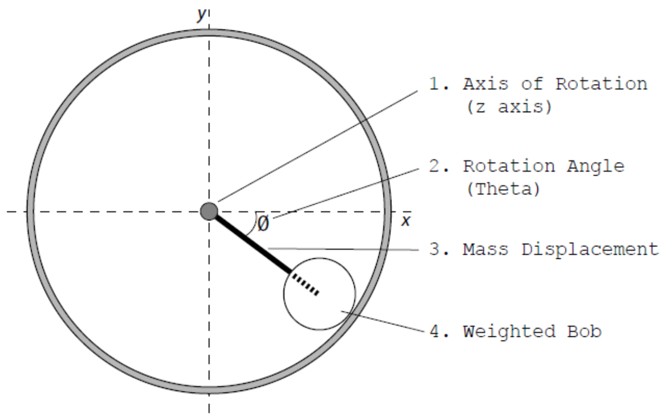


Figure 2.2: A spherical robot model with the pendulum drive armature and weighted bob.

2.2.1 HAMSTER BALL

This mechanism refers as hamster ball because it works like a hamster moving in its toy ball [5]. A small size of a wheeled mobile robot placed inside the ball. The wheeled mobile robot is remotely controlled. Furthermore, the weight of the wheeled mobile robot itself able to provide sufficient force to propel the robot especially when it is moving. Hence, in order to change the direction of the movement, the heading of the internal robot must be changed. Apart from that, single-wheeled or multi-wheeled vehicles can also be used. As for four-wheeled differential-drive robot, different motion curves formed as opposed to a single wheeled robot.

The advantages of this mechanism are easy to be fabricated and manageable. Next, the disadvantage is slippage. As the robot moves inside the spherical structure, some of the internal robot or driving mechanism happened. Secondly, there are much energy loss and control complications due to friction between the wheels and the ball. Thirdly, as the internal vehicle becomes airborne, traction between the shell and the internal robot's wheels becomes zero. Thus, the ball loses its momentum and affects the accuracy of positional tracking. Figure 2.2.1 illustrated the prototype and internal unit of the hamster ball robot.

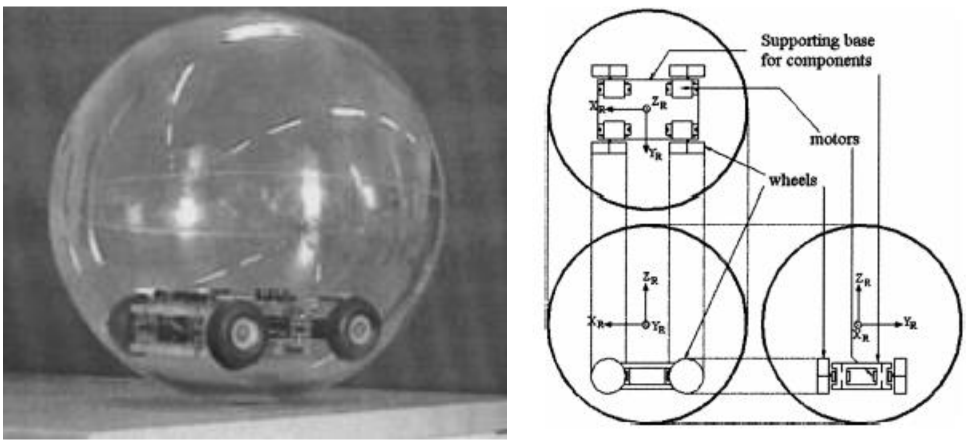


Figure 2.2.1: Prototype of a Hamster Ball design (left) and structure of the internal unit (right).

2.2.2 INTERNAL DRIVE UNIT (IDU)

Firstly, for spring-loaded design or fixed mechanism, a rod and spring attached to the top of the internal robot before being pressed up against the shell [6]. This forced the wheels to be in constant contact with the shell. A three degree of freedom ball bearing attached to the top of the spring. This allows the spring to move along the surface of the inner shell. This movement produced small friction.

The internal drive unit mechanism shown in Figure 2.2.2 allows the speed of the ball to be monitored easily and controlled by the motor wheel speed. This is proven especially when the robot is having a constant contact between the wheelbase and shell. Next, it has a low cost robot because the manufacturing cost is cheap. The system is simple and suitable to be developed and develop at university for the purpose of research. However, it is not practical for the real-world situations used. Furthermore, slippage may occur between the shell and wheels. Possibility of slippage can be reduced by adjusting the tension between the spring-loaded system and the internal robot. Unfortunately, higher friction forces would present throughout the robot. Next, an IDU system unable to make use of the stored momentum. As the wheel stops, the robot became inconsistent. Lastly, an off-axis center of mass contributes to unwanted pattern of travel from the robot.

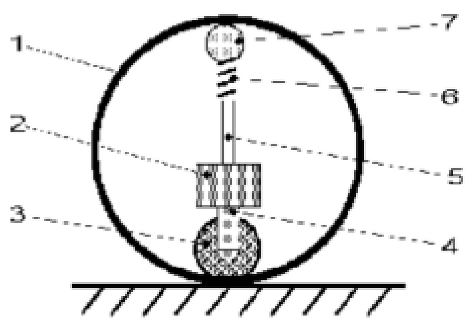


Figure 2.2.2: Structure of Spring-Loaded Design. 1 refers to the robot body (case), while 2 shows the controlling box. 3 indicates the driving wheel, 4 is steering axis, 5 is the supporting axis, 6 is the label for spring and 7 is the balance wheel.

2.2.3 UNIVERSAL WHEEL

Universal Wheel incorporates the principles of barycenter offset. Figure 2.2.3 presents a BHQ-3 and a series of robots that established their name from Boltzmann-Hamel equation [8]. Universal Wheel mechanism is a combination of hamster wheel and internal drive unit mechanism. The interior drive mechanism rotates freely inside of the robot due to the combination of wheels attached to it [7]. There are two DC drive motors that responsible in controlling the robot. Firstly, it controls the orientation of the IDU. Secondly, control the speed of the drive wheel. This enables the ball to move with a zero turning radius. At the same time, a higher degree of holonomic created. Moreover, the angular velocity of the driving wheel controls the robot's velocity. The translational velocity of the robot increases when the wheel spins faster. The robot able travel in water, sand and small slope. However, energy loss will be increased because of the presence of friction from the sponge wheel.

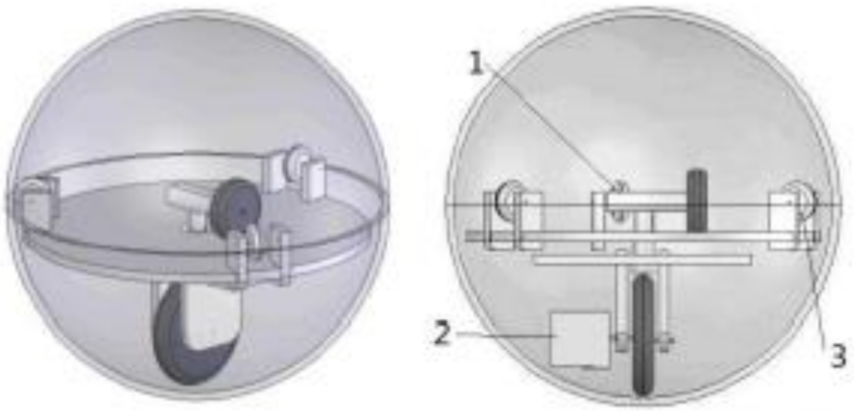
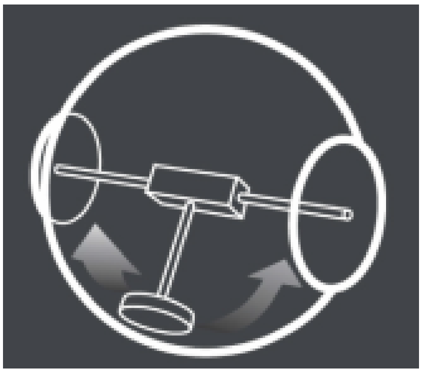


Figure 2.2.3: Structure of BHQ-3, 1 and 2 are the motors while 3 is the sponge wheels.

2.2.4 PENDULUM DRIVEN

There is a fixed shaft through the center of the outer shell of the robot. The bob and pendulum rotate around the shaft. This cause shifting to occur at the center of mass outward from the center. Thus, encouraging the shell to roll on the surface. By changing the pendulum to the left or right, the robot turns in the corresponding direction [7]. Apart from that, as the weight of the bob increases, the amount of torque that drives the robot will increase. One of the commercialized pendulum-driven robot is Rotundus as shown in Figure 2.2.4 (Left).

Next, further improvement being made as two pendulums used to drive the spherical robot. Its mechanical structure demonstrated in Figure 2.2.4 (Right). The pendulums drive the robot. These pendulums positioned diametrically opposite on the major axis of the ellipsoid shell [8]. Two DC servomotors used. As the pendulums rotated about the major axis, the position of the center of gravity also changed. At the same time, it affords the inertia force. In sum, this two pendulum driven robot involved eccentric moment, inertia moment and inertia force. Hence, the robot able to climb the slope and have a high speed.



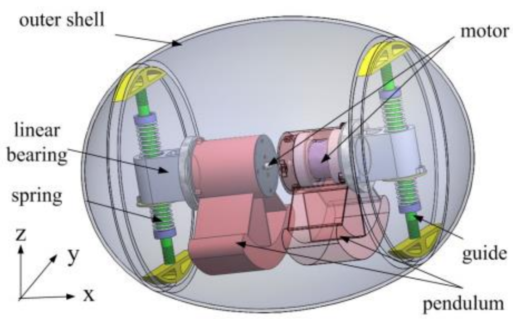


Figure 2.2.4: A commercialized pendulum-driven robot, Rotundus (left) and mechanical structure of the two pendulum-driven robot (right).

2.2.5 NOTABLE ENHANCEMENTS

N. Chadill develops a reconfigurable robot as shown in Figure 2.2.5 (Left). This robot able to transform from a sphere into a dual hemisphere platform with the help of three legs and omnidirectional wheels [9]. It can compact itself into a sphere for the purpose of transportation and deployment and at the same time function as a leg-wheeled robot after reconfiguration. The process of transformation driven by a motor. Each segment joint is provided with a motor. Then, after fully transformed, the robot body can be lifted off the ground by the robot legs. Apart from that, the hip joint of the legs enables rotation during climbing while the omnidirectional wheels support the robot when it is moving on the flat surface [10]. This robot manages to navigate the pathways autonomously like other wheeled vehicle.

Secondly, another reconfigurable spherical robot is Kisbot I. As shown in Figure 2.2.5 (Right), it has deployable legs with two types of drive modes which are pendulum-driven mode and wheel-driven mode. As the legs retracted to the interior of the robot, the robot can maneuver as a pendulum model [7]. Then, during wheeled mode, the legs extend, stabilizing the robot, and can be driven like a wheeled vehicle. It rotates independently of the other semi-sphere, allowing the robot to stabilize itself in unusual terrains. However, the design is quite complicated and exorbitant compared to other design.

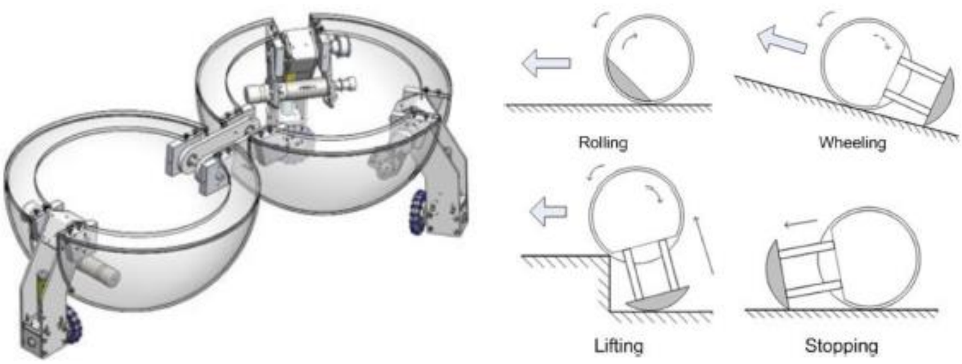


Figure 2.2.5: Spherical robot after reconfiguration (left) and Kisbot I’s movements (right).

2.3 CONSERVATION OF ANGULAR MOMENTUM PRINCIPLE

This finding study the spinning of a large flywheel as it spins rapidly and rotates about an axis. The laws of conservation of angular momentum used to control any movement produced by the sphere. This mechanism involves the output torque of the internal mechanism to the angular velocity of the Control Moment Gyroscopes (CMGs). If the angular velocity of the CMGs is increasing, the output torque will also increase. In addition, these systems have reaction forces in all three spatial dimensions. This is proven as the CMG spinning about the X-axis, then rotates about the Y-axis, torque will present about the Z-axis. In short, if the design does not consider the dimension of torque, the robot may steer in an unwanted direction [7].

2.3.1 BALANCING

The first approach was a disc-like object acts like a balancing on the edge or Gyrover [11]. Gyrover is a novel, single wheel gyroscopically stabilized robot that has an actuation mechanism fitted in the wheel [12]. An internal gyroscope used to balance the robot as illustrated in Figure 2.3.1. This produced precession torque to steer it. This principle and design really suit the condition that requires high speeds and rough terrain. Moreover, it's able to turn in place and simultaneously providing some degrees of holonomy [7]. The disadvantages of this balancing design are the difficulties in making precise movements of the robot, especially if the embedded electronics and mechanics are not designed correctly.

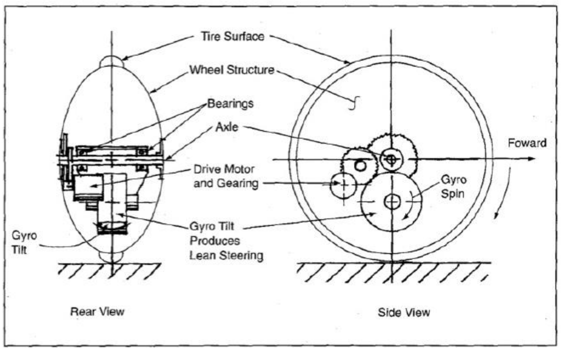


Figure 2.3.1: Mechanical breakdown of balancing spherical robot (Gyrover).

2.3.2 UNI-DIMENSIONAL COAM

The UNI-Dimensional COAM design of this mechanism consists of a variable speed rotor that is used for a bob as display in Figure 2.3.2 (Left). The acceleration produced by the spinning of CMG may be faster or slower and cause the shell to turn. If the CMG spins at a high rate, it moves up and down as if it was a bob that contribute to a precession torque [13]. The robot achieves higher torques compared to normal pendulum-based design. The advantage is the robot able to do reorientation in order to control its movement.

Apart from that, V. Joshi designed a robot that is regulated by two pairs of diametrically opposed CMG's as shown in Figure 2.3.2 (Right). A single motor controller controls each CMG pair. Thus, as a pair's angular velocity increases, the shell will rotate in the opposite direction to maintain the system's total angular momentum [14]. The ball's movement has a second degree of freedom because there is a second pair of angular velocity inside the ball. This enables it to move in a true holonomic manner.

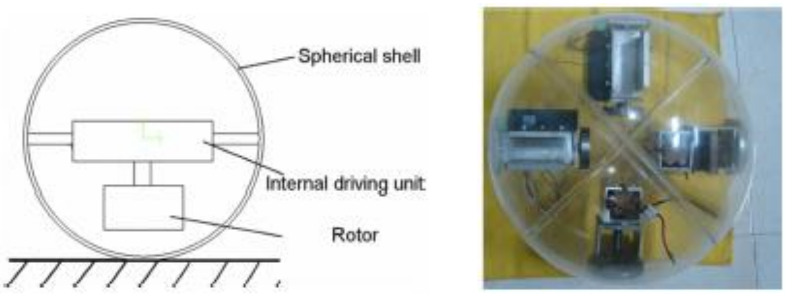


Figure 2.3.2: Schematic of rotor-based bob presented by S. Guanghui (left) and V. Joshi's diametrically opposed rotor pair design (right).

2.4 APPLICATIONS OF SPHERICAL ROBOT

2.4.1 PLANETARY SURFACE EXPLORATION

Planetary exploration missions usually depend on unmanned automated spacecraft and robots to gain the required scientific data. During earlier exploration missions, it involves remote-sensing satellites and gathered scientific measurements from orbit. One of the critical issues that need to be considered during the mission is the mobility of the robot. This is proven as the collection of samples from a single site might bring erroneous scientific conclusions on the nature including history of the whole planetary body. Current research interest is the study of developing a robot that can perform well on Mars. Furthermore, it needs to face a difficult operating condition such as move in dusty environment, filled with various types and size of obstacles [15]. However, normal mobile robots have limitations in this area and these robots have high maintenance.

Hence, spherical robot being chosen. It can still operate in such difficult terrain as the electrical components are embedded inside the shell. This allows the robot to face all kinds of obstacles and operating surfaces. Besides that, the shell can also serve as an efficient thermal protection. Figure 2.4.1 shows the image of animation of the micro-robots [16].

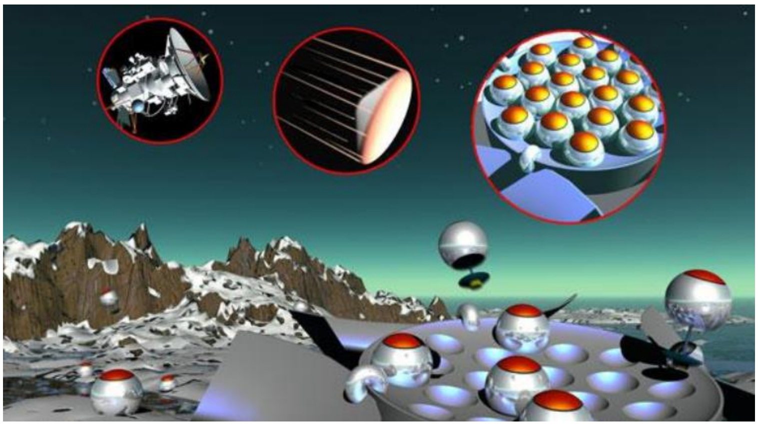


Figure 2.4.1: The micro-robots would land on the surface of a planet packed into a capsule.

2.4.2 SURVEILLANCE

Spherical Robot also being used for surveillance purpose. For example, to monitor the surroundings of airports or industrial plants to detect possible threats. A spherical robot which known as GroundBot is developed for security purpose [17]. Figure 2.4.2 presents the prototype of GroundBot. GroundBot capable to make navigation at outdoor terrain at speeds approaching 3m/s. Moreover, the steering and locomotion accomplished by displacement of its center of mass. Almost all of its weight suspended on a rigid axle mounted through the shell.

There are two perpendicular motors responsible in distributing and enabling the weight weight to rotate at the center. GroundBot also equipped with sensors and camera. The advantages of this robot are its stability and robustness. Next, its limitation is camera image stabilization. Reasons of having a spherical robot in surveillance area are to free the guards from monotonous patrolling, lowering cost and increasing security.

Figure 2.4.2: The spherical security robot GroundBot.

2.4.3 RECONNAISSANCE

Another application of spherical robot is reconnaissance. The prototype of a spherical robot named as Cyclops. Cyclops used for reconnaissance and surveillance purpose. The system functions either in a forward reconnaissance role, such as gathering all required information that is unknown [18]. This small size robot enables the robot to be used anywhere, especially in small spaces where soldier cannot reach easily and be the covertly patrol an area which has already been secured. In addition, a soldier can toss the system through an opening such as a blown-out window or doorway through which an ordinary-sized robot could not move. Cyclops has two degrees of freedom in its locomotion system. Hence, it can pivot in place along the vertical axis. This can be done by rotating a fixed horizontal axis through a small motor and gearhead. The conceptual aided design of Cyclops is provided in Figure 2.4.3.

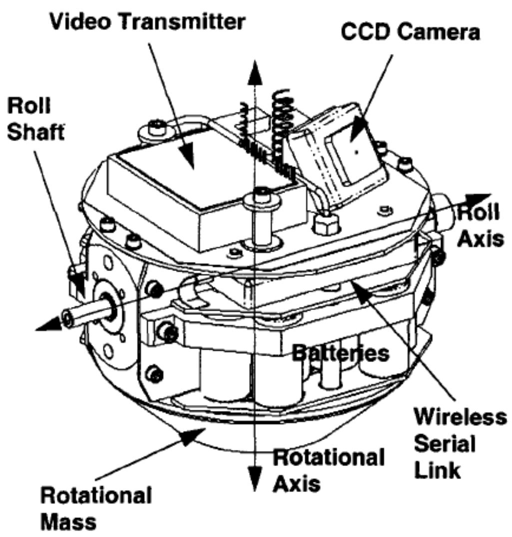


Figure 2.4.3: A CAD rendering of the Cyclops prototype.

CHAPTER 3

METHODOLOGY

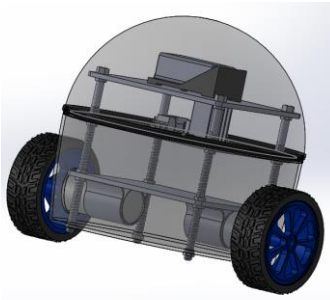
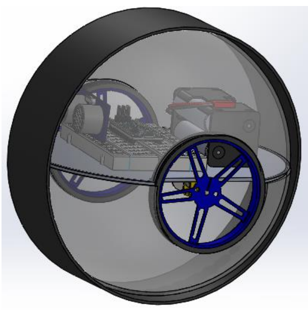
3.1 INTRODUCTION

This chapter presents the steps in designing and fabricating the spherical robot. Before starting doing the fabrication, the details for the drawing done using CAD Software, SolidWorks. The features of the spherical robot are revised and finalized to ensure that the robot able to do the required task. Secondly, comparison between two alternatives being made based on the scoring matrix. As a result, the most suitable and capable alternative concept is chosen. Thirdly, determining the material for each of the components. However, before choosing the material, study in its properties is done to make sure that the properties tally with the needs of the design. This is to ensure the materials fit the concept and function of the spherical robot. The fourth step is to make the connection to the microcontroller, motor driver, sensor, DC motor and battery. Programming completed using the Arduino Software. Lastly, there would be two types of test experienced by the prototype. These tests are Pre-Set Test and Free Style Test.

3.2 SPHERICAL ROBOT DESIGN

The first step in fabricating the spherical robot was designing all the required components. As for this spherical robot, there are a few main components (including electrical components) needed to assemble and complete it. Firstly, the hemisphere for the upper part and the lower part. Both of this hemisphere is required to form a shell for the robot. The other components are chassis, battery holder, batteries, Arduino UNO, breadboard, ultrasonic sensor, motors and wheels. Two designs have been made. These alternatives are compared and chosen using scoring matrix. The summary of alternative concepts is tabulated in Table 3.2.1.

Table 3.2.1: Summary of alternative concepts for the spherical robot.

Alternative Concepts	**Descriptions**
 Figure 3.2 (Top): The CAD of Alternative 1.	Strengths: i. All of the electrical components, embedded inside the shell. ii. Extra space for chassis. iii. High stability and better mobility. Weaknesses: i. The fabrication process is complicated. ii. Larger size. iii. High cost. iv. Heavier than Alternative 2. v. Unable to be used on all types of surfaces.
 Figure 3.2 (Bottom): The CAD of Alternative 2.	Strengths: i. All of the electrical components, embedded inside the shell. ii. Light. iii. Protected with rubber. iv. Easy to roll. v. Able to be used on all surfaces. vi. Small size. vii. Low cost viii. The fabrication processes are much more simpler than Alternative 1. Weaknesses: i. Hard to handle the mobility.

For the purpose of concept selection, both alternatives are compared and the weight of the criteria is determined. The criteria that need to be complied by the spherical robot are light, able to be used on all surfaces, small size, less number of components, low cost and easy to be manufactured. Representative weights of these criteria are listed in Table 2. A percentage is used to assign the weight of each criteria. The representative ratings are valued from 1 to 5. This indicated much worse to much better design. Finally, the total score for each design is calculated using formula below:

$$Total\ Score = \sum_{1}^{n} \mathrm{w_n} \times \mathrm{d_n} \qquad (1)$$

where, n is the count of selection criteria, w_n is the weight of nth criteria, and d_n is the rating of the nth criteria [19]. Table 3.2.2 shows the selection criteria and weight for the spherical robot.

Table 3.2.2: Selection Criteria and Weights.

Number	Selection Criteria	Weights
SC1	Light	15%
SC2	Able to be used on all surfaces	10%
SC3	Small size	20%
SC4	Less number of components	20%
SC5	Low cost	20%
SC6	Easy to be manufactured	15%

By referring Table 3.2.2, scoring matrix being done in order to choose the most suitable design. This design needs to fulfil the criteria required. Each of the alternatives had its own score and rating. The total score is calculated. In sum, the alternative concept with the highest score is chosen. Table 3.2.3 presents the concept scoring matrix.