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Design and Development of a Self Balancing Mono Wheel Electric Vehicle

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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.

KEYWORD: Hoverboard, Chopper drive, Electric Vehicle, PID controller

I. 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 [10]. 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).

II. 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 [2]

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 [11]

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.

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C. Design and Development of a Prototype Super-Capacitor Powered Electric Bicycle [8]

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 [9]

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.

III. PROPOSED DESIGN

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

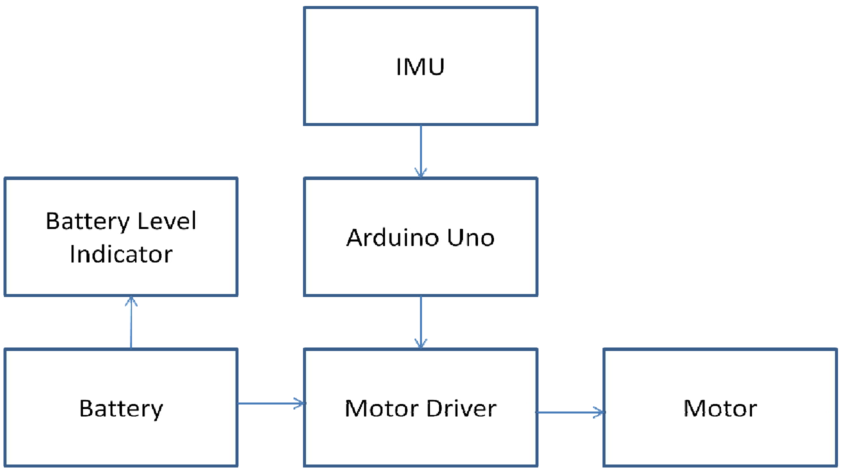

Fig.1. Functional Block Diagram

The description of the components is as follows:-

A. *Motor*

The motor used is a PMDC motor, which offers a good speed-torque characteristics and costing low. [1] The specifications of the motor are as follows :-

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%

Table 1. Motor Specifications

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Fig 2. 250W DC Motor

B. *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. [5] [6] [11]
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).

C. *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. The SDA and SCL pins are used to establish a connection with the Arduino pins A4 and A5 to receive the accelerometer and gyroscope data. The interrupt pint (INT) is to instruct the Arduino when to read the data from the module and this pin instruct the Arduino only when the values change.

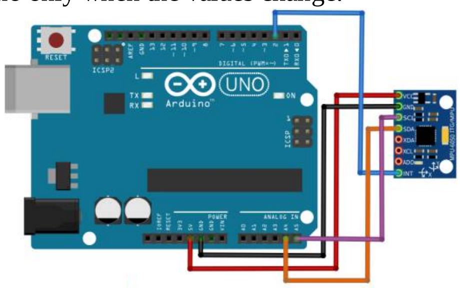

Fig.3. IMU Connection to Arduino

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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". [7]

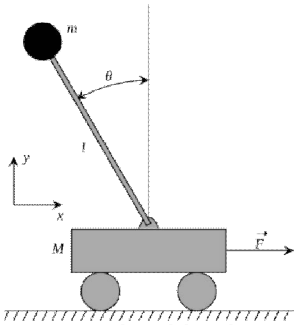

Fig.4. Inverted Pendulum diagram

$$\alpha = \frac{a\cos\theta + g\sin\theta}{r}$$

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.

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.

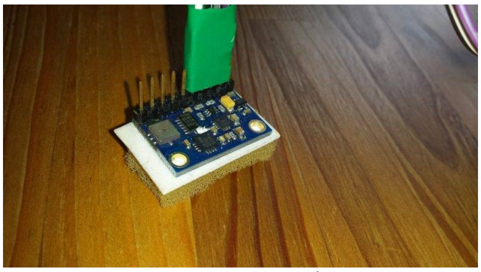
Fig 5.Sponge padding of IMU

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. [9]

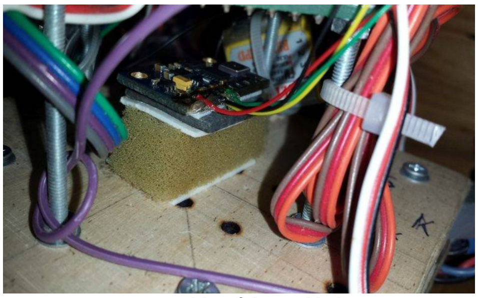
Fig 6.Assembly of the Padded IMU

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D. *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. [2]

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

Table 4.1:- Effect of PID Constants

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 setpoint, in our case 180°. 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.

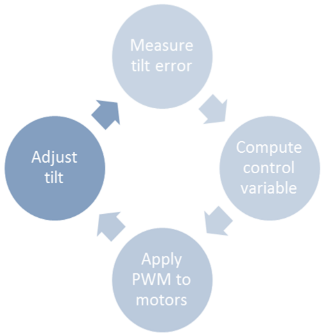

Fig 7. Balance Algorithm

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.

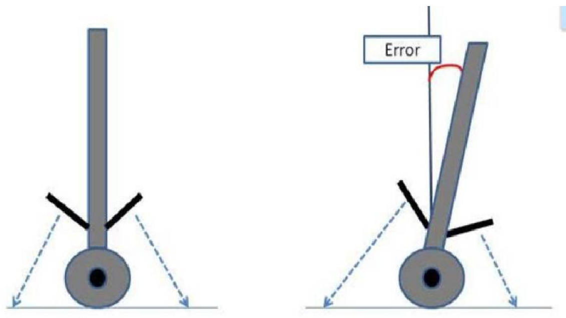

Fig 8.Pictorial representation of Balancing platform

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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 [9]

2. PD 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. [2]

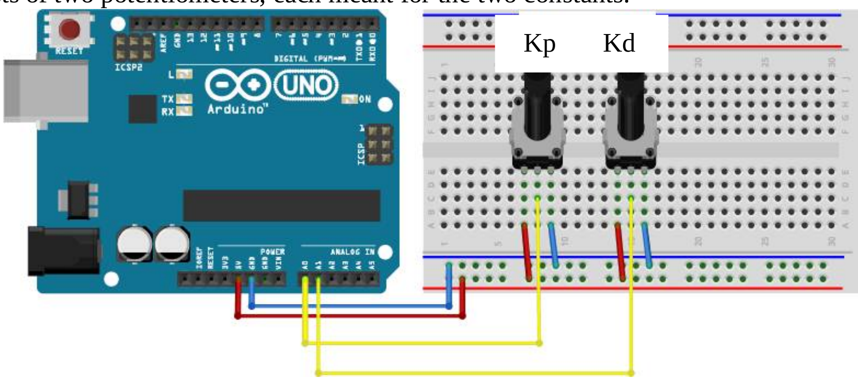

Fig 9.Circuit to manipulate PD constants

The potentiometers, as in Fig 9, 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.

E. *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.

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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:-

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

Table 5.1:- Specifications of the Battery

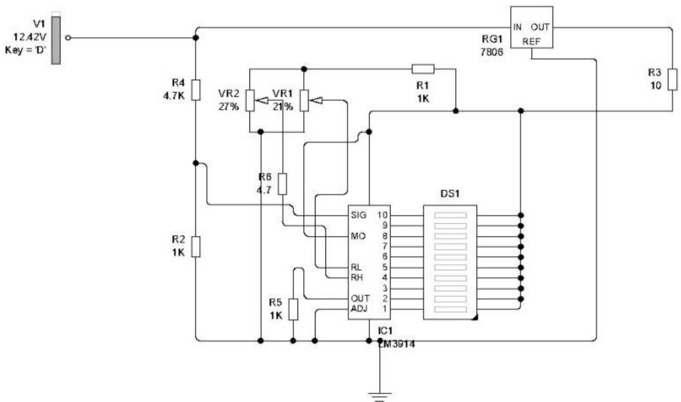

Fig 10.Simulation circuit of Battery Level Indicator

The circuit from the simulation was exported to PCB Design Software, and thereby etched onto a PCB. The circuit had undergone multiple revisions due to practical constraints. The common problem was maintenance of the sufficient voltage difference between the comparator pins and input voltage, which is critical to the operation of the battery level indicator.

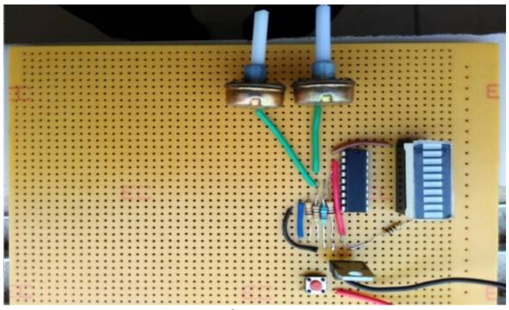

Fig 11.Hardware of Battery Level Indicator

F. Pseudo-Code

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

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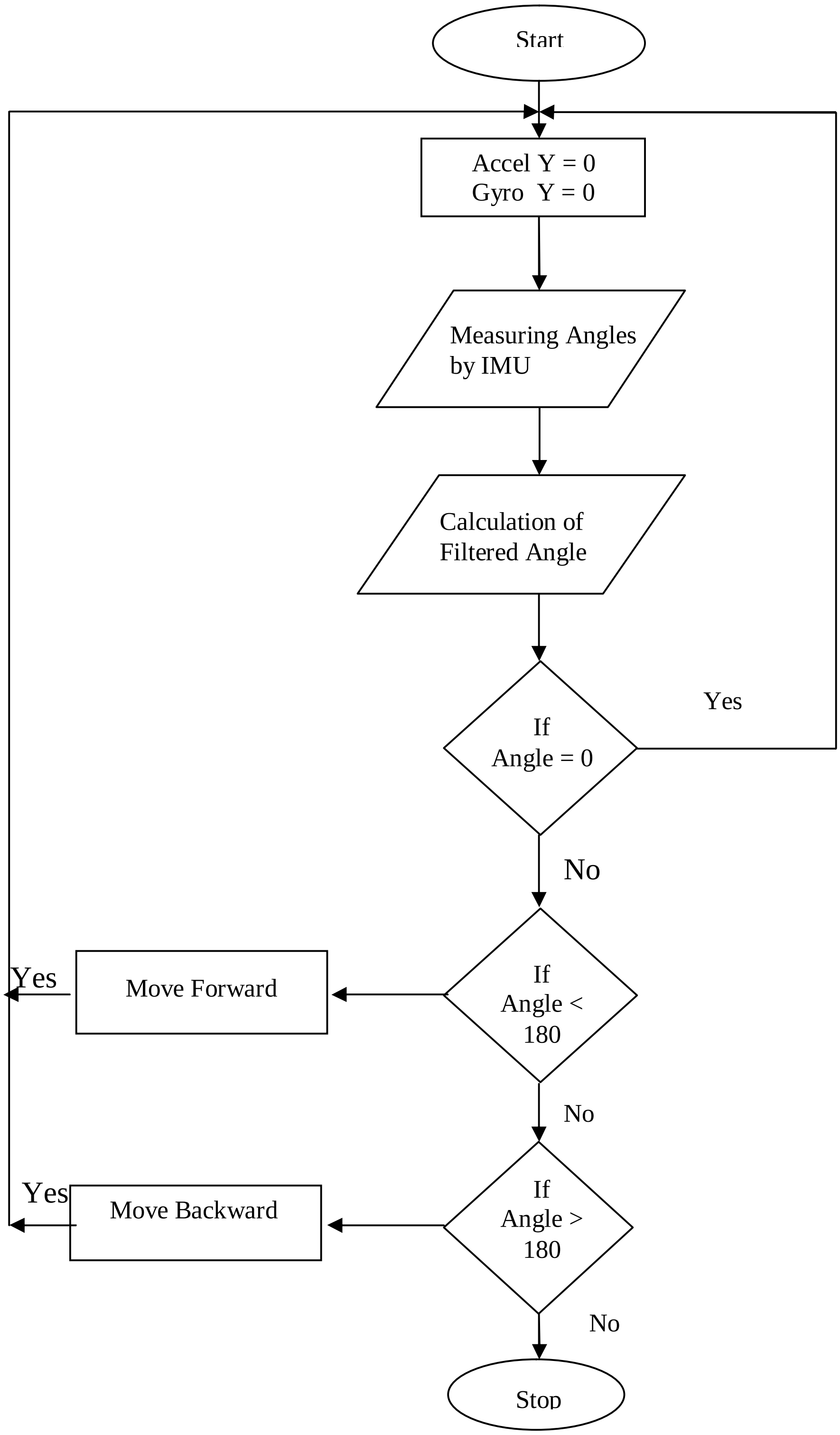

Fig 12. Flowchart of the Pseudo-Code

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IV. OBSERVATIONS

The Single wheel hoverboard responds well to the user inclination. The Fig 13 shows the fully assembled vehicle. The response of the PID algorithm requires little more tuning driving at high speeds. At low speeds, the hoverboard gives sufficient inclinatory response, which suffices the user into an aerodynamic posture.

Fig 13.Lateral View of the Hoverboard

V. 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-hoverboards available in the market. The inbuilt battery level indicator displays accurate readings of the charge remaining in the battery.

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BIOGRAPHY

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