Design and Fabrication of Self Balancing Two Wheeler by Gyroscopic Stabilization

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Abstract- **Stabilization of a two wheeled vehicle plays a vital role in today's cluttered roads and congested transportation systems. Gyroscopically stabilized vehicles will provide greater safety than normal two wheelers, thereby leading to lesser number of casualties from road accidents.**

There are two ways by which a two wheeled vehicle can be stabilized: dynamic stabilization and control motor gyroscope (CMG). This paper describes the working of the CMG technique in which the reactive precession torque of a high speed flywheel will act to balance the vehicle while keeping the rpm of the flywheel constant. In other words, when torque is applied to an axis normal to the spin axis, causing the gyroscope to precess, a moment is produced about a third axis, orthogonal to both the torque and spin axis. The resulting opposing reactive moment causes the stabilization of the vehicle.

A prototype with self-balancing mechanism has been modelled, fabricated and tested for the same. This paper proposes the mechanism to control and stabilize a two-wheeled prototype at zero forward velocity. The prototype has employed a single degree of freedom flywheel along with two types of motors- one to generate high rpm and the other to precess the axis of rotation.

Index Terms- stabilisation, gyroscope, precession moment, self-balancing, zero forward velocity, reactive moment, self-balancing vehicle, control motor gyroscope, safety.

I. INTRODUCTION

A gyroscope is a mechanical device consisting of a wheel or disc mounted so that it can spin rapidly about an axis. This axis is free to alter in direction. The orientation of the axis is not affected by tilting of the mounting. The very basic principle employed in the working of this project is that the rotor keeps swivelling. The rotation of the axis is what is known as precession.

Gyroscopic principle states that rigidity is the ability of a freely rotating mass to maintain its plane of spin when any external force is applied to it. The laws of gyroscope state that:

- First Law of Gyroscope: If a rotating wheel is so maintained as to be free to move about any axis passing through its centre of mass, its spin axis will remain fixed in space.
- Second Law of Gyroscope: When a torque acts on a spinning mass with an axis perpendicular to that of spin, then the latter will process about an axis perpendicular to both aforementioned axes.

Stabilization of unmanned vehicles is done by either stabilizing by steering or by stabilizing by an external apparatus. While the former technique is more studied, it has a major drawback; the body is stabilized only at high speed. Stabilization by an external apparatus is carried out here with the help of a control moment gyroscope. A CMG is a device which controls behaviour. A CMG consists of a rotor spinning at a high but constant velocity and a motorized gimbal that tilts the rotor's angular momentum. The most effective CMGs employ the motion of a single gimbal, i.e., precession of a single axis. When the gimbal rotates, the change in direction of the rotor's angular momentum represents a torque that reacts onto the body on which the CMG is mounted. This torque requires no energy because the motion is not due to a force but is due to a constraint. Hence they require very little power and hence give a greater output as compared to the electrical input

II. SYSTEM HARDWARE

Three elements comprise the system plant: the bicycle, a control gyroscope mounted in a single-axis gimbal frame, and a servomotor. The servomotor shaft is attached to the gimbal axis of the control gyroscope. Spin axis of the control gyro is vertical;

gimbal axis and the gyro spin axis are orthogonal. The gimbal frame of the gyro is attached to the bicycle frame so that when the bicycle is upright, the line connecting the earth contact points is perpendicular to both the gimbal axis and the gyro spin axis. When commanded by the controller, the DC servomotor torques the gyro about the gimbal axis, creating a precession torque. The precession torque of the gyro is exerted on the bicycle frame. When properly controlled, the precession torque should turn the bicycle towards the upright position. Following are the various components:

Brushless DC Motor

Brushless motors are more efficient as its velocity is determined by the frequency at which current is supplied, not the voltage. As brushes are absent, the mechanical energy loss due to friction is less which enhanced efficiency. BLDC motor can operate at high-speed under any condition. There is no sparking and much less noise during operation. More electromagnets could be used on the stator for more precise control. BLDC motors accelerate and decelerate easily as they are having low rotor inertia.

Servo Motor

Continuous rotation servo motor is quite related to the common positional rotation servo motor, but it can go in any direction indefinitely. The control signal, rather than set the static position of the servo, is understood as the speed and direction of rotation. The range of potential commands sources the servo to rotate clockwise or anticlockwise as preferred, at changing speed, depending on the command signal. This type of motor is used in a radar dish if you are riding one on a robot or you can use one as a drive motor on a mobile robot. Hence, we have chosen the continuous rotation servo motor.

Arduino Uno

The precession angle had to be an output of the body tilt angle. A sensor was therefore needed to be mounted on the frame for the required input tilt angle. Magnetic sensors for contactless angular position measurement and/or multidimensional magnetic field sensing are widely used in automation, robotics, mechatronics, industrial controls, navigation etc. as they are cheap and reliable. Due to the very small number of ring periphery contacts (8 only) and the five-contact parallel-field Hall sensor used, the magnetic sensitivity of such magnetometer is relatively low. It is about 30% lower compared to five-contact Hall transducers and about 40% less than the MPU6050. This was required since the vibrations set up in the body due to the rotation on the flywheel adversely affects sensors with high sensitivity.

MPU 6050

The MPU 6050 is a 6 degrees of freedom or a six-axis sensor, which means that it gives six values as output: three values from the accelerometer and three from the gyroscope. The MPU 6050 is a sensor based on MEMS (micro electro mechanical systems) technology.

Electronic Speed Controller

An electronic speed control or ESC is an electronic circuit with the purpose to vary a servo-motor's speed, its direction and possibly also to act as a dynamic brake. ESCs are often used on motors essentially providing an electronically-generated three-phase electric power low voltage source of energy for the motor.

Frame

The frame was modelled first on SOLIDWORKS. The precise material properties were assigned and the centre of gravity was obtained at every stage of assembly. The parts were so designed as to balance the model perfectly laterally.

Fig.1: Isometric View of Frame

III. SYSTEM SOFTWARE

The various pins on the Arduino were connected to the corresponding pins on HMC5883L and the BLDC to form a seamless circuit as illustrated

Pins on Arduino	Connected to
A5	SCL
A4	SDA
3.3V	VCC
Pin 9	Servo 1
Pin 10	Servo 2
Pin 12	ESC signal
GND	GND Servo
GND	GND MPU6050

Table.1: Connections of Arduino to Servomotor and BLDC

The various codes for the servomotor and brushless DC motor (via ESC) were combined into a single functioning code. The range of the servo motor was set according to required gimbal axis precession. Connect the Arduino to the PC. Open Arduino IDE. A combined code powers the servo motor and the BLDC. (Refer to appendix for code) Under 'Tools' select Board: Arduino/Genuino UNO and Port: COM14 (In our case.) Click Upload button on the upper left corner. Click the reset button on the Arduino board and then power it by the laptop.

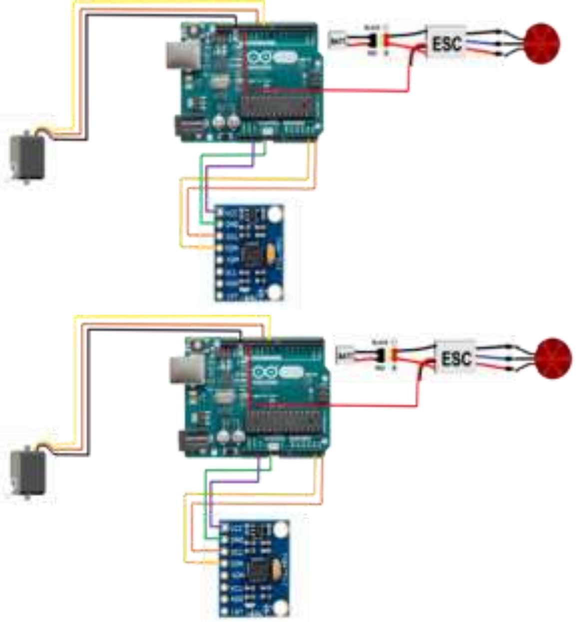

Fig.2: Complete Circuit Diagram

IV. CALCULATIONS

Assumptions:

Impact force on body = 1N
Moment of inertia of the system = 0.02592 kgm2
Average bumper size = 0.08 m

Calculations:

The angular momentum acting on disc is given by:

$$L = I\mathrm{w}$$

Torque acting on the disc:-

$$T = F \times r$$

$$T = \frac{d\vec{L}}{dt}$$

The angular velocity of the disc about the pivot point P is given by:

$$\Omega = \frac{\mathrm{d}\theta}{\mathrm{dt}}$$

$$= \frac{1}{L} \times T$$

$$= \frac{1}{L} \times r \times F$$

Therefore,

$$\frac{d\theta}{dt} = \frac{1}{L} \times r \times F$$

$$\frac{d\theta}{dt} = \frac{1}{mr^2w} \times r \times F$$

$$\boldsymbol{\frac{d\theta}{dt} = \frac{1}{mrw} \times F}$$

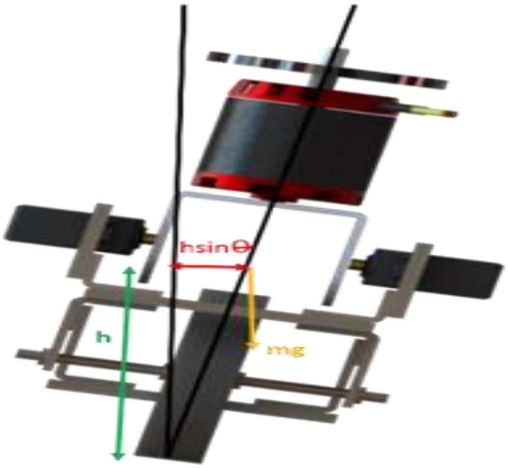

Fig.3: Position of CG and tilt angle

S.no.	Precession angle	Tilt distance (m)
1	5	0.007
2	10	0.014
3	15	0.02
4	20	0.027
5	25	0.034

Table.2: Precession angle and tilt distance readings

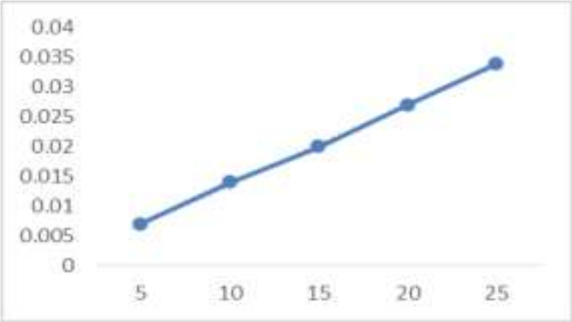

Fig.4: Precession angle and Tilt distance relationship

The graph above shows the relation between Precession angle and Tilt distance of the gyroscope. Here, if we vary the angle of precession axis, the distance of the precession axis from the normal varies accordingly. So, we can see that with increase in precession angle, the tilt distance also increases accordingly.

Now,

Radius of disc = 0.035m

Restoring torque = T

T=I×α

T=F×r

Moment of Inertia = I = m×r^2

For finalization of disc radius, angular momentum and moment of inertia were computed by calculations as follows:

S.no.	Radius	Moment of inertia	Angular momentum
1	0.01	0.0001	0.01884
2	0.015	0.000225	0.04239
3	0.02	0.0004	0.07536
4	0.025	0.000625	0.11775
5	0.03	0.0009	0.16956
6	0.035	0.001225	0.23079
7	0.04	0.0016	0.30144
8	0.045	0.002025	0.38151
9	0.05	0.0025	0.471

Table 3. Radius, Moment of inertia and Angular momentum readings

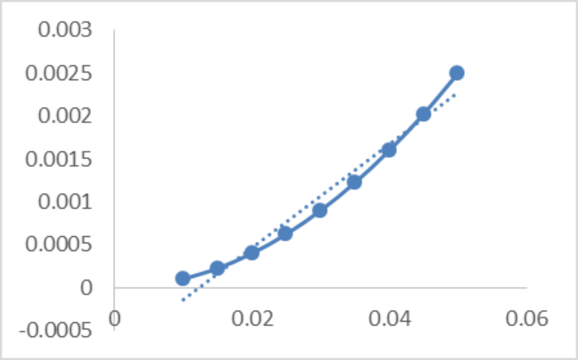

Fig 5: Moment of Inertia and radius relationship

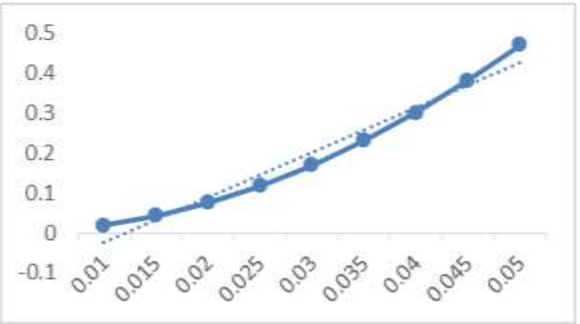

Fig 6: Angular momentum and radius relationship

Graph 1 gives us the clear idea that when we try to increase the radius of the gyro disc, the Moment of Inertia (MI) produced by the gyroscope increases. So, we can say that with varying radius of the gyro disc, the moment of inertia (MI) varies accordingly.

Graph 2 shows the relation between the radius of the gyro disc and the Angular Momentum produced by the gyroscope. Here, we can see that when we try to increase the radius of the gyro disc, the angular momentum also increases in response to the varying radius and vice versa which means that radius is a varying factor to obtain varying Angular Momentum values for the gyroscope.

Finalising the radius as 0.035m, we get:

$$I = 1 \times 0.035^2$$

$I = 12.25 \times 10^{-3}$ kgm^2

Force applies by disc for balancing of wheel:

F = I/r = 3.43 N

Angular velocity of disc (according to motor specifications):

w = 188.4 rad/s

Angular momentum = $L = Iw$ = 0.2308 kgm2/s

Angular velocity (about point P) = $\Omega = \frac{1}{L} \times r \times F =$ 0.52 rad/s

Angular acceleration = α = T / I = 3.086 rad/s2

Time for reaction to occur = t = 0.1413 s

Relationship between angles of tilt of vehicle to time of precession of gimbal axis is obtained as below:

S.no.	Angle (in degrees)	Time (in seconds)
1	1	0.001123
2	2	0.002247
3	4	0.004494
4	5	0.005617
5	6	0.006741
6	8	0.008987
7	10	0.01123
8	12	0.013481
9	14	0.01572
10	15	0.01685

Table 4: Angle-time calculations

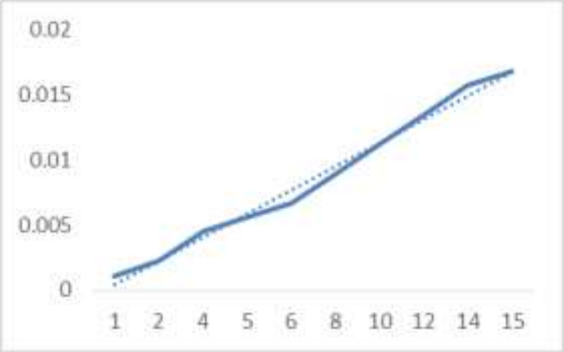

Fig 7. Angle-time relationship

Lean angle sensor output

A small gyroscope is used to measure the leaning angle of the body. An optical encoder inside the gyro housing senses the lean angle, and the sensor gain is Ks = 5 counts per degree. The encoder has finite resolution, however, so the sensing resolution is limited. Therefore, the lean angle sensor can determine the true position of the bicycle angle within one-fifth of a degree. Where, the fix () function rounds its argument to the nearest integer toward zero. In most control systems, small sensor quantization may be insignificant. Such is not the case for our system, where finite resolution greatly impacts the system behaviour. Under closed loop control, the body will move towards an upright position until it is within one-fifth degree of the vertical plane. At this point, the sensor indicates that the body is upright, generating a zero output. The controller output will become zero, but since the bicycle is not yet perfectly vertical, a greater leaning motion will result. In theory, the lean angle settles about some nonzero displacement.

VI. CONCLUSION

The balancing of a two wheeled in-line vehicle makes it safer and much more reliable. Safety is one of our top priorities with this project. The most important safety feature is our gyro stability system. This will keep the vehicle upright on its own without the external efforts of the driver, preventing the vehicle from rolling. It will also be more comfortable than any other two wheeled unbalanced vehicle while at the same time will require a very small space of parking. The thesis emphasized on the self-stabilization technology. From the thesis project some certain observation are provided:

- The force experienced due to the tilt of rotating wheels depends on the RPM of the wheel, the weight of the wheels and the angle of tilt.
- The higher the RPM, the bigger the counterforce. That means the counterforce is much larger when the RPM of the hub motor is larger.
- The direction of rotating wheel tilt determines the force direction of when spinning is in a particular direction.
- Weight attached to hub motor helps to stabilize the balancing.
- The more the tilt angle, more the force is needed to stabilize the chassis.

REFERENCES

[1] Ching-Chih Tsai, Hsu-Chih Huang and Shui-Chun Lin, “AdaptiveNeural Network Control of a Self-Balancing Two-Wheeled Scooter,” IEEE transactions on industrial electronics, vol. 57, no. 4, April 2010

[2] Pierpaolo De Filippi, Mara Tanelli, Matteo Corno, Sergio M. Savaresi, and Mario D. Santucci. “Electronic Stability Control for Powered Two-Wheelers”, IEEE transactions on control systems technology, vol. 22, no. 1, january 2014.

[3] Karthik, Ashraf, Asif Mustafa Baig And Akshay Rao, “Self Balancing Personal Transpoter” 4th Student Conference on Research and Development, pp. 180-183, June.2006.

[4] Miseon Han, KyungHwan Kim, DoYoun Kim and Jaesung Lee, “Implementation of Unicycle Segway Using Unscented Kalman Filter in LQR control”, 2013 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), October 31-November 2, 2013 / Ramada Plaza Jeju Hotel, Jeju, Korea.

[5] Osama Jamil, Mohsin Jamil, Yasar Ayaz, Khubab Ahmad, “Modeling, Control of a Two-Wheeled Self-Balancing Robot”, 2014 International Conference on Robotics and Emerging Allied Technologies in Engineering (iCREATE), Islamabad, Pakistan, April 22-24, 2014

[6] Pawel Bethke,Rafal Dlugosz and Tomasz Talaska, “ Project and realization of a two wheels balancing vehicle”, 20th International

Conference "Mixed Design of Integrated Circuits and Systems", June 20-22, 2013, Gdynia, Poland.

[7] M. A. Johnson, and M. H. Moradi, “PID Control: New Identification and Design Methods”. Springer, 2005.