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SELF-BALANCING ELECTRIC SCOOTER

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Abstract: Balancing a two-wheeled vehicle plays an important role in all transportation systems and has always been a challenging task. The study of the kinematics concept helps to understand the subject of balancing objects or bodies under static and dynamic conditions. The motion dynamics of a two-wheeler vehicle are very different from other vehicles. So many experiments and calculations conclude that a two-wheeler vehicle stays upright when it is steered to maintain its center of mass over its wheels. Either the rider steers to balance the vehicle or the vehicle itself balances above a definite velocity. Factors such as the gyroscopic effect, the center of mass, and mass distribution contribute to the self-stability of bicycles. The dynamic stabilization of a two-wheeled vehicle requires that a torque acting on the vehicle naturally be neutralized by a torque produced within the vehicle by a gyroscope.

We are planning to design and fabricate a self-balancing scooter with a gyroscopic effect. The construction of this bike includes design calculations, modeling, and a fabrication process in which the accelerometer sensor and gyroscope sensor are used to stabilize the vehicle. Arduino and motor controller combinations are used to give continuous commands to vehicles.

Along with self-balancing, the scooter is powered by two electric motors, which allow for easy maneuverability and fast acceleration. For the hardware we are using a bicycle, Arduino Uno board for real-time balance control, MPU 6050 sensor (3-axis gyro and 3-axis accelerometers), two BLDC motors for weight balancing and movement of the bike, and a high-powered battery. For designing we use Autodesk Fusion 360 and for coding, we use Arduino IDE for Windows.

***IndexTerms* - Self Balancing, Gyroscope, Accelerometer, Gyroscopic Effect, Motor Controlling.**

I. INTRODUCTION

Motorbikes are the most used conveyance option to travel from one location to another. They let riders move through confined places, are quick and flexible, and provide a thrilling sensation when riding on various surfaces. Different motorcycle models, including sport bikes, cruiser bikes, touring bikes, and mopeds, have been introduced over time to meet various client demands. Electric bikes are becoming more and more common throughout the world as a result of the favorable reaction they have received from motorbike consumers. Additionally, electric bikes have zero emissions, better power output, less maintenance, and unique looks, all of which are predicted to increase demand over time. The self-balancing and upright standing of battery-powered autonomous motorcycles will be possible even at very low speeds. Additionally, the introduction of a self-balancing mechanism in motorbikes could safeguard riders from roll-over injuries as well as protect them from falling after collisions.

In today's world, a motorbike is one of the best options for getting where you're going quickly and affordably. Bikes include a lot of advanced features that were developed to prevent accidents. There was a greater chance that an individual who was injured in an accident on the side of the road would die. When riding a bike, the rider frequently loses control in trying to gain stability. A self-balancing bike might be beneficial in the sense of safety and preventing vehicular damage if you want to avoid all these bike limitations. The "Gyroscopic effect" is the principle by which the self-balancing bikes operate. And for many years, it has been used in ships and airplanes. Bikes that tilt to the left or the right cause a reactive Gyroscopic couple to form in the opposite direction. Thus, the gyroscopic effect helps the vehicle maintain balance.

1.1 Gyroscopic Effect

The term "Gyroscopic effect" describes how a rotating wheel will frequently maintain its initial alignment. When a vehicle is moving, this phenomenon is utilized in mechanical navigation gyroscopes to retain a sense of direction. Because of the conservation of angular momentum, or spinning motion, we experience the gyroscopic effect. The overall angular momentum of a system needs to stay the same in the absence of an outside force and maintain its orientation. Therefore, a fast-spinning heavy wheel can tilt away from its original position with only a little amount of force. The bike still balances itself even if the wheels' angular momentum cancels out. By adding two more wheels that spin in the opposite direction from the original wheels and are designed to stay off the ground, the angular momentum of the wheels can be canceled out.

1.1.1 Gyroscopic Couple

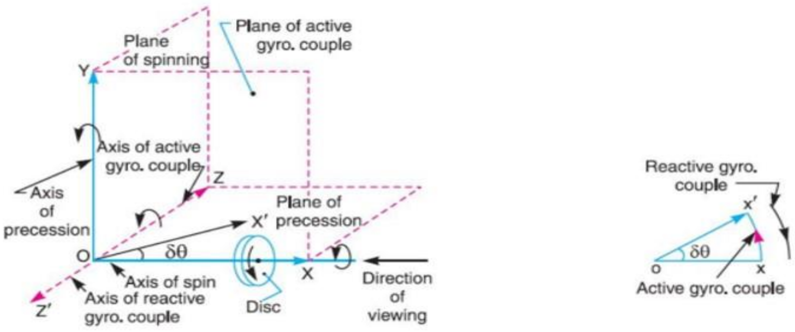

Fig 1.1: Gyroscopic Couple Representation

Consider a disc spinning with an angular velocity ω rad/s about the axis of spin OX, in an anticlockwise direction when seen from the front, as shown in Fig 1.1. Since the plane in which the disc is rotating is parallel to the plane YOZ, therefore it is called the plane of spinning. The plane XOZ is a horizontal plane and the axis of spin rotates in a plane parallel to the horizontal plane about an axis OY.

In other words, the axis of spin is said to be rotating or processing about an axis OY (which is perpendicular to both the axes OX and OZ) at an angular velocity ω_P rad/s. This horizontal plane XOZ is called the plane of precession and OY is the axis of precession.

Let I be the mass moment of inertia of the disc about OX, and ω be the Angular velocity of the disc. Therefore, the angular momentum of the disc = I.ω. Since the rate of change of angular momentum will result from the application of a couple to the disc, therefore the couple applied to the disc causes precession:

$C = I\,\omega\,\omega_P$

where C is the Gyroscopic Couple
I is the moment of inertia
ω is the Angular velocity, rad/s
ω_P is the Perpendicular angular velocity, rad/s

II. LITERATURE REVIEW

The authors in [1] developed a design for a scale model of the self-balancing cycle based on the principle of an inverted pendulum. They calculated various factors for designing the flywheel. They used MPU6050 for real-time gyro and 3-axis accelerometers an Arduino Uno board for real-time balance control, a servo motor for weight balancing movement and a 5-volt Li-ion battery power bank used for a power source.

In [2], deals with the study of various sensors, designing, and calculations of the model. They used an MPU6050 sensor, L298N Motor Controller, and Arduino Uno for the proposed model. They designed the model based on theoretical calculations and they used dc motor rotates at 2500rpm to stabilize the flywheel and they found that the experimental results and theoretical calculations were close.

The implementation of a bicycle with balancing capabilities was proposed in [3], which is based on the principle of an inverted pendulum. He calculated the Centre of Mass, Equations of Motions, and Transfer function for lean angle and stability used in designing the model. Also, he calculated the PID control equations to achieve stability at varying speeds.

The authors in [4] stated that "the vehicle is powered by a battery source. The motor DC 24v,250w (or) 500w, high torque whose speed will be controlled by a custom-designed circuit uses sensor like IMU, which mounts accelerometer and gyroscope is used to monitor the posture of the person".

The authors in [5] stated that "there are several ways to design an efficient self-balancing bicycle by using control moment gyroscope and mass balancing steering control and reaction wheel usage of CMG gives great effect".

The authors in [6] stated that "the rotation of the disc leads to the production of gyroscopic effect when the vehicle loses their balance reactive gyroscopic couple maintains stability".

In [7], deals with the designing of one-wheeled bike balancing using a gyroscope and accelerometer with a brushless dc hub motor and Arduino as a microcontroller, they used a Kalman filter to mix the data taken from both gyro and accelerometric sensors together, they suggest the improvisation of the unicycle by the usage of broad tire that much wider and has more contact area to the ground and the use of PID controller to minimize the error in output by adjusting the process control input.

III. OBJECTIVES

- To design a miniature bike that can balance itself in a controlled environment.

Walking around large compounds which are hectors wide like campus, zoos and other recreational areas are tiring. Sometimes it may be challenging to get from one point to another. Riding a bike that can balance itself in a controlled environment offers visitors to save energy and time. It may also benefit guest experience because they offer an easier way to give tours, and transport groups of guests who may tire walking the entire layout. It allows the visitors to explore all of the features inside the compound.

- To strengthen renewable energy sources.

There is a demand for more affordable and effective forms of transportation as the cost of fuel rises nowadays. Additionally, it is becoming ever more important to conserve energy for dealing with the issue of the depletion of fossil fuels. To solve this issue, we plan to design an electric scooter that is both environmentally friendly and low in pollutants. They decrease exhaust pollutants, lessen reliance on fossil fuels, boost neighbourhood health, guarantee energy security, and enhance opportunities for jobs and training. Decarbonizing the transportation sector through integrating electric transportation with renewable energy goals.

- To familiarize the tools and designing a bike in Autodesk Fusion 360.

Autodesk Fusion 360 helps to engineer products with a comprehensive set of modeling tools. Ensure our product form, fit, and function with diverse analysis methods. It is featured in sketching, direct modeling, surface modeling, parametric modeling, mesh modeling, freeform modeling, rendering, PCB design integration, and assemblies. Various tools in it are assigned for executing these features. Familiarising each tool provided in Autodesk Fusion 360 helps to design the required structure of a self-balancing bike.

- To understand the applicability of various sensors and actuators.

Based on the requirements, the self-balancing scooter uses an MPU6050 sensor for evaluating and navigating the terrain, a triple-axis accelerometer and gyro for calculating angular velocities and accelerations, and Arduino. The required states are obtained by processing the MPU6050 sensor. The information from the MPU6050 sensor is used to calculate the feedback controller gains, to have an overall better system response.

- To find out a cost-effective solution for making a self-balancing bike considering various possibilities.

The ever-growing traffic expenses, the increase in the level of pollution, and the shortage of resources have made us think of replacing the polluting vehicles with such which are environment friendly, economical and beneficial. By considering the energy requirements along with the vision of conserving renewable energy resources we came to form our project which completely relies on electric power. Along with low consumption of energy, our product offers low cost.

IV. DESIGN AND METHODOLOGY

4.1 Design

4.1.1 Calculations for the Model

These design calculations are for a series of bicycle models used by the adult age group. The flywheel design and the motor selection are according to these calculations. The gyroscopic torque and speed of the disc are calculated.

Torque (T) = $(P \times 60) / (2 \times 3.14 \times n)$
where P is Power,
n is the speed of the motor (in rps).

Mass of the whole system (M) = Mass of gear motor + Mass of servo motor + Mass of wheels + Mass of disc + Mass of frame + Mass of chassis + Mass of gimbal motor(balancing).
where all values are in Kgms.

Weight of total system = Total mass of the system × g
where g = 9.81. (acc. due to gravity)

Angular speed of the motor (ω) $=2\pi N/60$ rad/sec where N is the speed of the motor (in Rpm).

Moment of inertia of the disc(I) = $mdr^2/2$
where m is the mass of the disc,
d is the disc diameter,
r is the disc radius.

The highest precision speed of the disc is $\omega_P = Mghsin\theta/I\omega$
where M is the mass of the system, g = 9.81m/s,
$I\omega$ is the angular momentum,
θ is the angular tilt,
h is the disc center height.

Highest required gyroscopic torque $T = I\ \omega\ \omega_P$.

4.1.2 Scale Model

For demonstration, a 3D printed model has been designed by choosing the appropriate gimbal motor having an inbuilt encoder connected to the gimbal controller for more accurate and stable balancing, an Arduino controller is used for the movement part, a dc gear motor connected from a motor driver is used for the forward and backward movement which is attached in the back wheel, a servo motor is used for the left and right movement which is attached in the front wheel, a Bluetooth module is interfaced with Arduino for the connection with a mobile app, the movements are controlled from the mobile app.

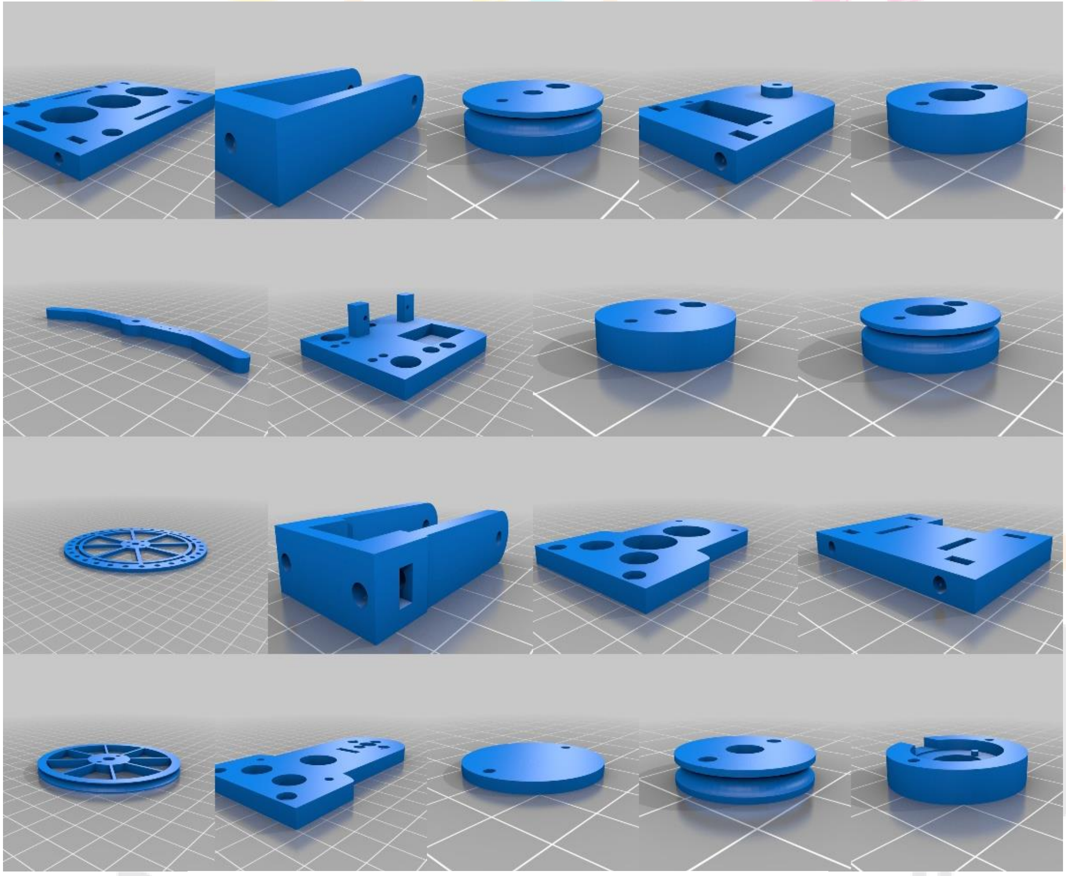

Fig 4.1: 3D Printed Parts

4.2 Methodology

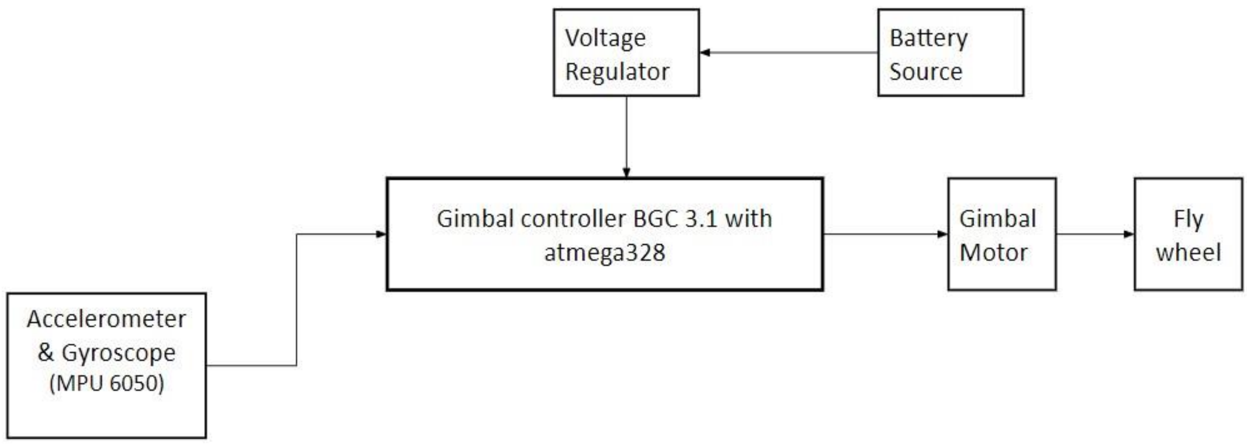

Fig 4.2: Block Diagram of Self-Balancing

Self-Balancing Working:

When the battery is connected, the power goes to the gimbal controller (BGC 3.1), an MPU6050 sensor is interfaced with the controller, and the values from the MPU6050 sensor module are taken continuously and fed to the controller. When there is a tilt of 5 to 10 degrees the sensor senses the tilt and sends the values to the controller and the controller provides the signal to the gimbal motor having an inbuilt encoder. The motor will rotate the flywheel in the opposite direction of the tilt at a higher speed and create momentum or a force opposite to the tilt. As a result, the cycle regains its stable position.

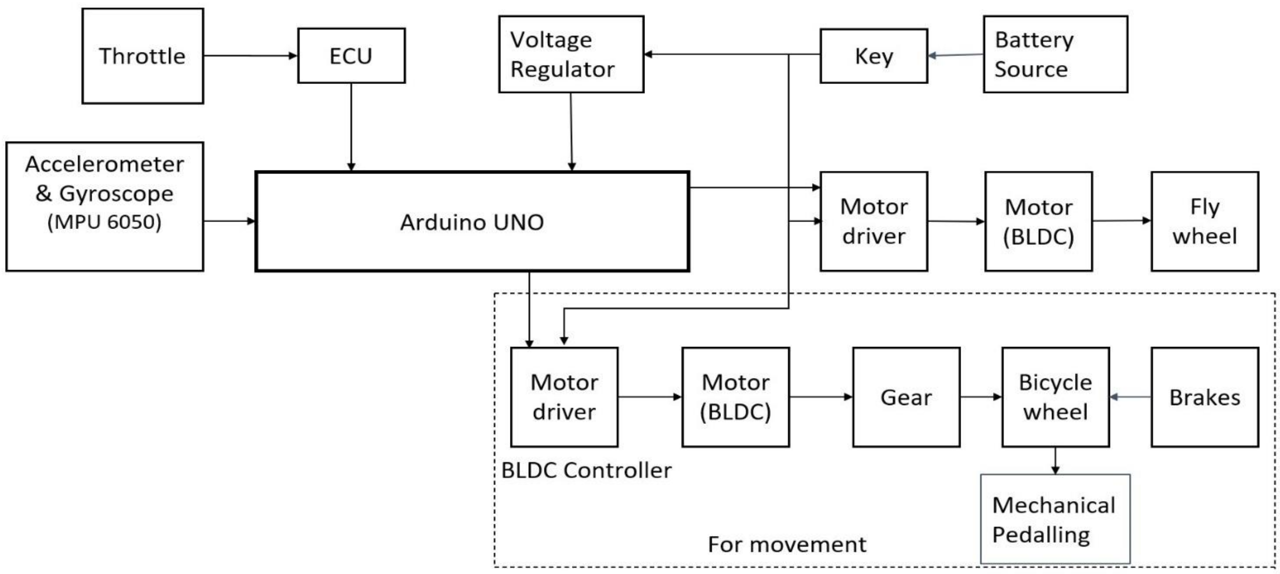

Fig 4.3: Block Diagram of Movement

Movement:

When the battery is connected the power goes to the Arduino controller, a Bluetooth module(HC-05) is interfaced with the controller, also a dc gear motor which is for forward and backward movement attached to the back wheel connected with the motor driver(L298N) to the controller, a servo motor is attached in front wheel for the left and right direction connected to the pins of Arduino. The movement is completely controlled in a mobile app, when a button is pressed the signal is received from the Bluetooth module to the controller and it works according to the received command.

Coding:

The coding of the gimbal controller is done in SimpleBGC GUI developed by BaseCam Electronics and Arduino controller coding is done in Arduino IDE**.**

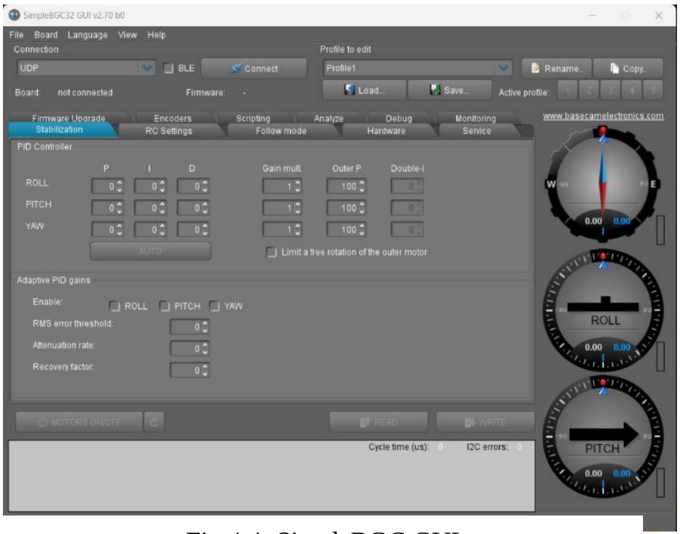

Fig 4.4: SimpleBGC GUI

Fig 4.5: Arduino IDE

4.3 Components Used

4.3.1 Arduino Uno

The Arduino Uno is a popular microcontroller board that is part of the Arduino family. It is widely used by hobbyists, students, and professionals for a variety of projects. The Uno is based on the ATmega328P microcontroller and offers a simple and user-friendly platform for prototyping and experimenting with electronics. It features a set of digital and analog input/output pins, allowing users to connect and control various sensors, actuators, and other components. The Uno can be programmed using the Arduino IDE (Integrated Development Environment), which offers a simplified programming language based on C/C++. It can be powered via USB or an external power supply, making it versatile and portable. The board also includes built-in LEDs and a reset button for easy debugging and programming. Overall, the Arduino Uno is an excellent choice for beginners and experienced users alike, providing a solid foundation for exploring the world of electronics and programming.

Fig 4.6: Arduino Uno

Specifications:

- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Operating Voltage: 5V
- Input Voltage: 7-12V
- I/O Pins: 14 (of which 6 provide PWM output)
- Analog Input Pins: 6
- DC Current per I/O Pin: 20 mA
- Flash Memory: 32 KB (ATmega328P, 0.5 KB used by bootloader)
- SRAM: 2 KB (ATmega328P)

- EEPROM: 1 KB (ATmega328P)
- Clock Speed: 16 MHz
- Reset Button Dimensions: 68.6mm x 53.4mm
- Weight: 25g

4.3.2 Simple BGC (Gimbal Controller)

Simple BGC, also known as the Simple Brushless Gimbal Controller, is a popular and versatile controller designed for stabilizing camera gimbals. It is widely used in the field of aerial photography, cinematography, and other applications that require smooth and steady camera movements.

The Simple BGC controller utilizes advanced algorithms and sensor inputs to precisely control the movements of the gimbal. It supports various brushless motors and can stabilize cameras of different sizes and weights. The controller can be easily configured and customized through a user-friendly software interface, allowing users to adjust parameters such as motor power, PID settings, and stabilization modes.

Fig 4.7: Simple BGC

The Simple BGC controller offers a range of features, including:

- Three-axis stabilization: It supports stabilization along three axes (pan, tilt, and roll) to provide smooth and stable camera movements.
- Sensor integration: It incorporates gyroscopes, accelerometers, and magnetometers to accurately detect and compensate for camera movements.
- Multiple control modes: It offers different control modes, such as follow mode, locked mode, and joystick control, to cater to various shooting scenarios.
- Power management: It has built-in voltage regulators and power distribution circuits to efficiently manage power for the gimbal and connected devices.
- Firmware updates: The controller firmware can be easily updated to benefit from the latest improvements and features.

Overall, the Simple BGC controller provides a reliable and flexible solution for stabilizing camera gimbals, allowing photographers and videographers to capture professional quality footage with ease.

4.3.3 MPU6050 Sensor Module

The MPU6050 is a popular and widely used integrated circuit (IC) that combines a 3-axis gyroscope and a 3-axis accelerometer in a single chip. It is commonly used for motion tracking and orientation sensing applications in various electronic applications. The MPU6050 has a 3-axis gyroscope that measures rotational movements. It can detect changes in angular velocity along the X, Y, and Z axes. The MPU-6050 has a 3-axis gyroscope that measures rotational movements. It can detect changes in angular velocity along the X, Y, and Z axes. The MPU6050 communicates with the microcontroller using the I2C (Inter-Integrated Circuit) protocol. It has a 16-bit register map accessible via the I2C interface, allowing the microcontroller to read sensor data and configure various settings. This is commonly used in applications such as robotics, drones, virtual reality (VR) devices, gaming controllers, motion tracking systems, etc... which require motion sensing applications. It provides accurate and reliable motion data, making it a popular choice.

Fig 4.8: MPU6050 Sensor

4.3.4 Gimbal Motor

A gimbal motor is a type of electric motor commonly used in stabilization systems, such as camera gimbals or drone gimbals. It plays a crucial role in maintaining stability and smooth movement by counteracting external forces and vibrations. The gimbal motor is designed to provide precise control and rapid response to changes in movement, ensuring that the camera or payload remains steady and level.

Fig 4.9: Gimbal Motor

Specifications of a typical gimbal motor include:

- Motor Type: Brushless DC (BLDC) motor.
- Motor Size: Compact and lightweight for easy integration into gimbal systems.
- Power Rating: Typically ranges from a few watts to several hundred watts.
- Speed: High rotational speed capability for quick adjustments and smooth tracking.
- Torque: Sufficient torque to support the weight of the payload and counteract external forces.
- Control: Compatible with electronic speed controllers (ESCs) for precise control and stabilization.
- Efficiency: High efficiency to maximize battery life and minimize power consumption.
- Noise Level: Low noise operation for optimal audio recording or filming.
- Durability: Designed for reliable and long-lasting performance under demanding conditions.
- Compatibility: Can be used with various gimbal systems, including handheld gimbals, aerial gimbals, or mobile phone gimbals. These specifications may vary depending on the specific application and requirements of the gimbal system.

4.3.5 DC Gear Motor

A DC gear motor is an electromechanical device that combines a DC motor and a gearbox to provide high torque output at low rotational speeds. It is widely used in various applications, including robotics, automation systems, electric vehicles, and industrial machinery.

DC gear motors consist of a DC motor and a set of gears that help in reducing the motor’s speed and increasing the torque output. The motor converts electrical energy into mechanical energy, and the gears transmit this energy to the output shaft, resulting in a precise and controlled movement.

Fig 4.10: DC Gear Motor

Here are some key specifications of a DC gear motor:

- Voltage: DC gear motors operate on a specific voltage range, typically between 6V and 24V, although higher voltage variants are also available.
- Speed: The rotational speed of a DC gear motor is determined by its gear ratio, which is the ratio of the number of teeth on the input and output gears. Gear motors offer a wide range of speed options, from high-speed models to low-speed models for applications requiring high torque.
- Torque: DC gear motors are known for their high torque output. Torque is the rotational force produced by the motor, and it is directly proportional to the current flowing through the motor.
- Size and Mounting: DC gear motors come in various sizes and mounting options to fit different application requirements. They can be compact and lightweight or larger and heavier, depending on the torque and speed needed.
- Efficiency: DC gear motors have a certain level of efficiency, which indicates how effectively they convert electrical energy into mechanical energy. Higher-efficiency motors are preferred for applications that require less power consumption.
- Control Options: Some DC gear motors offer additional control options, such as encoders or position sensors, to provide precise positioning and feedback.

Overall, DC gear motors are versatile devices that offer high torque output, controlled speed, and reliable performance, making them suitable for a wide range of applications.

4.3.6 Servo Motor

A servo motor is a type of rotary actuator that provides precise control over angular position, velocity, and acceleration. It is commonly used in various applications that require accurate and efficient motion control, such as robotics, industrial machinery, and automation systems.

Fig 4.11: Servo Motor

Specifications of a typical servo motor:

- Torque: Servo motors are available in different torque ratings, which indicate their rotational force output. The torque is usually specified in Newton meters (Nm) or ounce inches (oz-in).
- Speed: The speed of a servo motor refers to the rate at which it can rotate. It is typically measured in rotations per minute (RPM) or degrees per second (°/s).
- Voltage Rating: Servo motors operate within a specific voltage range, and their performance can vary based on the applied voltage. Common voltage ratings include 12V, 24V, or 48V.

- Control Signal: Servo motors are controlled by a control signal, typically a pulse-width modulation (PWM) signal. The control signal determines the desired position or speed of the motor.
- Feedback Mechanism: Servo motors usually incorporate a feedback mechanism, such as an encoder or a potentiometer, to provide accurate positional feedback to the control system.
- Size and Weight: Servo motors come in various sizes and weights, allowing for flexibility in different applications. Smaller servo motors are suitable for compact systems, while larger ones provide higher torque outputs.
- Construction: Servo motors are typically built with high-quality components to ensure reliability and durability. They often feature brushless designs for reduced maintenance requirements.
- Operating Temperature: Servo motors have specific operating temperature ranges, and their performance may be affected if operated outside these limits. It is important to consider the environmental conditions in which the motor will be used.
- Mounting Options: Servo motors offer different mounting options, such as flange mounting or base mounting, to facilitate their integration into various systems.
- Communication Interfaces: Some servo motors support communication interfaces, such as Ethernet or Modbus, allowing for advanced control and integration with other devices or systems.

4.3.7 HC05 Bluetooth Module

The HC05 is a popular Bluetooth module commonly used for wireless communication in various electronic applications. The HC05 module is designed to establish a wireless Bluetooth connection between devices. It uses the Bluetooth protocol to enable communication over short distances, typically up to 10 meters (or around 30 feet). The HC05 module interfaces with other devices using a serial communication protocol known as UART (Universal Asynchronous Receiver-Transmitter). It supports both the UART data transmission (TX and RX) and control signals.

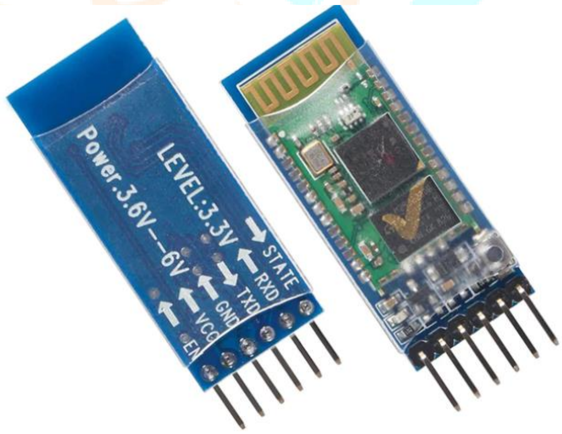

Fig 4.12: HC05 Bluetooth Module

The HC-05 module can operate in two modes: Master and Slave:

- In slave mode, the HC-05 module can connect to a master device (such as a smartphone or computer) that initiates the Bluetooth connection. It is often used for applications where the module needs to receive data from a master device.
- In master mode, the HC-05 module can initiate the Bluetooth connection and connect to other Bluetooth devices configured in slave mode. This mode is useful when you want the module to actively establish connections with other devices.

4.3.8 L298N Motor Driver

The L298N is a popular motor driver integrated circuit (IC) that can control and drive DC motors or stepper motors. The L298N motor driver IC can control two DC motors or one bipolar stepper motor. It provides bidirectional control, which means it can make the motors rotate in both forward and reverse directions. The L298N IC utilizes an H-bridge configuration to control the motor direction and speed. An H-bridge is a circuit arrangement that allows current to flow in either direction through the motor, enabling control over its rotation. The L298N IC utilizes an H-bridge configuration to control the motor direction and speed. An H-bridge is a circuit arrangement that allows current to flow in either direction through the motor, enabling control over its rotation.

The L298N allows speed control of the motors through pulse width modulation (PWM) signals. By varying the duty cycle of the PWM signal applied to the control pins, you can adjust the motor speed. The L298N has built-in current sensing functionality, which allows you to monitor the current being drawn by the motors. This feature can be useful for protecting the motors from excessive current or for feedback control in certain applications.

Fig 4.13: L298N Motor Driver

V. RESULTS & DISCUSSIONS

A scaled model of the bicycle was designed and 3D printed based on size requirements and a series of calculations. Assembling and fabrication of various components required for self-balancing as well as electric-powered movement were done successfully. Connections were soldered and placed at proper orientation and thus reducing the chances of error. The fully assembled model is shown below:

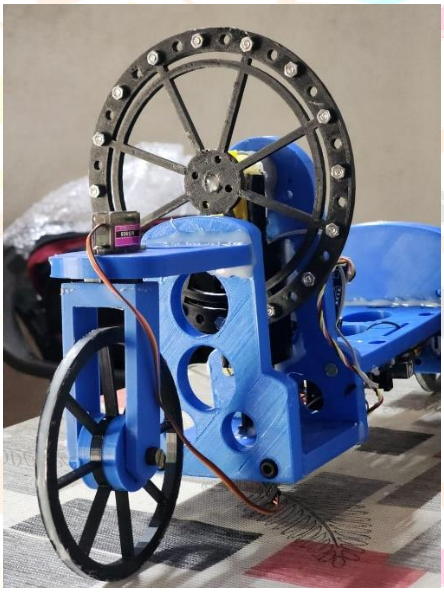

Fig 5.1: Front View

For electrically powered movement, we used a dc gear motor, servo motor, L298N motor driver, Arduino Uno, HC05 Bluetooth module, and a Bluetooth controller mobile application. A servo motor is connected to the front wheel for controlling the direction of movement. A gear motor is connected to the rear wheel for the control of movement. An HC05 Bluetooth module is used to establish the connection between the mobile application and the scooter and hence the movement is controlled by the user commands.

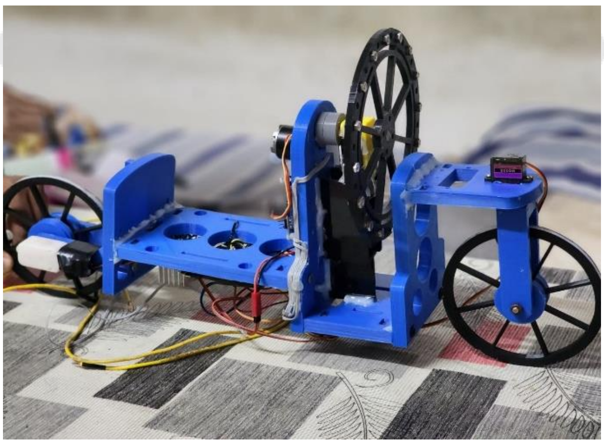

Fig 5.2: Side View

For balancing the model, an MPU6050 3-axis gyroscope and 3-axis accelerometer, a gimbal motor, a Simple BGC (gimbal controller), and a 3D-printed flywheel are used.

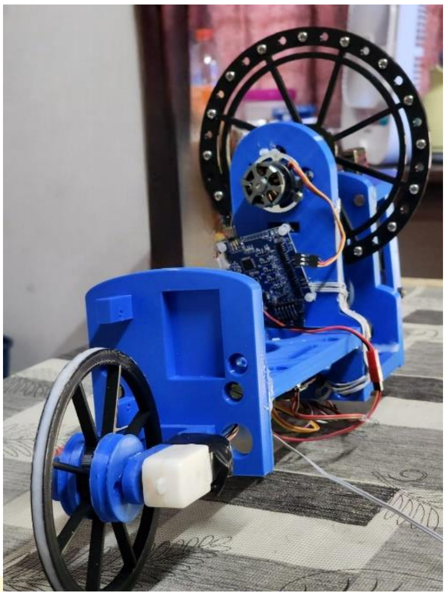

Fig 5.3: Back View

The gyroscope measures the tilt angle and provides information to the controller. The controller performs the torque calculation using the preprogrammed instructions by BGC firmware. Thereby providing information such as the direction in which the gimbal motor is to be rotated, how much speed it should possess, and how much power to be induced.

VI. CONCLUSION

In conclusion, we have successfully designed, simulated, and programmed a self-balancing electric scooter by incorporating various components and technologies. The key element in maintaining balance is the MPU6050 sensor, which evaluates the terrain and provides essential data for the system. By utilizing a triple-axis accelerometer and gyro, we can accurately calculate angular velocities and accelerations, enabling the scooter to maintain stability.

The use of the Gimbal controller provides efficient management of the balancing system and enhances the overall functionality. The gyroscope and accelerometer sensors work in tandem to provide an approximate value for the tilt angle of the scooter, ensuring precise balance control.

The use of Arduino provided a better performance for the movement of the model and thereby improve system mobility.

In the mechanical aspect, we successfully assembled a flywheel on the chassis, with the Gimbal controller which controls the motion through the gimbal motor. This integration allows for precise control of the scooter's speed and stability.

Furthermore, in the electrical part, we completed the necessary circuit diagram for our system, ensuring seamless integration and reliable performance. Through testing with a mini model, we gained valuable insights into the self-balancing principles and how to effectively control motor speed.

All the knowledge and experience gained from the initial project phase served as a solid foundation for the implementation of self-balancing in the 3D printed model. This holistic approach, combining design, simulation, programming, and testing, has resulted in a functional and efficient self-balancing electric scooter.

Overall, our project demonstrates the successful integration of sensor technology, Arduino programming, mechanical assembly, and electrical circuitry to create a self-balancing electric scooter that provides stability, control, and an enjoyable riding experience.

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