IMPLEMENTATION OF TWO WHEELED SELF BALANCING PLATFORM

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Abstract - The Self balancing robot is based on the inverted pendulum concept. In this concept an inverted pendulum is positioned on a cart and the cart is allowed to move on the horizontal axis and the pendulum is required to stand upright . This type of case is that of an unstable system. The angle measurement is done with the help of a sensor fusion of gyroscope and accelerometer i.e using an IMU, requiring filtering mechanism as both provide erroneous angle results. One such filter is the Kalman Filter, but the design and implementation of that filter is lengthy, tiresome and difficult to implement on smaller 8-bit micro controllers. This paper intends to design and implement a Self balancing robot with the help of a Complementary filter using PID algorithm as the control strategy. The robot is powered with a Hi-watt 9 volts battery to power the Arduino and sensor and AC to DC adapter to power the motor.

Key Words- Self balancing robot; mpu6050; inverted pendulum; complementary filter; PID

1.INTRODUCTION

Two wheeled balancing robots are based on inverted pendulum configuration which rely upon dynamic balancing systems for balancing and maneuvering. This robot basis provides exceptional robustness and capability due to their smaller size and power requirements. Such robots have their applications in surveillance and transportation purpose. In particular, the focus is on the electro-mechanical mechanisms & control algorithms required to enable the robot to perceive and act in real time for a dynamically changing world.

The self balancing robot (SBR), is a classic model of the inverted pendulum . The inverted pendulum concept in the simplest form, consists of a cart moved by two DC motors, to control the position of the inverted pendulum tending to rotate about a fixed position on the cart. The mathematical analysis is well researched in ref [1] and [2].

The primary requirement for the control of the system needs angle measurement of the pendulum with respect to the vertical axis. A stable angle point is fixed as a set point and the most best strategy is to drive the DC motors backward or forward so as to keep the inverted pendulum in the stable angle position, this system can be easily be seen in Segway system[13]

The angle measurement sensor used is an Inertial Measurement Unit (IMU), MPU-6050. The angle can be measured individually each by deploying an accelerometer by finding the angle between different forces acting on the pendulum or, alternatively, by using a gyroscope and integrating the angular velocity over time to get the angular measure of pendulum.

This method contains unwanted data as, Firstly, the accelerometer is sensitive to all the 'unwanted' forces acting on the system like vibrations from the DC motors, friction on the wheels and all the other forces except gravitational force. The resulting angle which is measured contains error and the error fades only after a certain period of time after the vibrations and other forces have stabilized or come to a halt. Secondly, the angle measurement from the gyroscope needes integration of the angular velocity to get angular data but even a minimal error in the measurement of the angular velocity will cause the measurement to drift away from the actual measurement in the long run as error gets integrated over time. Thus, the accelerometer is error free only after a certain period of time and the gyroscope reading is error free only in the initial period [3].

Due to the error in both these strategies, the deployment of a filter so as to remove or 'filter' away the errors by combining the measurement from both the accelerometer and gyroscope is necessary. One such strategy is of the Kalman filter, which uses mathematical estimation from the two measurements to produce an error free output.

Though mathematically proven, that it is best available filter to use as seen in the thesis paper [14], it is very difficult to integrate this technique on smaller microcontrollers (8-bit). The Complementary filter is a much simpler but effective filtering strategy and employs low pass and high pass filter to arrive at a nearly error free angle measure. The primary focus of this paper is for the implementation of this filter in the SBR .

Finally, the control strategy for obtaining the stable angle position is the Proportional-Integral-Derivative (PID) control method was applied after getting inputs from researches in [5, 6, 15].The value of PID parameters i.e. Kp, Ki and Kd have been obtained and applied to the

Arduino. The software has been written with logic to convert the digital data from the accelerometer to an acceleration magnitude vector. The magnitude is then compared to a predetermined mathematical function to infer the angle of tilt of the platform. The angle of tilt is then converted to angle of rotation for the motors to act on.

2. INVERTED PENDULUM MODEL

An **inverted pendulum** is a classic control problem. The process is non linear and unstable with one input signal and several output signals. The aim is to balance a pendulum on cart.

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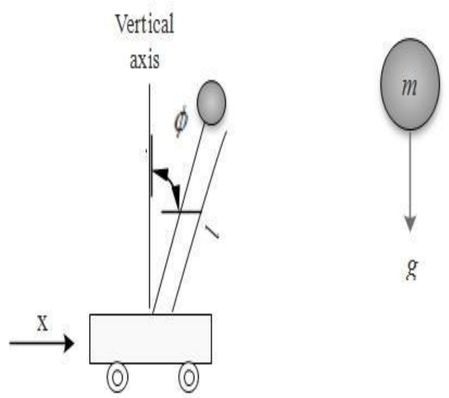

Fig 1: Inverted pendulum on a cart

In the following analysis of the pendulum cart system by Siebert [6], we mathematically obtain the transfer function of the pendulum-cart system.

The torque produced about the pivoting point at an angle ϕ due to gravitational acceleration, *g.* Let the torque be represented by "T" and "phi" represent the angle of tilt.

We get,

$$T=mgl\sin(\phi)$$

Based on above, we derive the following two equations for the vertical and horizontal rotational accelerations,

$$\ddot{\phi}_g = (\frac{g}{l})\sin(\phi) \qquad (1)$$

$$\ddot{\phi}_x = (\frac{\ddot{x}}{l})\cos(\phi) \qquad (2)$$

From (1) and (2), we combine them to get the final rotational acceleration acting on the system.

$$\ddot{\phi} = \ddot{\phi}_g + \ddot{\phi}_x = (\frac{g}{l})\sin(\phi) - (\frac{\ddot{x}}{l})\cos(\phi)$$

Finally applying Laplace operator to this, we get the following equation :

$$\frac{\phi(s)}{X(s)} = \frac{-s^2}{ls^2 - g} = \frac{\frac{-s^2}{g}}{(\tau s + 1)(\tau s - 1)}$$

3.BALANCING CONTROL

The feedback control used for improving the balancing action is the PID controller. PID stands for "Proportional, Integral, and Derivative." These three terms describe the basic elements of a PID controller.

A proportional-integral-derivative controller is a generic feedback controller. PID controller processes the "error" as the difference between a measured output and a desired given references and tries to minimize the error by adjusting the control parameters.

Giving look towards how the PID controller works in a closed-loop system using the system variable.

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_p \frac{de}{dt}$$

'e' represents the system error due to both system noise and measurement noise, the difference between the desired output value and the actual output produced. This error signal is given to the PID controller, and the controller determines both the derivative and the integral of this error. The input to the plant should be the summation of derivative constant multiplied by derivative error, proportional constant times the proportional error and integral times the integral error.

4. MECHANICAL STRUCTURE

The robot comprises of single foam platform mounted on the two DC motors of 300 rpm. The HW Hi-watt 9v battery is mounted on the top of the foam sheet. The Arduino Uno and L298N are mounted on the foam sheet . The IMU sensor was kept at lower platform made of a thin strip of foam kept over the two DC motors in between the so as to keep it as immune to vibrations as possible. The wheels used were generic robot wheels.

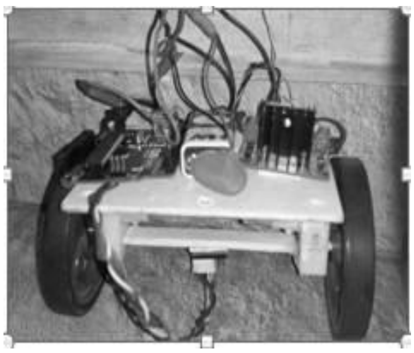

Fig2 : Self balancing robot in stationary position

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5. ELECTRONICS COMPONENTS

1 .ARDUINO UNO : The Arduino Uno is a microcontroller board based on the ATmega328 . It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. It is used for faster deployment of algorithm and ease of debugging capabilities and sensor interfacing is easier to implement with less code footprint

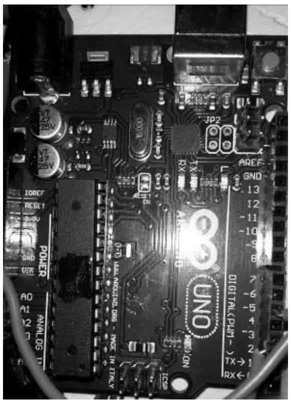


Fig 3: Arduino used in the project

2.MPU6050: The IMU sensor, MPU-6050, MEMS based, manufactured by InvenSense technologies was used. The module consists of 3-accelerometers and 3-Gyroscopes making the unit a 6 DOF (Degrees of freedom) sensor. The sensor works at a voltage level of 3.3v and I2C protocol as means of communication with the microcontroller.

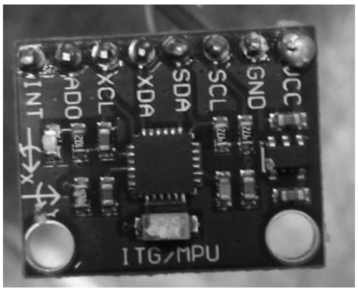


Fig 4 : MPU6050 sensor used in the project

3.L298N BOARD: H Bridge L298N motor driver is used to drive the two motors. It takes command from Arduino and draws power from AC to DC adapter.

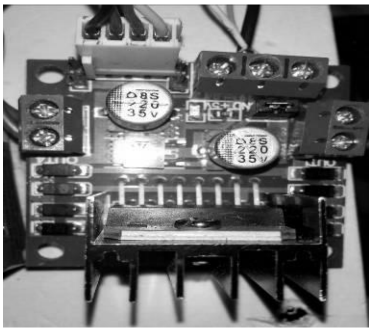


Fig 5 : l298N motor driver used in the project.

6.COMPLEMENTARY FILTER

The need for an alternative to Kalman filter arises from the fact that the Kalman filter is very cumbersome, difficult to understand and challenging to implement on a smaller 8-bit microcontroller. Thus a complementary filter serves this purpose of simplifying the difficulties faced while implementing simple first order high pass and low pass filters.

Complementary filters do not act on the signals. They are in fact filters to be associated with noise of the signal present. Thus the task of the filter is to estimate a stable angle from multiple sources containing erroneous data and which exhibit noise with different frequency content [8].

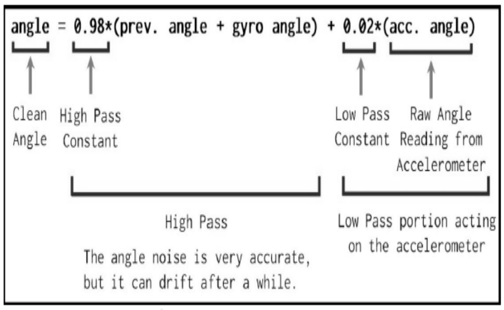


Fig 6 : complimentary equation description

The complementary filter is a frequency domain filter. Mathematically, it can be seen as use of two or more transfer functions which are complements of each other. So, if one data from the first sensor is represented by the transfer function G(s), then the other data from the second sensor is I-G(s) with the sum being the identity matrix I [8]. If the high frequency noise from one sensor and the low frequency from the second one are compliments of each other then, the complementary filter is applicable. The signal is passed through both high and low pass filter to remove the noise and final reconstruction takes place. In theory the Kalman filter should provide the best output and does not work in the frequency domain. But on the other hand the practical implementation of complementary filter does not vary much or rather is almost same as the kalman filter. What makes the difference in the two is the implementation. The software implementation of the complementary is quite easy with the use of just a digital high pass and a low pass filter. The filter consists of two filter coefficients and the following is the complementary filter equation

Final Angle = C*(Final Angle + GyroA *dt) + (1-C)*AccA

Where,

Final Angle= Final filtered angle

C= High pass filter coefficient

GyroA= Angle obtained from the gyroscope

AccA= Angle obtained from acceleration

dt=loop time since last iteration.

7. PROCESS AND BLOCK DIAGRAM

Initially circuit is connected.

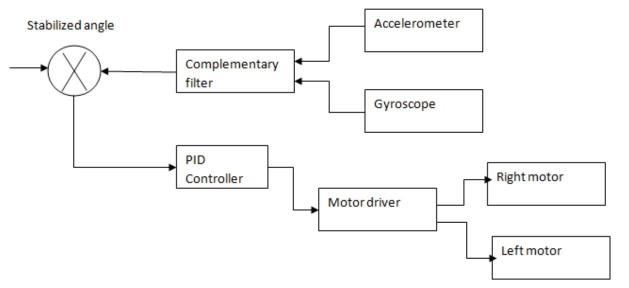


Fig 7: block diagram of control strategy

1.The values from the IMU sensor are passed through the complementary filter.

2. The complementary filter filters the values to give more appropriate values .

3.These values are the given to the PID controller which runs the loop to nullify the error signal to balance the self balancing robot.

4.A set point is established for running the PID controller.

5. The self balancing robot gets stabilized.

8. RESULTS

In Arduino IDE there is a serial communication tool available for plots. The following results are obtained from the serial plotter in Arduino IDE.

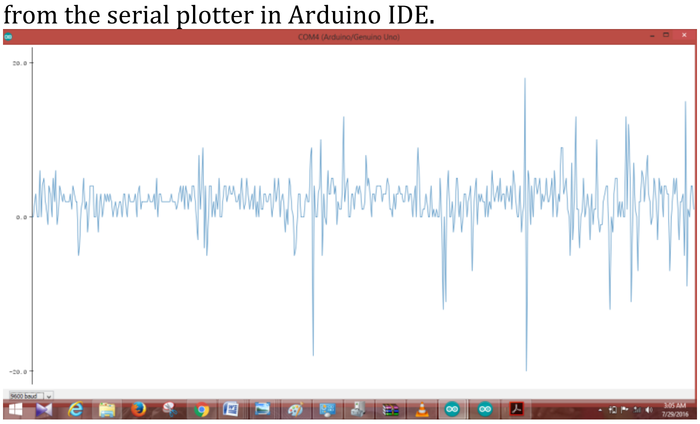


Fig 6 : angle of tilt on serial plotter

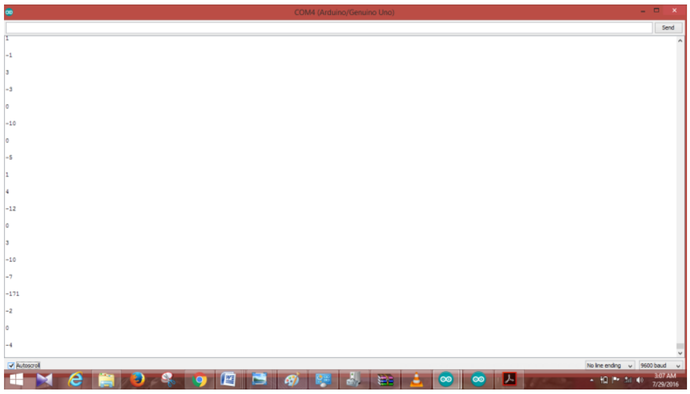
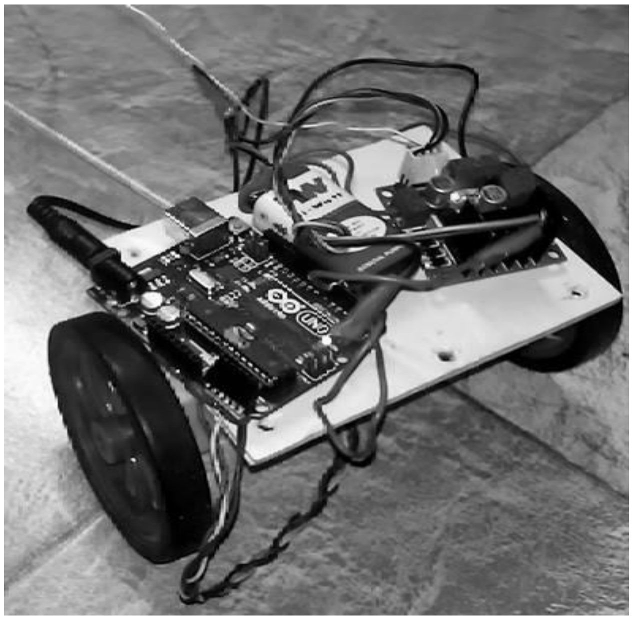


Fig 7: angle of tilt on serial monitor.

Above figures represent tilt angle w.r.t time on serial plotter and serial monitor respectively.

The self balancing robot is balanced using complimentary filters and PID controller . Below image shows the self balancing robot in action .



9.CONCLUSIONS

As performance limits in robotics are increasing, dynamic effects (and therefore dynamic stability) are becoming ever more important. This project has resulted in building a working self-balancing mobile robot on two wheels. The robot is successfully balanced . The paper has presented the process in which the project has been carried out from the design and production of specific parts to the integration of electronic, mechanical and software sections. Because of the need to use the knowledge in the fields of mechanics, electronics, programming and control, this project is extremely interdisciplinary and as such one of the most representative mechatronic problems. The stability of the Self Balancing Robot may be improved if a properly designed gearbox that is having negligible gear backlash is used. Further work includes increasing the level of stabilty of the robot. Also Self balancing robot can be connected with a Bluetooth module thus allowing the robot to be controlled while moving . Robot can be also made to avoid obstacles by adding Ultrasonic sensor.

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