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Self-balancing of a Two wheeler using Gyroscopic effect

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ABSTRACT

In this day and age automation has become more of a necessity than a luxury. Today despite of having a number of preventive safety measures to avoid road accident by two wheelers according to the surveys two-wheeler lead in the number of road accidents. The need for a self-stabilizing system for two wheelers is on high demand among the customers. This paper determines a method to develop a self-balancing bike using gyroscopic effect. Gyroscopic effects find its application in stabilizing systems for sectors like Military's rocket guidance systems, aeronautics and aerospace industries, ships etc. We have incorporated this principle in our two-wheeler model. In our current model we have used Inertial Measurement Unit(IMU), Encoder and servo motors, Momentum wheel to generate a counter torque to balance the roll in the two wheeler. The 3D model was designed using CAD modelling software and code was generated in the Arduino software. Designing and fabrication of the two-wheeler was completed and was tested for different tilt angle subjected to varying rotational speed of momentum wheel to counter balance and stabilize itself.

***Keywords**: Self-Balancing, Gyroscope, Gyroscopic Effect, Inertial Measurement Unit*

1. INTRODUCTION

A bike is one of the most common mode of transportation, since the world is focused to urbanization, the cities are going to be much more congested, hence bike being a sole best option for driving in such condition. The world is changing its priorities on the type of fuel they need for their vehicles, and with companies such as Tesla, promising an efficient and affordable electric cars by 2030, it seem that oil is going to be redundant in a few years. This is also application for the two wheeler industry. People nowadays require automation in everything; they need their lives to be simpler. Hence the self-balancing bike system. A bike which self-balance itself after a certain tilt in its angle without the drivers interference will decrease the amount of motorcycle accidents. This system will provide an additional safety factor which the traditional bike don't provide you. This mechanical system also provides autonomous control to your bike. For example, a person in standing outside a supermarket and he want his/her bike, now they can use their mobile phone to connect with the bike so that the bike can reach its destination, that is the location of the phone. For a system like this to work the bike has to have the ability to self-balance. This is achieved used gyroscopic principles. Gyroscopic effect an external couple which acts on the bike to which provides counter force which helps in balancing the bike.

2. METHODOLOGY

Initially a Mechatronics system design is made to determine the mechanical, electronics and communication devices that will be incorporated in the prototype. The mechatronic system layout helps to correlate different modules of the system which provides the base of the electrical design of the circuit.

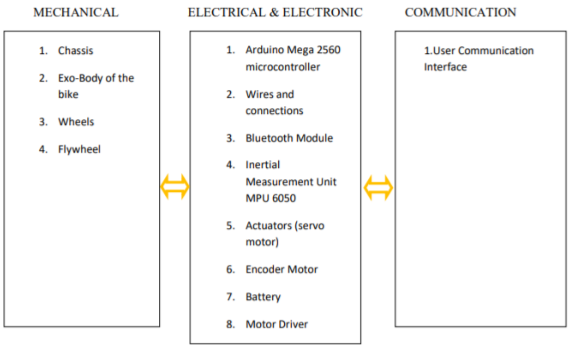

Fig. 1: Mechatronic System Design of a Two-wheeler

After the Mechatronic system design the initial layout with all the components was designed and based on the 2D sketch with proper dimensions different iterations of 3D model using SolidWorks Modelling were made, and the model was then subjected to various static and dynamics loading conditions to analyse its strength. After successful scrutiny and analysing various models the location of Centre of Mass of the final model was determined which will be used to determine the minimum gyroscopic counter torque required to stabilize the two-wheeler. Due to space constraints we tried to design a stacked layer model where components were stacked on different layer. To keep the Centre of Mass as close to ground the battery was stacked at the lowest level, this indirectly will help in providing stability during the cornering of the two-wheeler. The frame of the two wheeler was fabricated by Polyacrylate(PLA) of 1.75mm wire thickness using Fused Deposition Modelling Technique. The momentum wheel was fabricated out of Perspex acrylic sheet of 6mm thickness and 4 nuts were fastened across its periphery at an equal distance. We used servo motor with (0-180 degree rotation) for steering and L-motor was connected to the rear wheel for the forward and backward motion. We used IMU 6050(Inertial Measurement Unit) which incorporates both gyroscope sensor and accelerometer. IMU sensor provides three gyroscopic angles namely Yaw, Pitch and Roll, here roll angle is used to determine the amount of counter torque needed to stabilize the two-wheeler. Lithium polymer batteries are used for the system as it very economical and it also has high energy density as compared to conventional battery packs.[7] A closed feedback loop was developed in which the input from the IMU is processed on the Arduino MEGA 2560 microcontroller and then fed to the motor controller L239D which consist of H bridge transistors which help to provide clockwise and counter-clockwise rotation, then the value is finally fed to encoder motor which in turn rotates the momentum wheel in the opposite direction of the tilt to provide counter torque until the two-wheeler attains the neutral position, then the encoder motor sends the current value of its position and IMU determines the tilt angle and sends it again to MEGA 2560, and this feedback loop continues.

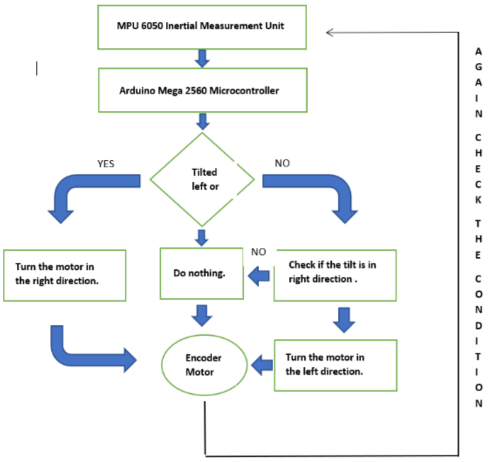

Fig. 2: Feedback loop of the system

Above figure shows the schematic of the closed feedback system loop, which was incorporated in the Mechatronic system design of the two-wheeler. After successfully mounting every component on the chassis of the two-wheeler, the prototype was made to stand still such that the IMU is parallel to the ground, then the calibration code was uploaded in the MEGA 2560 microcontroller and the neutral values of IMU were determined which will be served as the neutral position while calculating the tilt angle for the two-wheeler. After inserting the neutral values the final code was uploaded in the two-wheeler for test trials.

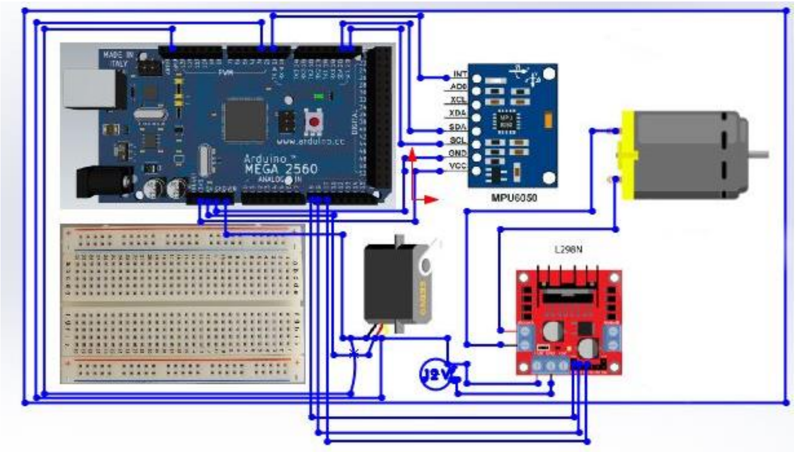

Fig. 3: Electrical Circuit Diagram for the Two-wheeler

Table 1: Battery Specification [4]

1. Battery type	Lithium Polymer Battery Pack (LiPo)
2. Capacity (mAh)	1500
3. Weight (gm)	111
4. Output Voltage (V)	11.1

5. Charge Rate (C)	1-3 C (Recommended)
6. Dimensions (L * B * H)	74 * 34 * 24 mm
7. Maximum Burst Discharge	50 C (10 sec)
8. Maximum Charge Rate	5 C

Table 2: Encoder Motor Specifications [5]

1. Brand and Model	Cytron SPG30E-30K
2. Rated Voltage (V)	12
3. Weight (gm)	170
4. Output Power (Watt)	1.1
5. Rated RPM	150
6. Rated Torque(Kg-cm)	1.3
7. Stall Torque(Kg-cm)	5.2
8. Shaft Type	D-type
9.Shaft Diameter(mm)	6
10.Shaft Length(mm)	15.5
11. Gear Ratio	30:1
12.Gearbox Diameter(mm)	37
13. Gearbox Length(mm)	22
14. Motor Diameter(mm)	32

3.DESIGN CALCULATIONS

Let the mass of the system is = M kg
Distance of the centre of mass from the ground = h

Tilt angle = Θ

The torque induced = $Mgh\sin\Theta$

$\therefore$ Reactive Gyroscopic Torque = $Mgh\sin\Theta$ (opposite direction)

Centre of Mass (CM) from the ground, h = (CMwheel * Mwheel) + (CMchassis * Mchassis) + (CMframe * Mframe) + (CMdisc * Mdisc) + (CMencodermotor * Mencodermotor) + (CMbattery * Mbattery)

CM = Centre of Mass; Mx = Mass of x;

Moment of inertia of the disc,

$$I=m_d r^2/2 \text{ ----}\rightarrow m_d \text{ is the mass of disc}$$

The highest precision speed of the disc is $\omega p= mgh\sin\theta/I\omega$

Highest Required Gyroscopic Torque $\tau' = I\omega\omega p$

ω= angular speed of encoder motor and can be calculated by the formula $\omega = (2*pi*N)/60$ rad/sec

Torque induced at max inclination = mghsin (x) where x is 30 degree

M= mass of total system which is calculated as:

1) Mass of arduino Mega=86 grams

2) Breadboard with IMU =97 grams

3) Servo = 78 grams

4) Rear motor= 70 gram

5) Support structure and wheels= 130 gram

6) Momentum wheel = 32 gram

7) Battery = 140 gram

Total mass (M)=0.633 kg

The centre of mass is at a height of 7 cm from base. The IMU is going to be calibrated as per this values.

Radius of momentum wheel = 0.045m

To counteract the deflection in the centre of mass of the body we need to equalize the centrifugal force produced by the momentum wheel to potential energy reduced by the deflection [1].

$$Mgh\sin(\Theta) = mrw^2$$

M = mass of the bike = 0.633 kg

m = mass of the momentum wheel = 0.032 kg

→0.633*9.81*0.07*sin(30) = 0.032*0.045*w^2 (taking maximum deflection to be 30 degree)

→w = 12.285 rad/sec

→w = 2*pi*N/60

→12.285*60/(2*pi) = N

→N = 118 rpm required (approx.) is required to be produced by the momentum wheel to generate enough force to provide stability at its highest tilt.

Moment of inertia of momentum wheel = I=mr^2/2=3.24*10^-5 kgm^2

Angular speed= (2*pi*118)/60 = 12.285rad/sec

counter torque produced by momentum wheel = I(alpha)=3.24*10^-5 *(12.285/0.142)

= 0.00280 N-m

Where 0.142 is the average time taken for each response of IMU. So the counter torque generated will balance the tipping of the bike.

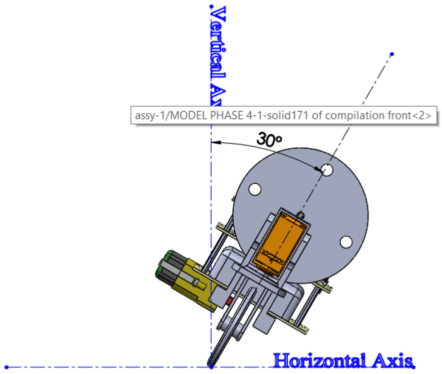

Fig. 4: Maximum Tilt Angle of the Two-wheeler Model without slipping

As the bike tilts in either direction, the new roll angle will be continuously fed to the Arduino where it will do the necessary calculation as per the code and give the motor controller the values for RPM, which can be clockwise or anticlockwise. As the bike return to its stable position, it will oscillate because of its inertia[6]. Since the motors has variable speed control, the inertial force will be counteracted by the motor(due to its closed feedback system), thus returning the bike to its vertical position.

4. CAD MODEL AND MANUFACTURING

As per the max RPM required by the motor to counter the maximum tilt, the motors and motor controller was selected. Various CAD models for the prototype were created for finding out the model with optimum centre of mass. All the placement of the hardware were done keeping in mind to place the centre of mass as near as possible to the vertical axis. Thus the below model 3D model was generated.

Traditional designs of a self-balancing bike involved the momentum wheel to be flat on the horizontal axis. In this design as the wheel is directed towards the vertical axis, it reduces the space required by the mechanical system. This allows us to keep the electronic hardware in optimum position so as to maintain the centre of mass and well as reduce the chassis weight.

The momentum wheel was 3D printed using PLA and bolts were attached to the 4 diametrically opposite corners of the disc. This was done to reduce cost, as laser cutting a small flywheel turned out to be very expensive as compared to the 3D printed model. Printed circuit boards(PCB) were used to provide based for the installation of the Arduino, motor controller, motor's and the sensors. The servo motor in the front can be used to provide steering control, if an Bluetooth module were used, wherein we can control the steering system using a smartphone.

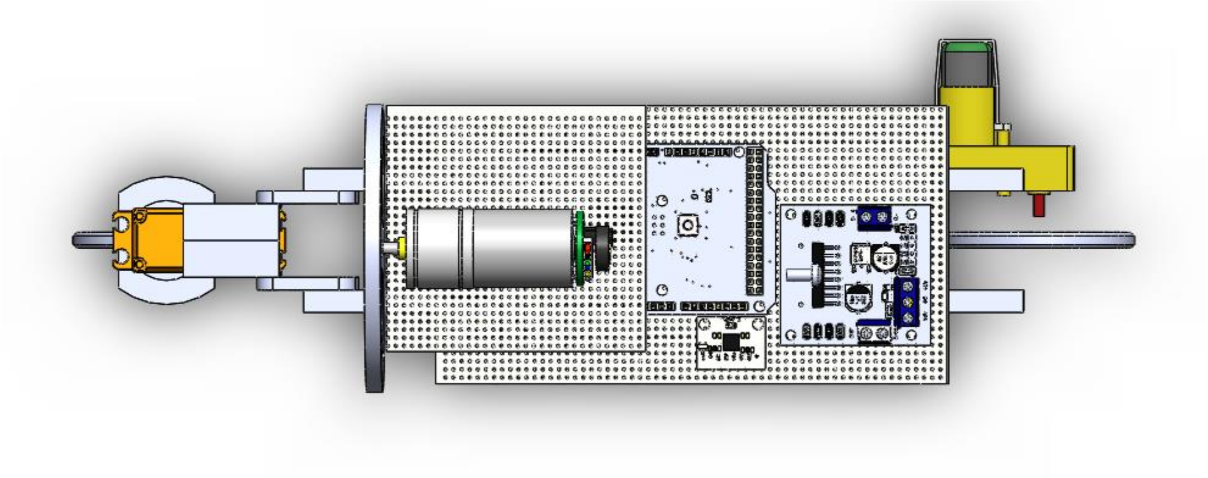

Fig. 5: Top view of the Two wheeler Model

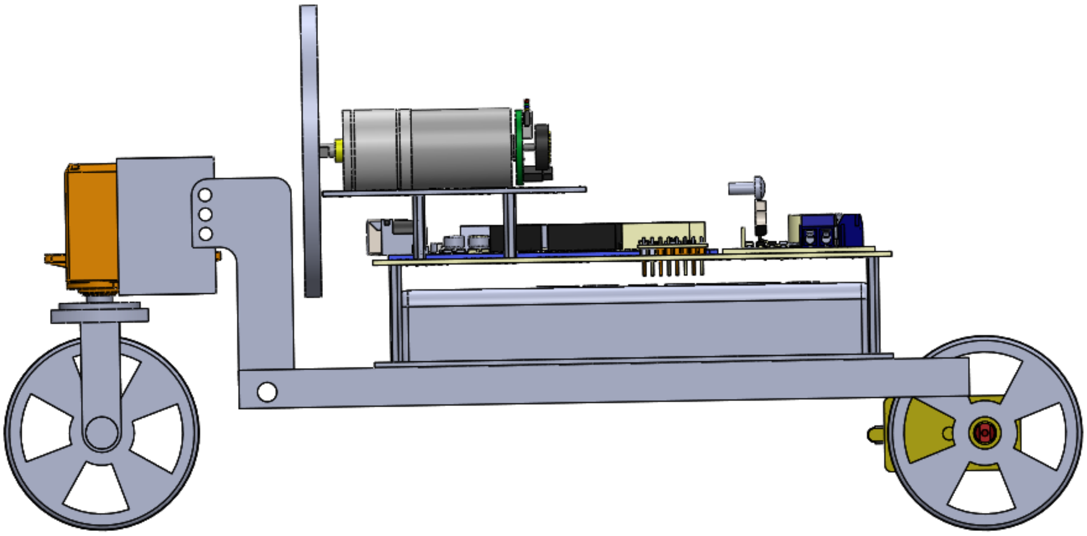

Fig. 6: Side view of the Two wheeler Model

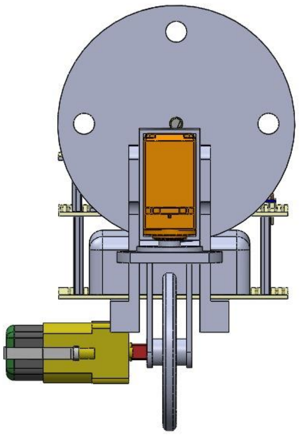

Fig. 7: Front view of the Two wheeler Model

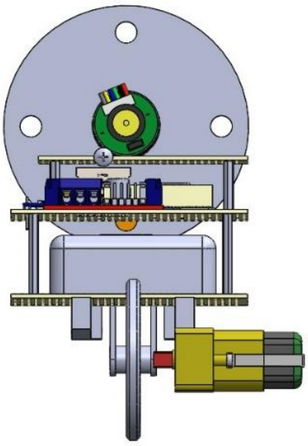

Fig. 8: Rear view of the Two wheeler Model

5. CONCLUSION

A successful self-balancing two wheeler bike using gyroscopic effect was developed. The prototype model was able to self-balance at an maximum of 118 rpm and counter toque 0.28 N-cm for the maximum tilt of 30 degree along the vertical axis.

Throughout the course of the project the main idea was to minimise space occupied and weight of the complete assembly and to attain Centre of Gravity as close to ground as possible, the use of vertical momentum flywheel and stacking components on a layered structure helped to reduce the size of the two-wheeler model. Experimental and theoretical values of torque and required rotational speed were observed and studied, and it was inferred that experimental value had minimum deviation from the later. The system is further integrated with the wireless user communication interface which will provide user the ability to control the bike remotely. Overall the method used to provide self-balancing action to the Two-wheeler provided plausible results.

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