INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 6.078
(Volume 6, Issue 3)
Available online at: www.ijariit.com

Design and analysis of single wheel hover-board

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ABSTRACT

The 'Single Wheel Hover-board' is a personal electric vehicle running on a single wheel. The vehicle is powered by a battery source. The motor (DC 24V, 250W, High Torque) is in skew with the shaft of the wheel with the help of a chain drive, whose speed will be controlled by a custom designed 'Speed control' circuit, capable for currents about 50A. The control of the motor direction is the posture of the persons driving it. Intelligent sensors like IMU, which houses accelerometer and gyroscope is used to monitor the posture of the person and accordingly the processor signals the speed controller circuit. Additional features for the Hover-board includes the regenerative braking, inbuilt battery charging capability, battery level indicator.

Keywords— *Hover-board, Chopper drive, Electric Vehicle, PID controller*

1. INTRODUCTION

With the alarming rate of depreciation of fossil fuel level and the increasing carbon footprint per person, the advent to more sustainable means of transportation is crucial for the longevity of the present resources. The world has two important reasons to switch our transportation options for the sake of longevity of the world we know.

The first reason has apparently surfaced up recently after a long time. According to a Morgan Stanley report, the efficiency of a General Electric gas turbine at a thermal electric power plant achieves ~66% efficiency. On the other hand, Internal Combustion engine on an average (2 stroke and 4 stroke) scores about 27% efficiency. With same source fuel, the data collected from them is a stark contrast. The reason is Combustion engine operates in fixed constraint boundary, ranging from weight, cylinder arrangement etc. Whereas, a power plant can be afforded to have additional components, like secondary generator that makes use of the flue steam, and thus adds up to the efficiency.

The second reason is increasing dependency on fossil fuels. The use of IC engine-based vehicles for short distance commute harms the efficiency the engine. It also contributes to the carbon footprint of the commuter.

The "Single Wheel Hover-board" is a personal electric vehicle, suited for casual and short commutation. It's a vehicle that balances on a single wheel, and operates according to the direction of inclination of the driver (forward and backward).

2. LITERATURE SURVEY

The project required survey and learning exposure to some related projects. The following projects were referred.

(a) Two-Wheeled Balancing Robot Controller Designed Using PID: In this paper, the use of PID Controller with IMU Sensor for an elevated wheeled-platform was justified. The paper deals with counteracting with effect of gravity on the platform. The PID Controller was deployed to sense the inclination of the platform against the ground level, and compute control variables for counteract the fall with providing sufficient counter-torque, so that the platform stays parallel with respect to ground.

(b) Speed Control of D.C. Motor Using Chopper: The use of chopper drive was observed in the paper. The performance of the four-quadrant chopper drive is observed, which concludes the effectiveness of the driver for closed loop operation. The operations motoring and braking anointed in the paper increases the likelihood of the deployment of the Four-Quadrant-Chopper drive for the overall drive purpose of the DC Motor.

(c) Design and Development of a Prototype Super-Capacitor Powered Electric Bicycle: The use of PMDC motor for traction purpose, instead of the traditional BLDC motor is justified in this paper. The paper deals of equipping a bicycle with a PMDC Motor and Super-Capacitors for long-distance commute. The motor driver exhibits regenerative braking, which is a significant feature of our project.

(d) Self-Balancing Scooter: This final year project is important from the standpoint of our project. The project gives a clear picture of the physics, coding and electronics required to make a self-balancing Macro-entity. The project deals with the use of higher traction DC motors, critical operation of the motor driver and its safety, and complexity of the coding to implement self-balancing operation.

3. PROPOSED DESIGN

The block diagram below represents the components and function flow between each of them.

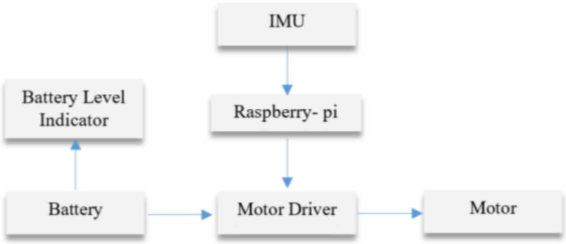

Fig. 1: Functional Block Diagram

The description of the components is as follows:

3.1 Motor

The motor used is a PMDC motor, which offers a good speed-torque characteristic and costing low. The specifications of the motor are as follow:

Table 1: Motor Specifications

Rated Power	250W
Rated Voltage	24V DC
Rated Speed	2650 RPM
No Load Speed	3000 RPM
Full Load Current	≤13.7A
Rated Torque	0.80 N.m (80 Kg.cm)
Stall Torque	0.50 N.m (50 Kg.cm)
No load current	≤2.2A
Efficiency	≥78%

3.2 Motor Driver

The motor driver is a four-quadrant chopper. This enables the board to perform forward motoring and regenerative modes, and reverse motoring and regenerative modes.

Features:

- Bi-directional control for 1 brushed DC motor.
- Motor Voltage: 5V - 30V.
- Maximum Current: 80A peak (1 second), 30A continuously.
- Reverse polarity protection.
- 3.3V and 5V logic level input.
- Fully NMOS H-Bridge for better efficiency and no heat sink is required.
- Speed control PWM frequency up to 20KHz (Actual output frequency is same as input frequency when external PWM is selected).

3.3 IMU Sensor

The inclination of the driver is sensed by a component called Inertial Measurement Unit (IMU) MPU6050. It houses 3- DOF Accelerometer and 3-DOF Gyroscope. The MPU 6050 is a 6 DOF which means that it gives six values as output. The value consist three values from the accelerometer and three from the gyroscope. This chip uses I2C (Inter Integrated Circuit) protocol for communication. The module has on board Digital Motion Processor (DMP) capable of processing complex 9-axis Motion-Fusion algorithms. To interface MPU6050 using Raspberry Pi, we should ensure that I2C protocol on Raspberry Pi is turned on. So before going for interfacing MPU6050 with raspberry Pi, we need to make some I2C configurations on Raspberry Pi which you can refer Raspberry Pi I2C.After configuring I2C on Raspberry Pi, let's interface Raspberry Pi with MPU6050.

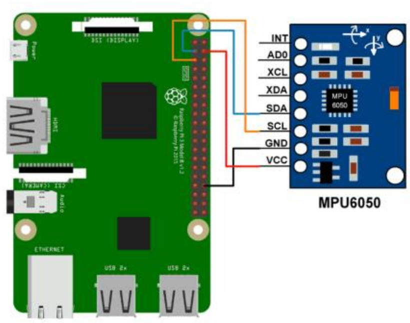

Fig. 2: IMU Connection to Raspberry-pi

3.3.1 Inverted Pendulum Test Case: The computation of control variables is sampled by a mathematical model of a classical physics test-case called "Inverted Pendulum". Those accelerations are integrated to compute the linear velocities, and angular velocities, which are then integrated to compute the linear position and angle of the balance bot.

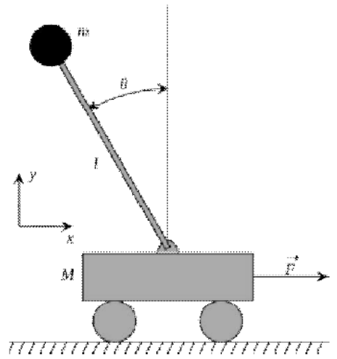

Fig. 3: Inverted Pendulum diagram

3.3.2 Smoothening of IMU outputs: The telemetry of the IMU sensor was disturbed by the mechanical vibrations, which led the IMU to produce noisier responses to the microcontroller. The IMU was padded with absorptive materials, like sponge and rubber pads. These IMU was fixed onto the sponge padding and fixed on the frame to absorb vibrations. The response of the IMU improved. The second solution which we applied was on the program. The program for reading the values from the sensor was tweaked and coded to take average of over 20 values for increasing accuracy of the response from the sensor.

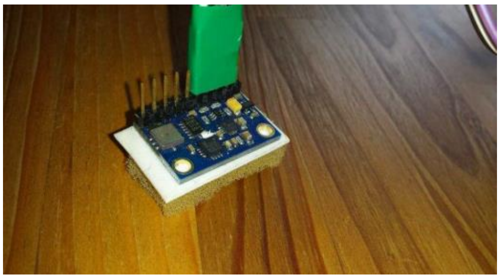

Fig. 4: Sponge padding of IMU

3.4 PID Controller

The control algorithm that is used to maintain its balance position on the self-balancing two-wheel robot was the PID controller. The proportional, integral and derivative (PID) controller is well known as a three-term controller. The Proportional Integral Derivative (PID) controller is a control loop feedback mechanism that is widely used in the industry. The controller attempts to adjust and correct the error between the measured process and the desired process and output corrective measures to adjust the process accordingly.

Table 2: Effect of PID Constants

Response	Rise Time	Overshoot	Settling Time	Steady State Error
Kp	Decrease	Increase	Small Variation	Decrease
Ki	Decrease	Increase	Increase	Eliminated
Kd	Small Change	Decrease	Decrease	No change

3.4.1 PID Algorithm: The PID algorithm accepts the real time values from the IMU sensor, namely the acceleration and gyro-rates, and computes the steady state error with reference to a set-point, in our case 180o. The PID controller then applies its control on the PWM values to the motor in order to correct the error and hence balance the platform.

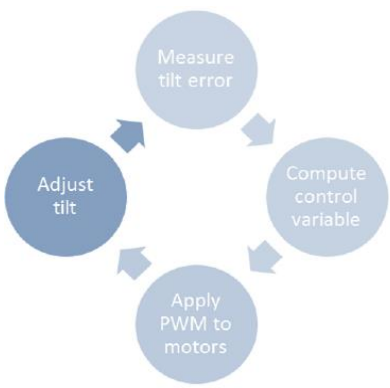

Fig. 5: Balance Algorithm

The response of the PID controller is all dependent on the weightage we assert on certain computing variables. The weightages are called as PID constants, namely Kp, Kd and Ki. The Fig 8 shows a simple representation of the concept of self-balance.

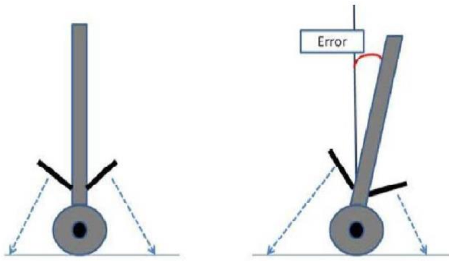

Fig. 6: Pictorial representation of Balancing platform

The basic algorithm of PID controller is as follows:

Error = Current Reading – Setpoint
Error = Setpoint – Current Reading

Below are the equations involved in calculating the output PID:

Output Proportional Term = Kp*Error
Output Integral Term = KpKi * Summation of Error * T = KpKiT* (Summation of Error)
Output Differential Term = Kp*Kd*(Error – Previous Error)/T = (Kp*Kd/T)*(Error – Previous Error)

The simplification of the formula is as below.

Output Proportional Term = Kp*Error
Output Integral Term = Ki* (Summation of Error)
Output Differential Term = Kd*(Error – Previous Error)

Overall, the output PID controller for balancing control system will be:

Output PID controller = Output Proportional Term + Output Integral Term + Output Differential Term.

3.4.2 PID Tuning: The tuning of the PID controller is required to optimize the balance algorithm. The initial PID constants of the algorithm were fixed at lowly values. In-order to change the values of the constants Kp and Kd on the go, we devised a circuit which consists of two potentiometers, each meant for the two constants. The potentiometers were turned on the go by observing the behavior of the board. The microcontroller read the analog values from the potentiometers, and accordingly updated the values of the PD constants. Each constant affects the system in different ways:

- Increasing Kp improves rise time, while worsening settling time.
- Increasing Kd improves rise time, overshoot, and settling time (to a point).
- Increasing Ki improves steady-state error, but can have undesirable effects on the controller. The Integral constant was decided to kept constant. While it improves the steady state error, slight mismatch leads to its dominance over other constants, which makes the system to react rather erratically to input values.

The following steps were taken to tweak the PD constants:

- Set Kp = Kd = 0.
- Adjust Kp until the system remains in balance, but rapidly oscillates around equilibrium.
- Adjust Kd until the system reaches steady state.

3.5 Battery Level Indicator

The simplified LM3914 block diagram is to give the general idea of the circuit's operation. The Signals from the battery 11.8V to 13.8V is compared to high input impedance buffer, and is protected against reverse and overvoltage signals. The signal is then diverted to a series of 10 comparators; each of which is biased to a different comparison level by the resistor string. The battery we are using is a lead-acid-battery. The specifications of the battery are follows:

Table 3: Specifications of the Battery

Capacity	7Ah
Voltage	12V
Useful Voltage Levels	11.8 V – 14.4 V
Number of Batteries	2
Architecture	Series

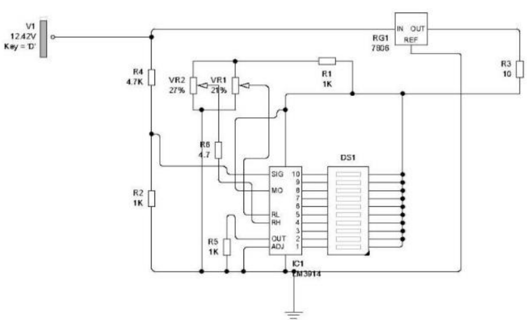

Fig. 7: Simulation circuit of Battery Level Indicator

3.6 Pseudo-Code

Before proceeding with the programming of the hover-board, a pseudo code was developed as an architecture for further improvements.

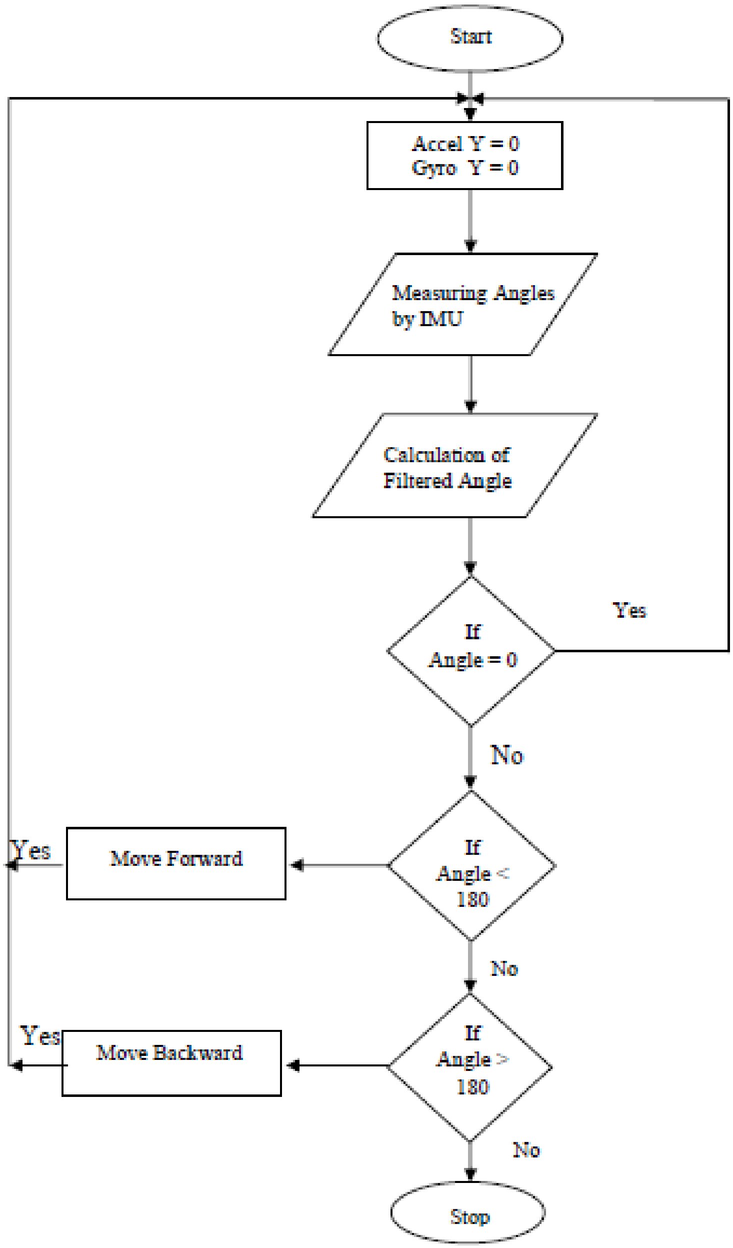

Fig. 8: Flowchart of the Pseudo-Code

4. DESIGN

3D model of the Hover-board is created using Solid Works 2016, CATIA**.** The main components of the hover-board are modeled separately and assembled. The main parts of this assembly are,

- Foot plate (700*270*2.56mm)
- Pneumatic tyre 10.5” (0.2688m)
- Motor
- Sprocket for reduction of speed
- Batteries
- Plummer block bearings

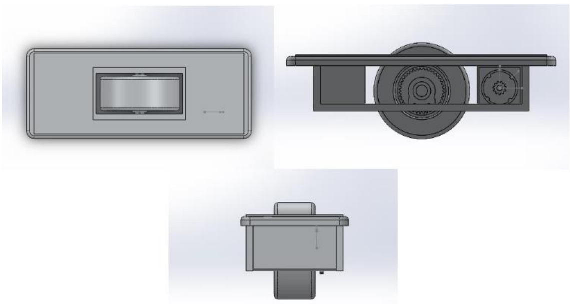

Fig. 9: Different Views of the Hover-board

4.1 Analysis

The aim of this analysis is to check the deformation, stresses and strains induced due to loading on the footplate of the hover-board. Here loading included the weight of the person, weight of the batteries, motors and other components. However, the weight of the person is the predominant factor that affects the loading.

Total load = 100 kg
No. of positions = 2
Type of load = uniformly distributed
Type of analysis = Static Structural

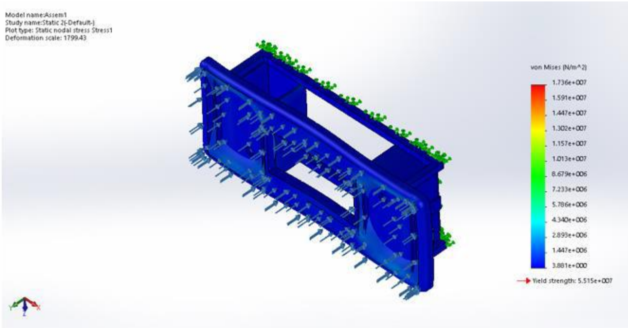

Fig. 10: Stress analysis of the Hover-board

From the above results the maximum stresses are induced footer. This maximum stress developed is not more than 17MPa. However, this maximum stress value is very less than the ultimate tensile strength (310MPa) and yield strength (276 MPa) of the Aluminium alloy 6061-T6.

Developed stress (17MPa) << Yield strength (276Mpa)

Since, the maximum developed stress is almost 16 times less than the tensile yield strength; there is minimum or no possibility of failure. So, the design is Safe.

5. CONCLUSION AND FUTURE WORK

The hardware is performing the balancing function in a hassle-free manner with the user standing on it. The PID algorithm's response is just perfect and is intuitive enough for any new user to perceive the how-to for this hardware. The skateboard posture provides more aerodynamic and grip advantage over the current two-wheel-hover-boards available in the market. The inbuilt battery level indicator displays accurate readings of the charge remaining in the battery.

6. REFERENCES

[1] Kavita Burse, Siddharth Shukla, Vikas Jain,"Study of Energy Saving Through Regenerative Braking In DC Drive", IJAIR ISSN: 2278- 7844 , 2012
[2] Karthik, Ashraf, Asif Mustafa Baig and Akshay Rao, "Self-Balancing Personal Transporter" 4th Student Conference on Research and Development, pp. 180-183, June. 2006.
[3] M. Ehsani, K. M. Rahman, and H. A. Toliyat, "Propulsion system design of electric and hybrid vehicles," IEEE Transactions on Industrial Electronics, vol. 44, pp. 19-27, 1997.
[4] F. Salmasi, "Control strategies for hybrid electric vehicles: Evolution, classification, comparison, and future trends," IEEE Trans. Veh. Technol., vol. 56, no. 5, pp. 2393–2404, 2007.
[5] Krunal Shah, Vidhi Shah, Deepak Mistry, "Chopper Based Speed Control of DC Motor" International Journal of Electrical and Electronics Research, Vol. 3, Issue 1, pp: 254-259, 2015.
[6] Chinnaiyan V. Kumar, Jerome Joritha, Karpagam, J. S.Sheikh Mohammed, "Design and Implementation of High Power DC-DC converter and speed control of dc motor using TMS 320F240DSP", Proceedings of India International Conference on Power Electronics, 2006.
[7] C. Huang, "The Development of Self-Balancing Controller for One-Wheeled Vehicles," Engineering, Vol. 2 No. 4, 2010, pp. 212-219.
[8] Keagan Malan, Michael Coutlakis, James Braid, "Design and Development of a Prototype Super-Capacitor Powered Electric Bicycle", IEEE International Energy Conference (ENERGYCON), Cavtat, pp. 1434-1439, 2014
[9] Mrs.Lekhsmy.S ,Aleesha George , Athira C.V, "Self Balancing Robot", International Journal of Computer Engineering In Research Trend, Volume2, Issue 12, pp.1091-1095, December-2015
[10] Lindsay G, Macmillan A, Woodward A, "Moving urban trips from cars to bicycles: impact on health and emissions", Australian and New Zealand Journal of Public Health, Volume 35, Issue 1, pages 54–60, February 2011