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Development of A Two Wheeled Self Balancing Robot with Speech Recognition and Navigation Algorithm

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Abstract. This paper is aimed to discuss modeling, construction and development of navigation algorithm of a two wheeled self balancing mobile robot in an enclosure. In this paper, we have discussed the design of two of the main controller algorithms, namely PID algorithms, on the robot model. Simulation is performed in the SIMULINK environment. The controller is developed primarily for self-balancing of the robot and also it's positioning. As for the navigation in an enclosure, template matching algorithm is proposed for precise measurement of the robot position. The navigation system needs to be calibrated before navigation process starts. Almost all of the earlier template matching algorithms that can be found in the open literature can only trace the robot. But the proposed algorithm here can also locate the position of other objects in an enclosure, like furniture, tables etc. This will enable the robot to know the exact location of every stationary object in the enclosure. Moreover, some additional features, such as Speech Recognition and Object Detection, are added. For Object Detection, the single board Computer Raspberry Pi is used. The system is programmed to analyze images captured via the camera, which are then processed through background subtraction, followed by active noise reduction.

INTRODUCTION

Two wheeled Self Balancing Robots are one of the most widely discussed robots in the modern world and academia. Some reviews and previous works are at [1],[2],[3]. In this paper, the movement, the positioning system and navigation of the robot have been discussed. For navigation, a unique internal positioning system (IPS) has been developed. Previously, various IPS were developed like Wireless Indoor Positioning System [6] Ultrasonic Indoor Positioning System [7, 8]. But the common problem with those methods is that, those systems only could detect the robot in an enclosure. To locate other objects, wireless receivers with micro processors must be embedded on them. That will make the process more time-consuming. Also, the robot has to process huge amount of data from three Ultrasonic transmitters to get location, namely using the "Trilateration" technique. This process makes whole system slower. In this project, "Object tracking" method is proposed as a simple but effective solution for positioning. Because Object tracking method will allow not only to locate other objects in the enclosure but also it will take less time because the robot microprocessor will not need to do extra work. Another approach that makes this system unique is that, another PID controller [4] [5] is developed. There are various types of Methods for Object tracking.

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Such as Point tracking [9, 10], Kernel Tracking [11] and Silhouette Tracking [12, 13].In this project Point Tracking method is used. Because the Camera will be on much higher level than the robot, so Point Tracking will cause negligible error. Moreover, if Kernel or Silhouette tracking were used they will consume more time for processing signals which will make the system inefficient. In case of object detection methods there are also various methods [14]. Like Color Detection, Edge detection or Canny Edge Detector [15] etc. But these methods have some problems. Like Color Detection is too much simple and less accurate to specify the robot only. But Edge detection and Canny edge detectors are more time consuming. That is why the combination of the above three methods, Template Matching [16] is used in this project. For Vocal and visual information that can be used as communication media to allow machines to interact with people has attracted considerable attention in the development of intelligent human-machine interaction devices [17]. Speech processing has been one of the most exciting areas of the signal processing which has made it possible for machine to follow human voice commands and understand human languages. Automatic speech recognition (ASR) techniques have been widely used in numerous practical applications in recent years [18]. With the improvement of modern technology in case of smart phone devices and its device applications, the ASR function is attracting much attention to the people who has the fascination of communicating with the machine. The hidden Markov model (HMM) [19], artificial neural network (ANN) [20], and support vector machine (SVM) [21] are frequently used computational models for performing speech recognition tasks.

SELF BALANCING

Mathematical Modeling

The Basic Transfer Function that is used for this system is taken from Control tutorials of Prof. Bill Messner and Prof. Dawn Tilbury which are available at [23]. The Transfer Function is given below,

$$\phi(s) = \frac{\frac{ml}{s}}{s^3 + \frac{b(I+ml^2)}{q}s^2 - \frac{(M+m)mgl}{q}s - \frac{bmgl}{q}} f(s) \tag{1}$$

Where $\phi =$ yaw angle, M = Mass of Lower Base, m = Mass of Upper Part, I = Moment of Inertia b = Damping Coefficient and $q = [(M+m)(I+ml^2) - (ml)^2]$. Here f(s) is the Laplace Transformation of the Force Required, F(t). This force, is directly connected to the Torque of the Motor, τ.

$$\mathrm{F} = 2\tau r \tag{2}$$

Again, we can show that torque τ, is dependant on The Input Voltage of the Motor.

$$I = mr^2 \tag{3}$$

$$\tau = I\alpha \tag{4}$$

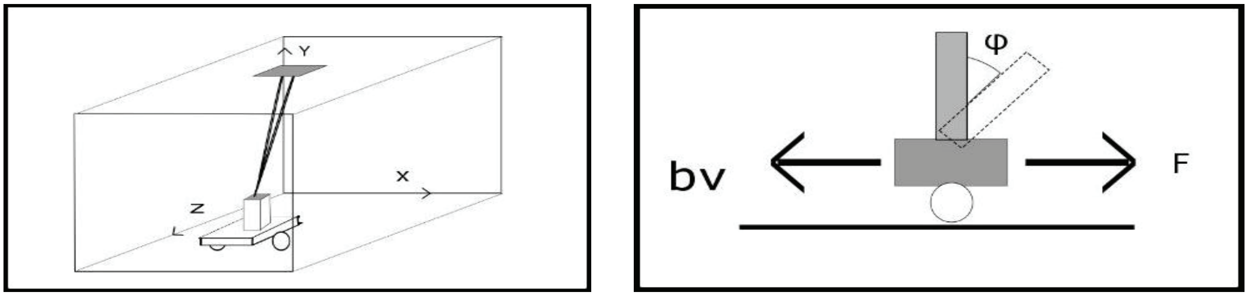
From [22], we know the relation between Input Voltage and Angular Displacement of the Motor,

$$\frac{\theta(s)}{E(s)} = \frac{\frac{K_t}{R_a J_m}}{s\left[s + \frac{1}{J_m\left(D_m + \frac{K_t K_b}{R_a}\right)}\right]} \tag{5}$$

Here, the value of $K_t R_a$ and K_b can be obtained from the Relationship between the Torque, τ and angular velocity ω [22],

$$T_m = -\frac{K_b K_m}{R_a}\omega_m + \frac{K_t}{R_a}e_a \tag{6}$$

We know that,



(a) (b)

FIGURE 1. (a) Free Body Diagram of The Positioning System , (b) Free Body Diagram of The Self Balancing.

$$\alpha(s) = s^2\theta(s) \tag{7}$$

So, the equation (5) will become,

$$\frac{\alpha(s)}{E(s)} = s\frac{\frac{K_j}{R_a J_m}}{[s+\frac{1}{J_m}\left(D_m+\frac{K_j K_m}{R_a}\right)]} \tag{8}$$

Now, from equation (1),(2) ,(4) and (8) the final Equation will become ,

$$\phi(s) = AE(s) \tag{9}$$

Where,

$$A = \frac{ml}{s^3+\frac{b(I+ml^2)}{q}s^2-\frac{(M+m)mgl}{q}s-\frac{bmgl}{q}}\frac{1}{2mr^3}\frac{\frac{K_t}{R_a J_m}}{[s+\frac{1}{J_m}\left(D_m+\frac{K_t K_b}{R_a}\right)]} \tag{10}$$

This is the Required relation between input voltage and yaw angle, ϕ.

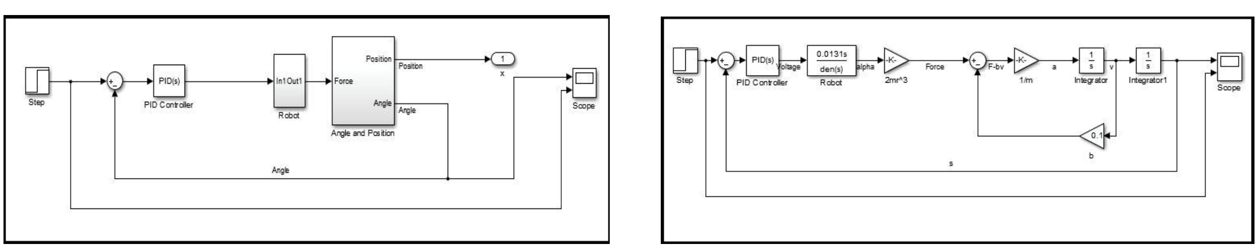
Controller Design

By definition, the Formula for PID controller is

$$E = K_p e(t) + K_j \int e(t) + \frac{d}{dt}e(t) \tag{11}$$

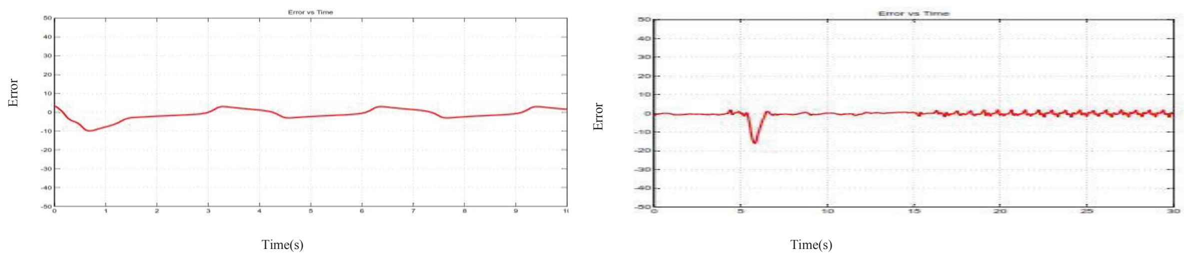
Where,

$$e(t) = S_p - \phi(t) \tag{12}$$



(a) (b)

FIGURE 2. SIMULINK Model of (a) Self Balancing Robot and (b) Navigation System



(a) (b)

FIGURE 3. (a) Simulation and (b) Practical Results

The Free body Diagrams of the project is shown in Fig. 1**.**

Simulation

A SIMULINK Model has been developed for the Self Balancing of the Robot (Fig. 2(a)). By trial and error the PID gains, K_p, K_d and K_i are determined . They are 113,1.38 and 0.13 respectively. Fig 3 shows the simulation results.

NAVIGATION SYSTEM

Algorithm

The Algorithm Used for Navigation System is given below,

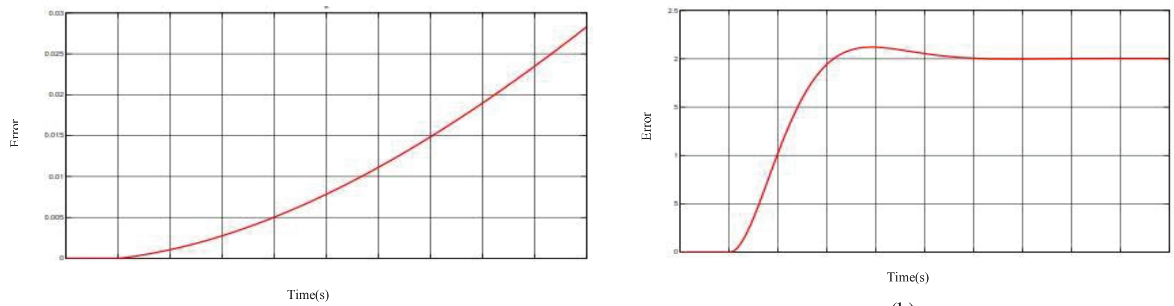
1. Load the template and convert it to grayscale image.
2. Measure the Height and width of the template.
3. Start Capturing Images.
4. Convert Every Image into a Grayscale Image.
5. Match Template Using Squared Difference Method.
6. Search for the Minimum value in the resultant Probability Matrix.
7. If the Minimum Value is equal to Desired Calibrated Minimum Value, then the location of the minimum in the resultant matrix is the location of the top left corner of the template matrix.
8. Determine the Bottom Right Corner of the Resultant Template Matched Area. Then Derive the Center of the template averaging the points.
9. Else there is no robot in the room.
10. Go to Step 3.

Mathematical Model

For modeling the navigation system, we have to start again from equation (12). Using Newton's Second Law,

$$ma = f - bv \tag{13}$$

Where, b is the Damping Coefficient, which is assumed to be 0.1 and v is the linear velocity. m and a are mass of the robot and linear acceleration respectively. Now,



(a) (b)

FIGURE 4. Navigation System Simulation Results (a) Without Controller and (b) With Controller

$$x = \int\int a = \int\int \left[\frac{F - bv}{m}\right] \tag{14}$$

$$E = K_p e(t) + K_i \int e(t) + K_d \frac{d}{dt} e(t) \tag{15}$$

Where,

$$e(t) = S_p - x \tag{16}$$

The SIMULINK Block Diagram for the Navigation system is shown in Fig. 2(b) with PID controller block.

Simulation and Practical Results

Using SIMULINK PID controller block, the Correct PID parameters are determined using PID tuning. The gains are K_p = 2696, K_i=259 and K_d = -1321. The Simulation result using controller is shown in Fig. 4(b). We can observe from Fig. 4(a) that the position goes to infinite without the controller. Which won't happen if we use the controller. In Fig. 4 the Positioning of the Robot is shown. From the Image processing, the Location is shown to be x=693, y=1354. Which Corresponds to x = 18 and y = 44. The Real Position was x = 20, y=44 cm.

(a) (b) (c)

FIGURE 5. (a) Template (b) Detected Object (c) Prototype

OBJECT DETECTION

Algorithm

1. Capture Image.
2. Subtract Background using Template Matching.
3. Sharpen Noisy Images
4. Convert to Binary Images.

(a) (b) (c) (d)

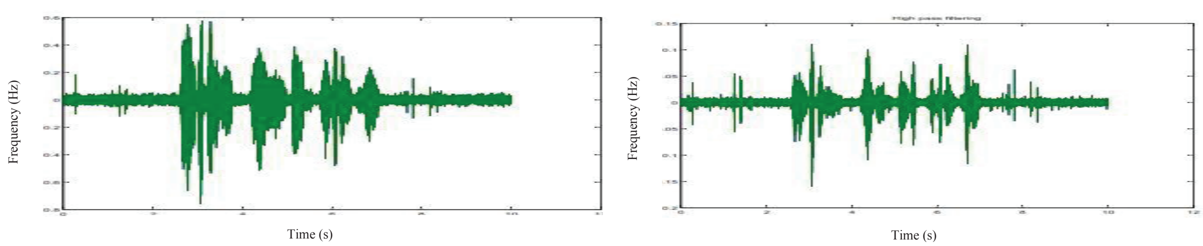
FIGURE 6. (a) Prototype (b) Current Frame (c) Subtracted Background (d) Shape and Centroid Detection

5. Detect Shapes of the Object using Contour Detection Algorithm.
6. Determine Centroid of the Object by drawing Rectangles where ever Contours are Matched.
7. Go To Step 1. The Whole Process is shown in Fig. 6

SPEECH RECOGNITION

Algorithm

1. Take Voice Input
2. Filter the Signal Using Kalman Filtering. Original Voice Signal and High pass filtered signal is shown in Fig. 7
3. Translate the filtered signal to text Command.
4. Search Object according to the text
5. If No Object Name is stored in the memory surf through Internet to find the Object
6. Do Job according to the Voice Command
7. Go to Step 1.



(a) (b)

FIGURE 7. (a) Original Voice Command (b) Filtered Voice Command.

CONCLUSION

The Prototype of the Robot is shown in Fig. 5(c). We have developed a mathematical model of the robot. Here, the input is Voltage supplied to the motors and the output is the yaw angle of the robot. Existing works on inverted pendulum always have force as input not voltage of the actuator. Also mathematical model has been developed for the navigation system. Controllers for both of the systems had been developed and the practical experiments' results match quite perfectly with the simulation results. The Use of Object tracking technique as Navigation system makes the robot move more accurately and smoothly. Here the Speed of the Image processing for Object tracking is increased using OpenCV platform. Again, the use of the "Raspberry Pi" makes the robot work fast for object detecting and sound processing. For processing the sound signal, "Kalman filtering" technique has been used. Still there are some areas of development and future work of the Robot. As the System is a Nonlinear System, we need to develop a non linear controller for best result. For navigation, we need to devise algorithms for multi room enclosure. With all of these constraints the robot gave us good result.

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