J. Basic. Appl. Sci. Res., 3(1)843-848, 2013
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Autonomous Dual Wheel Self Balancing Robot Based on Microcontroller

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ABSTRACT

An autonomous dual wheel self balancing robot is developed that is capable of balancing its position around pre-determined position. Initially the system was nonlinear and unstable. It is observed that the system becomes stable after re-designing the physical structure of the system using PID controller and analyzing its dynamic behavior using mathematical modeling. The position of self balancing robot is controlled by PID controller. Simulation results using PROTEOUS, MATLAB, and VM lab are observed and verified vital responses of different components. Balancing is claimed and shown the verification for this nonlinear and unstable system. Some fluctuations in forward or backward around its mean position is observed, afterwards it acquires its balanced position in reasonable settling time. The research is applicable in gardening, hospitals, shopping malls and defense systems etc.

KEYWORDS: Two wheel robot, Self-balance, Microcontroller, controllability, Actuators.

INTRODUCTION

The Conquest of robots in human's life is in different ways like guard robots, services robots, fire-fighter robots, entertaining robots and human robots. There is an immense research going on making them cheap, efficient and reliable. An important class of autonomous wheel mobile robots is dual wheel upright self-balancing robots. Their movement is usually flexible. Dual wheel Robots has two wheels and a vertical body frame on which all circuitry is placed. Its mechanism is like a human that balances. It adjusts its possition, when it is about to fall forward or backward to aviod the unstablility. Unlike conventional mobile robots, dual wheel self-balancing robots bring practical advantages as follows:1) Movement on zero radius curve, 2) High tolerant to impulsive force, 3) Small foot print help to move on dangerous places, 4) Greater stability over slopes. The working of these systems is like single inverted pendulum [1] as shown in Fig 1. Motion of robot in the system is not planar and the motors driving the wheels are directly mounted on its body.

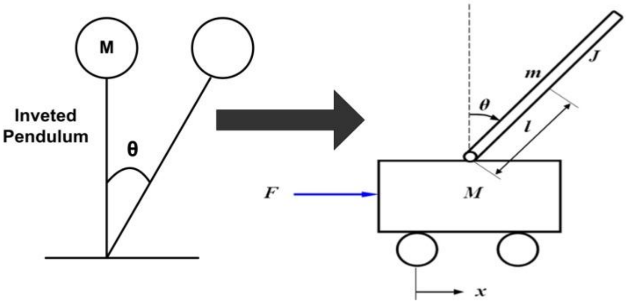

Fig. 1. Inverted pendulum as analogy of self balancing robot.

Literature survey shows that two wheel self-balancing robot and *segway* is commercially available [2, 3, 4]. Another mobile robot is *Joe* that used for radio control, made by Swiss Federal Institute of Technology Switzerland [5, 6]. They used two state space controllers for controlling its horizontal and vertical rotation (pitch, yaw). Filters help to calculate tilt angle driven by accelerometer and gyroscope. David built *Nbot* robot. This robot is balanced with help of four parameters position, velocity, angular position and velocity of wheels .The output of the gyroscope and accelerometer is together by kalman filter, so the input is accurate for the stability. The purpose of this robot is to move up and down to stairs [7, 8]. *Legway* was constructed by Steven Hassenplug. In this robot mind storms robotic kit was used. The tilt angle is measured by two Electro Optical Proximity Detector (EOPD). There is another famous *Equibot* robot made by Dan Piponi. It uses sharp infrared ranger GP2D120 to measure the distance of the robot from the ground. By using this distance microcontroller is able to calculate the tilt angle [9].

In this paper, two wheel self balancing robot is developed by mathematical modeling of its dynamic behavior using differential equations which leads to state space model of the system, designing its controller in Proteous and its stability is achieved by PID controller and linearizing the state space model. Differential equations of system were observed and existing constants of equations were measured and after mathematical simulations a best location of center of gravity and

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sensors were determined. System coding is done on VM lab. The robot is balanced and controlled through a series of operation on the system feedback. Measurement is taken out from accelerometer and send it to analog to digital converter, then it is controlled and regulate by PID controller, the values taken from PID controler are then used for timer configuration for its duty cycle setting, which further generates a PWM for that value of accelerometer and give it to motor controller circuit and it drives the system actuators to balance on set point.

Rest of the paper is organized as follows: In section 2 we explain structural design of our robotic system. In section 3 mathematical modeling of robot is presented. In section 4 robotic system development is shown. In section 5, we have discussed our results. Finally, in section 6, we make concluding remarks.

ROBOTIC SYSTEM-STRUCTURAL DESIGN

A two wheel self balancing robot based on microcontroller is developed, driven by servo motors and it consists of one vertical frame carrying weight of all circuitry supported by two wheels. This vertical frame has two circuit boards of H-bridges and other one is to control the overall operation of the robot. Motion of servo motors is controlled by H-bridges in clockwise or anticlockwise direction. Two batteries along with two servo motors are placed on horizontal plate. Our robot is balanced and controlled through a linearization of system feedback using PID controller.

Robot Chassis: The robot contains two vertical plates on which two slots are inserted one is very near to the earth and other is right above to it. One horizontal plate contain the battery of the robot and the other one contains the circuitry on it. The horizontal plates can adjust and move up and down but the height of the robot is fixed and can not be change due to centre of gravity beacause the control circuits are mounted to the body [10]. Only one way to change it by replacing the vertical plates of the robot and increasing it length or decreasing.

Material, Size and Weight: The material used in a design limits the durability, strength, maintainability, energy efficiency and operating capability of the robot. They also impact on the size and contribute to the total weight of the final design. A heavier material such a metal is typically stronger then lighter materials such as plastics but it requires more energy to move. The size of the design impacts on its ability to navigate around, through or over obstacles as well as its transportability.

Several options are available for joining the chassis pieces together such as bolts, screws and welding but rivets were the preferred method in this case. The estimated total weight goal was initially 5Kg. The weight values calculated for each respective layer as follows

Chassis Weight = 4.325 kg (including Motor and Wheel) Height = 21 cm.

Motors: There are many types of motors that can be used to move the robot in any direction. DC Servo motor is used to control the movement of the robot along with feedback. There are two main reasons for the selection of servo motor. One is Gear ratio and other is encoder. There are two pulleys in the servo motor. The smaller pulley with gear ratio 68.5:1and it rotates 68.5 times than larger pulley for one complete revolution as shown in Fig 2. The actuators are controlled by H-bridges which takes PWM from Microcontroller.

An encoder is a device or transducer that converts information from one format or code to another, in order to get standardization, speed, secrecy and security. Encoders with 500 and 34250=68.5x500 counts per revolution(CPR) are used for small and large pulley respectively. The speed of the motor can be controlled by altering the duty cycle percentage, which is calculated as follows.

$$Duty\ Cycle = \frac{T_{ON}}{T_{ON} + T_{OFF}} = \frac{T_{ON}}{Time\ Period}$$

Accelerometer MMA7260QT are used to find out the linear acceleration of robot. Fig 3 is showing overall structural view of our two wheels self balancing robotic system.

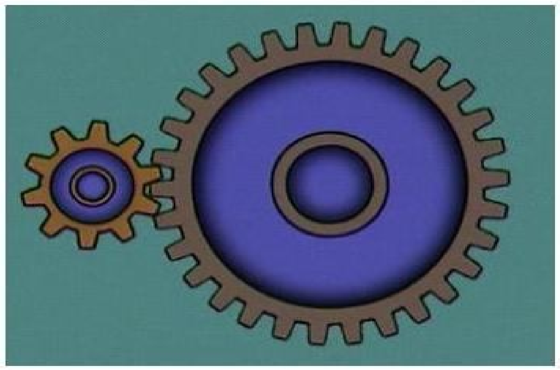


Fig. 2. Gears of servo motor.

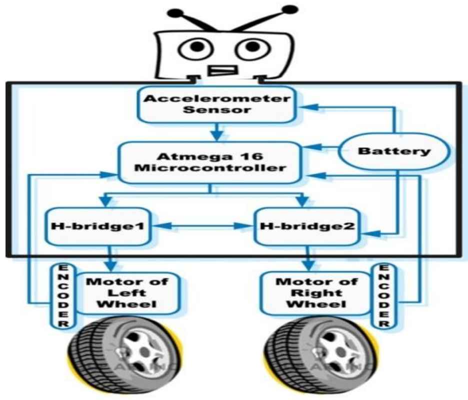


Fig. 3. Flow chart showing overall system mechanism.

ROBOTIC SYSTEM MODELLING

Dynamics of Robots: Mathematical modeling in 3 dimensions is proposed considering its position and orientation of roll, pitch, yaw. For simplicity, orientation in y axis (yaw) is focused. So it has one Degrees Of Freedom (DOF). It assumed that center of gravity of robot is located at point P and θ_p presents the pitch angle. The coordinate of point P will change if robot moves away from its initial location along X0 axis as shown in Fig 4.

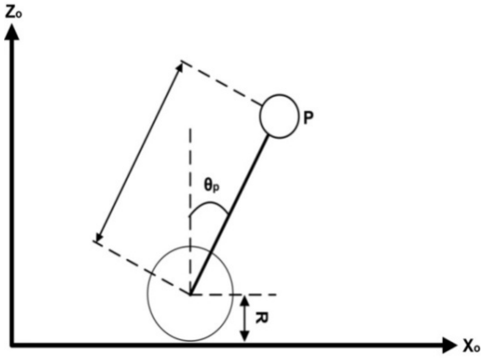


Fig. 4. Dynamic modeling of robot having single dimension instability [11].

The linear continuous state space representation of the robot is shown in equation 1.

$$\begin{bmatrix}\dot{x}\\ \ddot{x}\\ \dot{\varphi}\\ \ddot{\varphi}\end{bmatrix}=\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & \frac{[2K_M K_e(M_P l_r - I_P - M_P l^2)]}{r^2 R\alpha} & \frac{M_P^2 g l^2}{\alpha} & 0\\ 0 & 0 & 0 & 1\\ 0 & \frac{2K_m K_e(r\beta - M_p l)}{r^2 R\alpha} & \frac{M_p g l\beta}{\alpha} & 0\end{bmatrix}\begin{bmatrix}x\\ \dot{x}\\ \varphi\\ \dot{\varphi}\end{bmatrix}+\begin{bmatrix}0\\ \frac{2K_m(I_P + M_P l^2 - M_P l r)}{rR\alpha}\\ 0\\ 2K_m(M_P - r\beta)/rR\alpha\end{bmatrix}V_a \qquad (1)$$

Where,
x - Displacement
$\dot{x}$ - Displacement velocity
φ - Angle
$\dot{\varphi}$- Angular velocity
θ - Parameters position
$\ddot{x}$ - Linear Motion acting on center of wheel
$\ddot{\varphi}$- Angular motion acting on wheel

$$\beta = (2M_\omega + \frac{2I_\omega}{r^2} + M_P)$$

$$\alpha = (I_p\beta + 2M_P l^2(M_\omega + I_\omega/r^2)$$

ROBOTIC SYSTEM DEVELOPMENT

System Mechanism: Our robotic system is shown in Fig 5. The system monitors the accelerometer value and tries to process it as much accurate as possible. The accelerometer (MMA7260QT) sends signal to RC filter. After removal of noise it is send to Microcontroller (ATmega16) for analog to digital conversion. Afterwards PID controller finds the error [6]. The Microcontroller generates Pulse Width Modulation (PWM) and H-bridge takes PWM from microcontroller to rotate both motors either in clockwise or anticlockwise direction. Table 1 shows all designed specification of the designed robot.

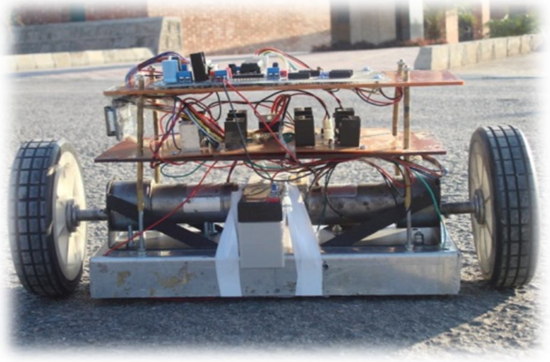


Fig. 5. Proposed and designed two wheel self balancing robot

Table 1. Parameters of our Two Wheel Self Balancing Robot

Symbol	Parameter	Value
M_m	Motor Mass	671g = 0.671 kg
K_m	Back EMF Constant	4.58x10-2 = 0.0458 Vs/Rad
K_T	Torque Constant	4.58x10-2 = 0.0458 Nm/A
Km	Motor Constant	2.90x10-2 Nm/W-2
R_T	Resistance (Armature/Terminal)	2.49 Ω
T_F	Fraction Torque	5.6x10-3 = 0.0056 Nm
I_r	Motor rotor Inertia	7.10x10-6 Kg.m2
Iw	Robot Wheel Inertia = (Mw x R^2)/2	2.3250
I_L	Robot Chassis Inertia = (h^2 + d^2) /12	0.1124
D	Distance between Contact Patches of Wheels	16 cm
G	Gravitational Force	9.81 m/s2
L	Distance between Centre of gravity and Centre of Wheels	1.5 cm
M_P	Chassis Mass	4.325 kg
R	Wheel Radius	3.05 inches

Controlling Mechanism: Controllability of a system is the ability of the system to attain the desired state within a finite period. To achieve controllability of nonlinear self balancing robot is daunting task. In desgined robotic system, PID controller is used to regulate and achieve the required trajectory. This process is carried out by discreatizing the angles observed by accelerometer as shown in Fig 6. Microcontroller generates the PWM signal by comparing it with error signal of controller and moves the motors either in clockwise direction or anticlockwise direction.

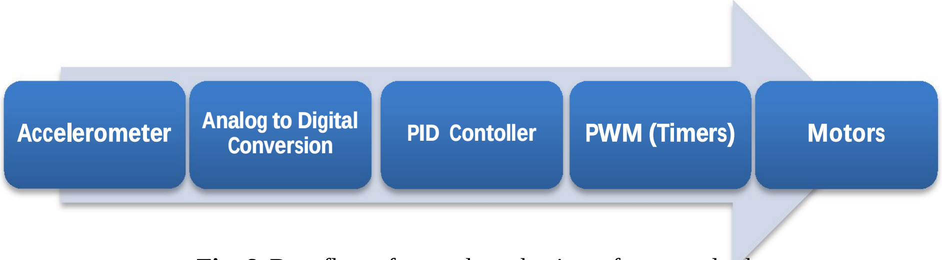


Fig. 6. Data flow of control mechanism of proposed robot.

PID Controller: PID Controller is a common feedback loop component in an industrial control systems and applications.[12, 13, 14, 15] This finds the difference between actual set point or pre-determined position and result comes from the system.Optimum value of gains of PI controller is calculated for the proposed design requirement.

$$K_p = 1 \text{ and } K_i = 0.01$$

If higher the value of K_p, the faster the controller response but a too high value leads to an undesirable oscillations. Integral term K_i is used to reduce the steady state error, osicallations and jerks. The position of robot is calibrated through accelerometer. The reference input u(t) is relationship of mass and voltage of accelerometer as shown in equation 2 [16].

$$u(t) = MV(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{d}{dt} e(t) \qquad (2)$$

Here;
P_{out}: Proportional term of output
K_p: Proportional gain, a tuning parameter
K_i: Integral gain, a tuning parameter
K_d: Derivative gain, a tuning parameter
e: Error = $SP–PV$
t: Time or instantaneous time (the present)

In Table2, the maximum error is 170 which occurs in one direction. It is assumed that the value of timer register 128 at which it will generate 50% duty cycle. (Say "half Val"). In general form we can write it as:

Ocr2 = (p.v *half_val) / accelero (3)
D.C = (p.v*50)/170 (4)
Ocr2 = (D.C*128)/50 (5)
Using (3) in (4) gives
Ocr2 = ((p.v * 50)/170) * (128/50) (6)
Ocr2 = (p.v * 128) / 170 (7)

RESULTS

Figure7 shows the response of system while it is controlled by Proportional Integral (PI) controller. The gains are Kp=1 and Ki=0 which are calculated by eq (2). Fluctuation in system causes oscillation, PID controller finds error and system goes to stable within 4ms according to 2% criterion. The sensor calibration is the first step to use the sensor correctly and with accuracy. Figure 8 shows the plot of calibration of accelerometer, which is taken at run time. As in this paper the degree of freedom is one, so when accelerometer moves from 90^0 to 0^0 the voltages increases and when it moves from 90^0 to 180^0 voltages decreases because 0^0 is our set point. Fig 9 shows the accelerometer behavior, it can be observed that the disturbance in the system creates lesser peaks in the voltage and indicates that there is tilt angle in the system. At 0^0 it generates 2.3 V which is a maximum amplitude without disturbance in system, but the system requries some time to stablize. Afterwards peak amplitude remains maximum because system moves around its means position and microcontroller according to accelerometer reading generates the PWM signal.

In table 2 the parameters of two wheel self balancing robot are shown. The maximum timer value in the timer register is responsible for the generation of more duty cycle and vise versa.

Table 2. Microcontroller Timer register value corresponding to Accelerometer reading

Accelerometer reading	Duty cycle (%)	Timer register value
340	100	255
170	50	128
0	0	0

lf balancing robot are shown.

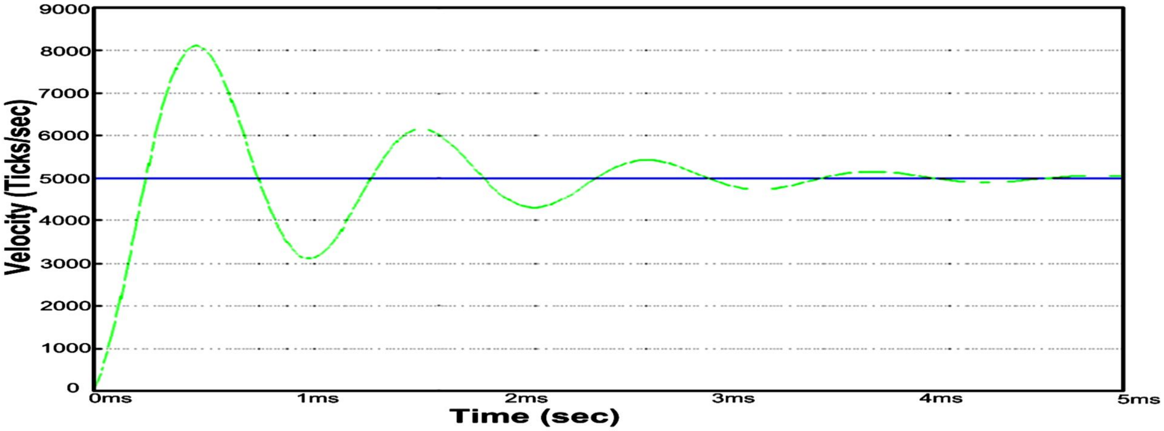
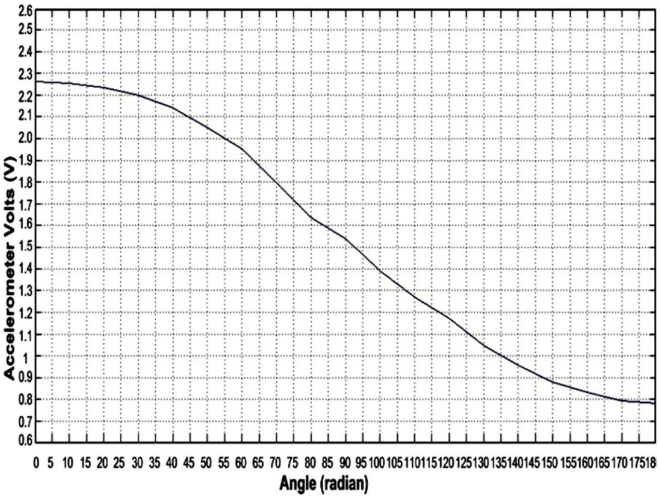


Fig. 7. PID controller response of proposed system.



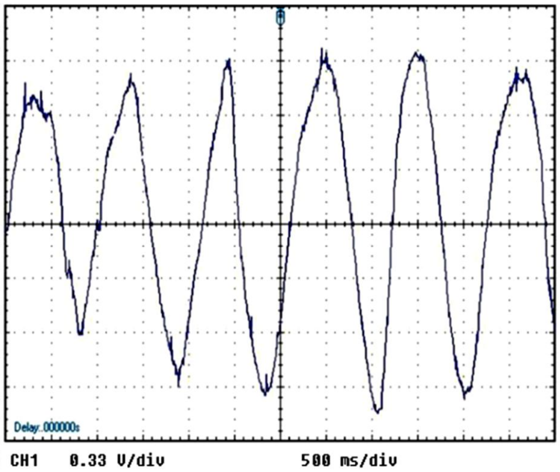


Fig. 8. Accelerometer response in voltages tilted to particular angle.

Fig. 9. Accelerometer voltage variations subject to when constraint of unbalancing condition.

Conclusion

The dynamic mathematical model of the balancing robot is formulated by differential equation method using state space modeling procedure. A PID controller is designed to find out the difference between actual set balance point and out come from over all system. The measurement of accelerometer, analog to digital converter, PID controller and microcontroller generated PWM for actuators are used to balance a system and leads the whole system to balance point by rotating the motors either in clockwise or in anticlockwise direction. Measuremet result shows stable and balanced points even for sever condiations.

Acknowledgment

The author acknowledges COMSATS Institute of Information Technology, Islamabad, Pakistan and National Development Complex (NDC) for the support of Research funding.

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