

Image Processing Based Self Balancing Robot

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Abstract: Now-a-days, self-balancing robots are becoming popular because of their ability to balance itself on two wheels. The project is designed to implement the self-balancing robot which balances itself on two wheels and navigate its path around and perform image processing. Balancing unit and the image processing unit forms the entire system. The balancing unit performs the function of keeping the robot stable and the image processing unit is used to navigate the path. The System has been designed using IMU6050, Arduino board, two DC motors and the raspberry pi. The PID controller is used to improve the stability of the system and the image processing system is developed to detect the variety of signs such as start, stop, and right, left and navigate the robot accordingly.

Keywords: MPU6050, Arduino board, Raspberry Pi, PID controller

1. Introduction

Self-balancing robot balances itself on two wheels and provides the unique stability which differentiates it from other ordinary robots. This ability of robot allows it to navigate on various terrains, sharp corners etc. These abilities of robot solves the number of challenges in industry and the society. The basic idea of self-balancing is to drive the wheels in the direction in which the robot tilts. The general design of the robot is the simple rectangular body on two wheels. The robot body comprises of the three layers placed on one another. The bottom layer consists of the two wheels and MPU6050 sensor. The first layer consists of the Arduino board, L298N the motor driver circuit and the MPU6050 sensor. The second layer consists of the raspberry pi which is used for image processing. Balancing robot is designed using 6DOF MPU6050, Arduino board and the two DC motors. Here the MPU6050 consists of accelerometer which gives the component's acceleration and the Gyroscope gives the component's angular velocity along its three axis. The sensors communicates over I2C protocol. The microcontroller (Arduino) continuously reads the data from the IMU sensor and calculates the angle of the tilt of the robot with respect to the setpoint, with the help of the data.

The controller sends the appropriate signals to the motor driver circuit to drive the motors. Raspberry pi is used for Image processing which operates at 700MHz.

1.1 Block Diagram

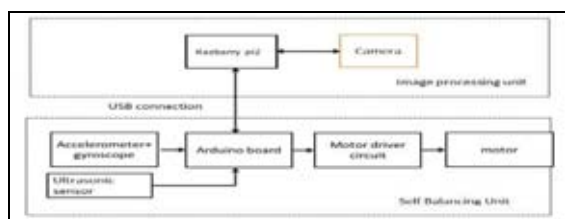


Figure1: Block Diagram

2. Working

In order to keep the robot stable, we have to continuously monitor the angle of the tilt of the robot and drive the wheels accordingly.

2.1 Angle estimation

The IMU sensor consisting of accelerometer and the gyroscope is used to find the angle of the tilt. Accelerometer and gyroscope are individually unstable and cannot give accurate angle so we need to combine the data to get the accurate angle. The accelerometer is used to measure the linear acceleration and the Gyroscope measures angular velocity which is integrated to find the angle of tilt. For a small interval of time, the gyroscope value remains accurate, but since it experiences the drift and integration gives the error, after some time the gyroscope reading becomes unreliable. So we require some way to combine these two values.[1] This is done with the help of the Kalman filter. The filter is used to remove the noise that can affect the performance of the system under control. Kalman Filter is not easy to implement and requires heavy effort in programming. [2] Kalman filter will predict the future state from current and previous states using weighted averaging.

2.2 Balancing control:

The PID control algorithm used to maintain the balance on two wheel robot. PID stands for proportional, integral, and derivative terms. [3] These terms have their own gain constants k_p, k_i and k_d known as the proportional gain, integral gain and the derivative gain constants. PID controller uses the concept of negative feedback control. The measured position will be subtracted from the reference set point value to produce an error. [4] The error is given back to the PID controller. The PID algorithm processes this error and tries to adjust the input signal provided to PID. This control signal will help to drive the motor through motor driver circuit to correct the position. The set-point value is defined as 'zero degree'. PID can be represented in mathematical form as follows:

$$\text{Correction} = K_p * \text{error} + K_i * \int \text{error} + K_d * d/dt(\text{error}); \quad (1)$$

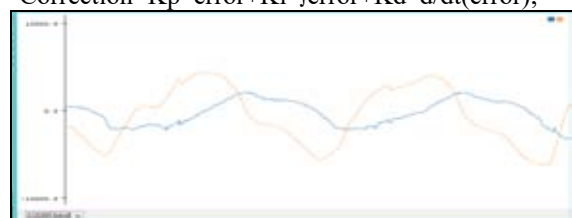


Figure 2: Raw data from MPU6050

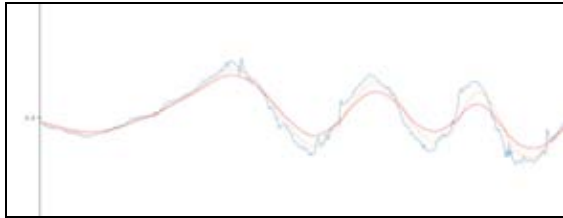


Figure 3: Comparison of Kalman filtering and complementary filtering

The gain values K_p , K_i and K_d can be set through various algorithms like Ziegler-Nichols, Twiddle or Auto tuning. The comparison of P, PI and PID controller is given in figure 2. We have used a practical approach to set these values. The P is responsible for oscillations of the system, the I is responsible for response time of the system and D is used to increase the sensitivity of the system. The values of these gain constants are set experimentally. First we make the K_i and K_d values as zero and vary the K_p value till we get sustained oscillations. [5] Once the K_p value is set we vary the K_i value and afterwards the K_d value to increase the response time and sensitivity of the system.

Table 1: ziegler – nichols

Control Type	K_p	K_i	K_d
P	$0.5K_u$	-	-
PI	$0.45K_u$	$1.2K_p/T_u$	-
PD	$0.8K_u$	-	$K_p T_u/8$
PID	$0.6K_u$	$2K_p/T_u$	$K_p T_u/8$

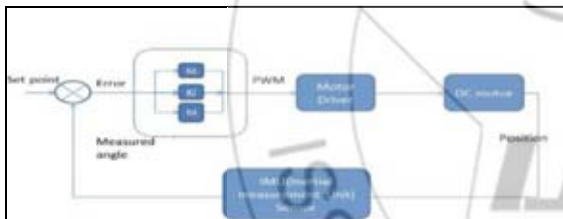


Figure 4: Modeled system

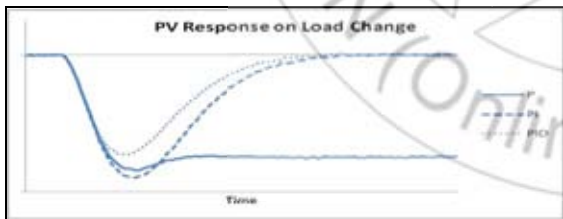


Figure 5: Comparisons of P, PI and PID

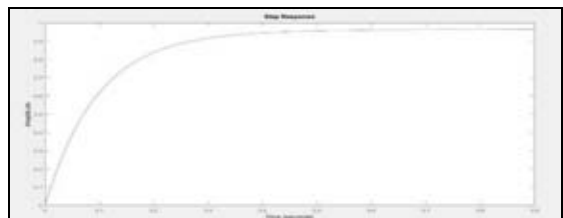


Figure 6: PID response for values of K_p , K_i and K_d using MATLAB simulation.

3. Image Detection

The image detection and the navigation of the robot can be achieved by using the ultrasonic sensor and the image processing system. With the help of this feature the robot is

able to navigate its path and decides what to be done when it detects the obstacle. For this purpose, raspberry pi is interfaced with the digital camera. The ultrasonic sensor is interfaced to the Arduino board.[6] The ultrasonic sensor uses the concept of sonar to detect the obstacles and measure the distance between them. The sensor transmits a high frequency sound wave on applying the appropriate trigger signal which is not audible to humans. The wave is transmitted and gets reflected by the obstacle and it is captured by the receiver, for calculating the distance between the sensor and the obstacle, the elapsed time is calculated between sending and the receiving waves.[7] So the distance in meters can be calculated as,

$$\text{Distance} = 343 * \text{elapsed time} / 2 \quad (2)$$

The Arduino board continuously measures the distance of the robot to the nearest obstacle in front of it. This distance is then compared with the reference value for e.g. 30 cm in this case and if this distance is less than the reference value, the Raspberry pi triggers the camera and captures the image. The image is then processed to obtain some useful information. Based on the information obtained from the image, the microcontroller navigates the path of the robot.[9] The colour image captured by the camera is converted to black and white image. The image is then cropped to remove any unwanted part of the frame. The size of the image can be reduced since the captured image is of reasonably high resolution. The size gets reduced and this image can be scanned for recognizing any symbol on it. For recognizing the symbol template matching has been used. The raspberry pi sends the appropriate signals to the microcontroller to turn the robot in the appropriate direction. This shows that using the image processing system the robot can easily navigate its path and move around accordingly.

4. Conclusion

We have designed and implemented the self-balancing robot which balances itself on two wheels and navigate its path around with the help of image processing system. Here by varying the various values of k_p, k_i , and k_d of the PID controller and by using the Kalman filter system is balanced and is capable of navigating along the smooth surface as shown.

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