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A Two Wheel Self-Balancing Scooter

Samarth M. Goudar
Dept. of Electronics and Telecommunication Engineering

Atul B. Jadhav
Dept. of Electronics and Telecommunication Engineering

Gajanan V. Giri
Dept. of Electronics and Telecommunication Engineering

Nikhil R. Shimpi
Dept. of Electronics and Telecommunication Engineering

MIT Academy of Engineering Pune
samarthmg@gmail.com, jatulkumar5@gmail.com, gajugiri1111@gmail.com, nrshimpi@entc.mitaoe.ac.in

***Abstract-* The metropolitan cities always have to deal with the problem of traffic congestion each day. The main reason for the traffic congestion is due to more number of vehicles. With the increase in adult population more and more people want to use their own vehicle for personal transport, which eventually causes space and parking issues in cities. Even for going to a small distance people prefer to use their own vehicles rather than going by walk. In addition to the traffic congestion, it is also leading to pollution. Hence we propose to design and build a vehicle which will be efficient, less polluting and solve the problem of traffic congestion to a large extent. One of the challenging task in a two wheeled mobile system is balancing its tilt to upright position, this is due to its mechanical design and its instability. This project is implemented on non-linear based controller in balancing the two wheeled mobile system.**

A Fuzzy Logic Controller (FLC) is implemented on the two wheeled mobile system. The FLC controller performance gives superior result as compared to various other controllers and methodologies implemented until now. PID control is integrated with feedback control that gives stability to the robot. Simulation and experimental results demonstrate the robustness and good performance of the proposed PID control method.

I. INTRODUCTION

Segway personal transport is a mechanically unstable, two-wheel self-balancing vehicle.This vehicle uses the sensory capability and intelligent control to stay upright. While Segway is a well-known commercial product, research into the control of such a mechanical system is diverse. A two-wheel self-balancing vehicle is very similar to the inverted pendulum[1-2]. A two wheel self-balancing scooter is a mechanical system with nonlinear dynamics. It has three degrees of freedom but only two wheels are controlled by using motors to control the motion. It has the advantage of turning on the spot and due to its small body, the scooter can enter to the place where the conventional four wheels vehicle cannot enter. In the control of two wheel self-balancing scooter tilt balancing and position and velocity tracking, linear and non-linear controllers are used.

To overcome the restrictions of linear controllers, a FLC and PID controller for balancing the scooter is used. The FLC is better in controlling of settling time and less overshoot, while the PID is better in controlling of steady state error and rise time[6].

In this paper, we explain the design, and control of a two-wheel self-balancing scooter. The scooter is driven by two DC motors, and uses Arduino Mega 2560 board processor, a gyroscope angle determination. To compensate for gyro drifts, a complementary filter is used. A proportional-integral-differential (PID) control, and a proportional-integral proportional-differential control based on linear-quadratic regulator (LQR) design. The approach is stable to modeling errors which can be incurred during determination of moments of inertia and motor gains. Simulation and experimental results are presented, which show that stability of the upright position is gained with PI-PD control within small tilt angles.

II. STRUCTURE OF THE TWO-WHEEL SELF BALANCING SCOOTER

The structure of a self-balancing vehicle is classified into three parts: sensors, motor and motor control, and micro-controller [3-5]. This section talks about the application and advantage of the sensors on the proposed balancing vehicle, and how these sensors are used to obtain measurements of acceleration, distance traveled, and tilt angle. Section II (B) describes motor selection and control for the balancing scooter. Also it discusses the reason behind choosing the Arduino processor and how it is deployed.

Fig. 1. Balancing Robot

A. Selection and Application of Sensors

To balance the scooter, data of the scooter's tilt angle and angular velocity are needed. Using MEMS sensors gyroscope we can measure the data needed for balancing control.

1) Gyroscope: The gyroscope is the sensor which measures the angular velocity of the balancing scooter, and sends the data to the micro controller. The present vehicle uses the MPU6050 Gyroscope, which sends data via serial communication to the micro controller, and has the advantage of three-axis angular measurement, low-power consumption, and low cost. By integrating the angular velocity will yield the angle directly; however, this process will also integrate noise in the gyroscope measurement. As a result, the value of will diverge. Fig. 2 shows the output of a simulated gyroscope output results.

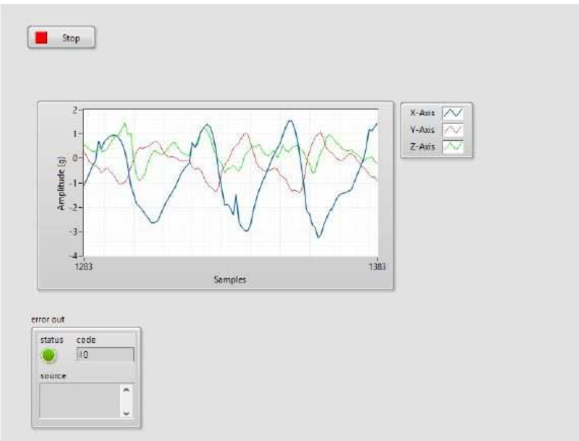

Fig. 2. Gyroscope Output

B. Motor and Motor Control Board

Motor selection for the balancing vehicle needs torque output instead of velocity, because it has to oppose the rotational moment that gravity applies on the vehicle. Hence, the motors need to provide enough torque to correct the vehicle's body back to a balanced state. Each motor provides a sufficient torque for our purpose. The large currents drawn by the motors are supplied by the SmartDriveDuo-10 motor control board, which can delivery a 14-Ampere continuous output current at a maximum operating voltage of 24 Volts.

C. Arduino 2560 Mega Micro controller Board

Selection of the development board is based on the following considerations:

1) Performance: The self-balancing vehicle needs real-time response to calculate and correct the tilt angle. Hence, the micro controller board should provide a processing speed that is fast enough to perform the processing tasks, including data acquisition, control computation and signal output, within the sampling time. The Arduino Mega development board uses the ATmega2560 which has a maximum clock rate of 16 MHz.

2) I/O Pins: Another issue is the number of I/O pins available. On the vehicle, sensors are used to obtain measurements, the gyroscope calculates the tilt angle. A motor control board is interfaced with the micro controller board for PWM signals. Base on the output of these sensors and the motor control board, it has been determined that at least thirty I/O pins are needed. The Arduino Mega features 54 general-purpose digital I/O pins of which 15 provide PWM output. Some of the digital I/O pins also support serial communication such as I2C and SPI, as well as interrupt handles. The board also has sixteen 10-bit analog inputs for 0-5V input.

D. Power Supply

For power supply, the motors need a voltage between 24V and the micro controller board needs 5V.Hence, two sets of batteries are incorporated 24V battery.

III. ANGLE ESTIMATION AND BALANCING CONTROL

The architecture of the self-balancing vehicle is as shown in Fig.3, where the forward loop is of the vehicle, a controller which delivers a motor-control signal, and the inner-loop of controller for wheel synchronization. Feedback is provided through a complementary filter whose function is to calculate the tilt angle from gyroscope measurements.

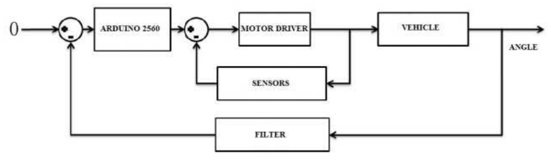

Fig. 3. Architecture of the system

A. Angle Estimation via Complementary Filter

Gyroscope is used to measure the angular velocity of the vehicle. In the balancing the vehicle, the tilt angle is corrected to the upright position by using motors[5].

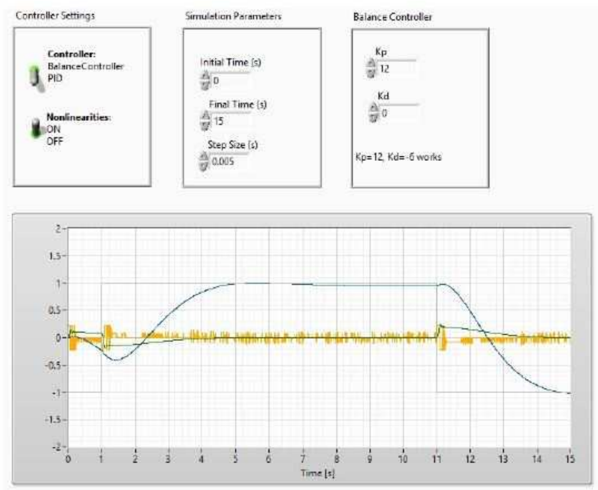

Fig. 4. Performance under noise

This requires the values of tilt angle which must Fig. 4. Performance under noise of Balancing Robot be accurate. This is done by using gyroscope, as the gyroscope provides the angular velocity, integrating it will produce the angle. However, the gyroscope measurement contains lot of noise. Hence the previous method will not only integrate the angular velocity, but also the noise. This will make the integrated data different from the correct angle.

To solve the problem of angle measurement, we are using complementary filter [7].The complementary filter uses the measurements of the gyroscope. As input to estimate the bias in the gyroscope-measured angular velocity. Subtracting the estimated bias yields the estimated angular velocity and integrating it provides the estimated angle. After tuning the filter, its performance under noise is tested as shown in Fig. 4 The best estimate of the angle is provided by the complementary filter.

B. Controlling Of Motors

If the same motor control signal is sent to the motors driver board, both motors rotate at the same speed. But in practically there are many reasons for which the motors do not rotate at same speed under the same input signal, because of terrain and uneven ground. Hence synchronization of both motors is necessary. Hence a simple PI controller is used. This controller adjusts the PWM inputs to the motors so that the difference between the left and right motor tracks zero.

C. Balancing Control Of Vehicle

PID control is a fundamental method which is used and implemented. The PID control is used because it is easy to implement.

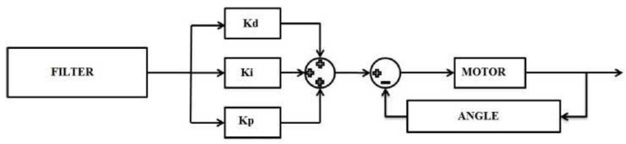

Fig. 5. Block diagram of balancing vehicle

The block diagram of the PID controller is as shown in Fig. 5, where the complementary filter gives the angular velocity and angle.

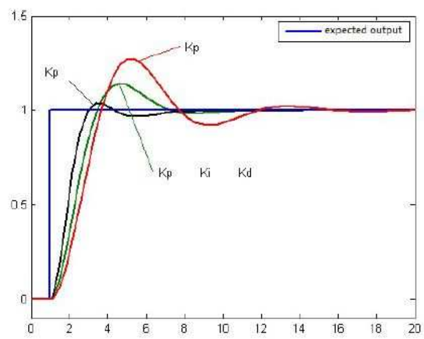

Fig. 6. PI-PD Output

Instead of differentiating the angle measurement which will amplify noise, differential control is implemented by multiplying the differential gain Kd. Proportional control is given by the proportional gain Kp, whereas numerical integration and multiplication by the integral gain Ki yields the integral control. Taking the tilt angle as output, the transfer function is derived. LQR control can also be implemented as a PI-PD controller where the actual measurements used are the wheel velocity, and the tilt angle returned by the complementary filter

IV. RESTULTS

The results shown in Fig.4-6, shows that the stability with PID control is marginal and angular oscillations exceed the torque limit of the motors and cannot be contained. Moreover, it is found that the vehicle's position drifts during balancing due to C.G. misalignment. But stability is achieved by PI-PD control rather than the PID control.

V. CONCLUSION

We have designed and constructed a two-wheel self-balancing scooter using low-cost components, and stabilizing it with PI-PD controller for the balancing motion. Design improvement for better balancing motion can be done by mechanical design such as relocating the centre of mass, better sensor placement. Low-cost hardware such Xbee can be added to the scooter, so that the user can control its motion remotely.

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