Middle-East Journal of Scientific Research 24 (3): 564-570, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.03.23036

# A Study of Control of Self Balancing Robot System

*A. Aswathy and S. Sumathi*

Department of EEE, Mahendra Engineering College, Tamilnadu

**Abstract:** An automated or self-balancing robot is a special type of wheeled mobile robot or simply we can call as automated cycle. Due to its instability in balancing, become one of the hot research topics. There are different system models to control like Proportional Integral Derivative (PID) System pole placement and Linear-quadratic regulator (LQR). The investigations for controlling the dynamic behavior and the balancing results a product with fully automated. In conventional Uni-cycle, the rider can control the speed of travel by leaning forwards or back. PID controller is used for controlling speed. This paper show, how the robot is controlled by LQR controller. Moreover by using different controllers for controlling balance and speed will increase the application level and also the development of the implementation of new features in to the vehicle.

**Key words:** Self-balancing robot · PID controller · LQR controller

## INTRODUCTION

Global warming and global pollution are the problems which has no easy solutions. Reducing the use of automobiles and motorcycles are one of the best ways to reduce pollution as well as global warming. One of the major reasons for increasing disease rate in human beings is pollution. So in order to reduce this pollution and high density in traffic we need economically well, lighter new innovations. Also that must meet our daily requirement. The research for such lighter vehicle starts from 1987 by Proff. Yamafuji [1]. But the fact is that yet the product is not commercialized. The system can be implemented pitch, role, yaw measuring sensors and feedback controllers [2].

The most complicated part in designing such a robot is its balancing problem. For simplifying the balancing problem we can move with one wheeled vehicle [3,4,5] rather than two wheels. The problem with two wheeled vehicle is two wheeled synchronization and body balancing need to consider simultaneously. For this synchronization the vehicle need number of sensors and its monitoring. Increase in number of sensors increases the cost and complication. This is the reason behind why we choose one wheeled vehicle [3, 6] it will maintain all the merits of two wheeled vehicle with simple cost effective, non-complicated mechanism.

Due to the friendliness and light weight, people use bicycle for short distance transportation. For short distance transportation like in large industries, universities, colleges, hospitals, private areas we can use robot vehicle. To designing a comfortable vehicle, the inherent nonlinearity should be under control. Both Mechanical and Electronics Engineers are behind this, with several mechatronic solutions [8].

The system can be implemented pitch, role, yaw measuring sensors and feedback controllers [9]. Earlier steering based acceleration control is applied for controlling purpose. The controlling action is done by servomotor and electric motors [6]. This type of model is developed based on the principle, equilibrium of gravity and centrifugal force. Later self-balancing robot developed by using gyroscope and accelerometers. The sensors used for measuring inertia together known as IMU sensors (Inertia Measuring Unit). The sensors detect the inclination and controller produce control signals as torque to overcome the inclinations.

Due to the friendliness and light weight, people use bicycle for short distance transportation. For short distance transportation like in large industries, universities, colleges, hospitals, private areas we can use robot vehicle [7,8]. To designing a comfortable vehicle, the inherent nonlinearity should be under control. Both Mechanical and Electronics Engineers are behind this, with several mechatronic solutions [9,10].

The research workers generally concentrated on PID controllers. For human transporter vehicle, [11] studies show that LQR has several advantages than PID. The following discussions in this paper include design and modeling of LQR control system and speed control by using BLDC motor [12]. The BLDC motor can be

**Corresponding Author:** A. Aswathy, Department of EEE, Mahendra Engineering College, Tamilnadu, India.

Fig. 1: One-wheeled balancing robot vehicle.

controlled using PID controller. The Mechanical and Kinematics studies are already discussed topics, hence have no scope in this paper.

**Working Methodology:** Both unicycle and electric vehicle has its own merits and demerits. Unicycle has problem in balancing in pitch and yaw direction. In electric vehicles gyroscopes are used to balance the vehicle. The speed is physically controlled by lean back and forth. The corresponding control action is taken done according to gyroscope output signal. The Working Procedure is given below;

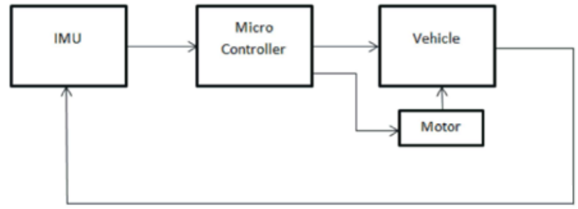


Fig. 2: Basic layout diagram

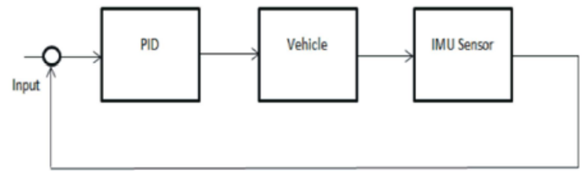


Fig. 3: PID controlled robot vehicle control system.

- The IMU sensors the pitch angle and data will send to microcontroller.
- A LQR and for speed controlling PID control algorithm is programmed into the microcontroller.
- The Microcontroller then processes the output in reference to input from IMU and sends out PWM signals.
- The PWM signals are fed to motor driver which then controls the motor.
- Torque of the motor is according to the output voltage and input applied.

**How to Control Robot:** The earlier methods or already implemented vehicles are using PID controller just because of the simplicity. The LQR has several advantages.

- LQR can integrate all output state variables to calculate a output control signal, where a PID controller will fail without a precise feedback.
- Comparing to PID for LQR the time taken to achieve steady state response and overshoot is low.
- Multiple feedback will results accurate controlling signals according to the sensors output.

**LQR Control System:** The basic block diagram of a LQR control system is shown in the block diagram. From the block diagram itself we can see there are multiple feedbacks and this are compared with a reference input.

The working of LQR system is similar with conventional closed loop control system, except a reference input is given to control the system. The output of the control system is fed to vehicle, where an actuator is used for applying necessary corrective balance actions.

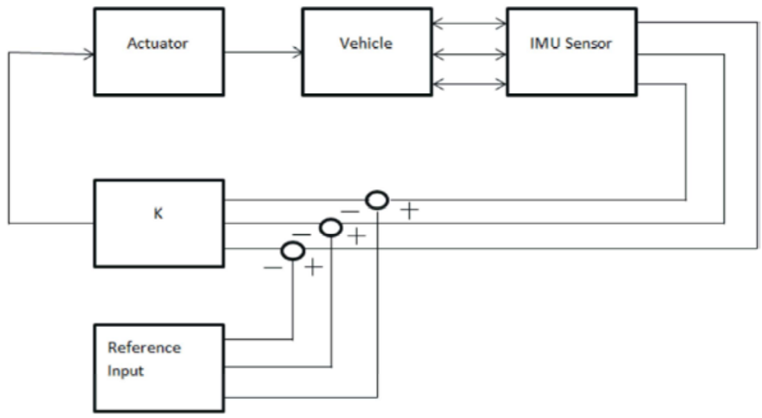


Fig. 4: LQR controlled robot vehicle control system.

**Modelling of Lqr Control System:** The robot system has state equations [12].

$$\dot{x}(t) = Ax(t) + Bu \tag{1}$$

A and B are constant matrices. The state space equations can also be written as

$$u = -Kx + v \tag{2}$$

By combining (1) and (2) we get

$$\dot{x} = (A - BK)x + Bv \tag{3}$$

Assume v=0, Two constants are used for getting optimum solution. The constants are Q and R

$$J = \frac{1}{2}\int_0^\infty (x^T Qx + u^T Ru)dt \tag{4}$$

Q is positive semi definite,

$$(x^T Qx \geq 0)$$

R to be positive definite,

$$(u^T Ru > 0)$$

By substituting (2) in (4) we get

$$J = \frac{1}{2}\int_0^\infty x^T (Q + K^T RK)xdt \tag{5}$$

For calculating K a constant matrix P is assumed. The P matrix such that,

$$\frac{d}{dt}(x^T Px) = -x^T (Q + K^T RK)x \tag{6}$$

And can be simplified into form

$$A^T P + PA + Q + K^T RK - K^T B^T P - PBK = 0 \tag{7}$$

Then we can set

$$K = R^{-1} B^T P$$

(7) is changed to

$$PA + A^T P + PB^{-1} RBP + Q = 0 \tag{8}$$

The values of P and K can be calculated from equation (7) and (8).
And U (t) can calculate from following equation.

$$U' = u' = -Kx = -R^{-1} B^T Px \tag{9}$$

By trial and error method $k_1$ $k_2$ $k_3$ values can be obtained, $k_1$ is inclination angle. $k_2$ $k_3$ cannot be negative. The control ability of motor will reduce with high R value. So in order to set R with a low value R is taken as 1.

Furthermore for an LQR system larger value of P causes fast inclination response. Hence the value of p is taken as 50 times greater than q and r.

$$\begin{bmatrix} p & 0 & 0 \\ 0 & q & 0 \\ 0 & 0 & r \end{bmatrix}$$

$$\begin{bmatrix} 200 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 10 \end{bmatrix}$$

From this gain can be calculated [2] as,

$$[-24.30 \quad 18.80 \quad 62.5]$$

The values are put in Simulink file and can be executed. The same can be implemented using lqry () in MATLAB.

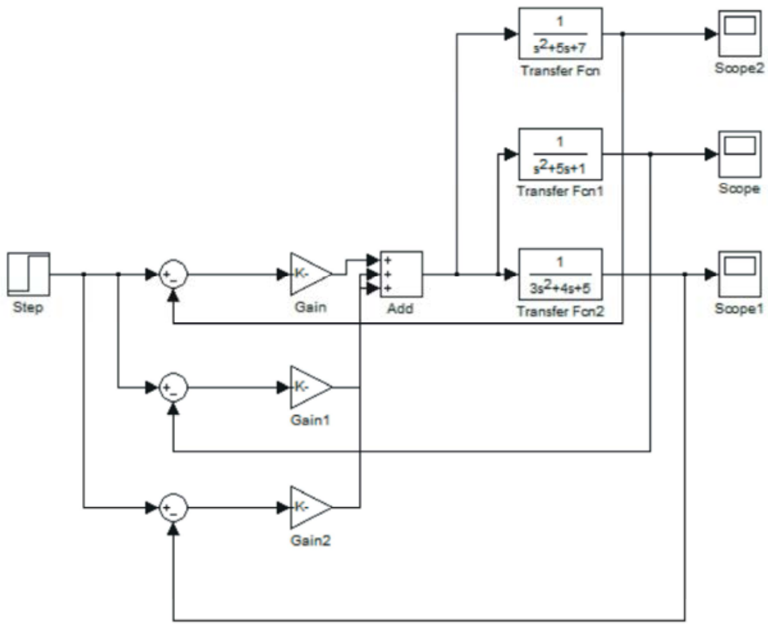


Fig. 5: LQR controller Simulink diagram.

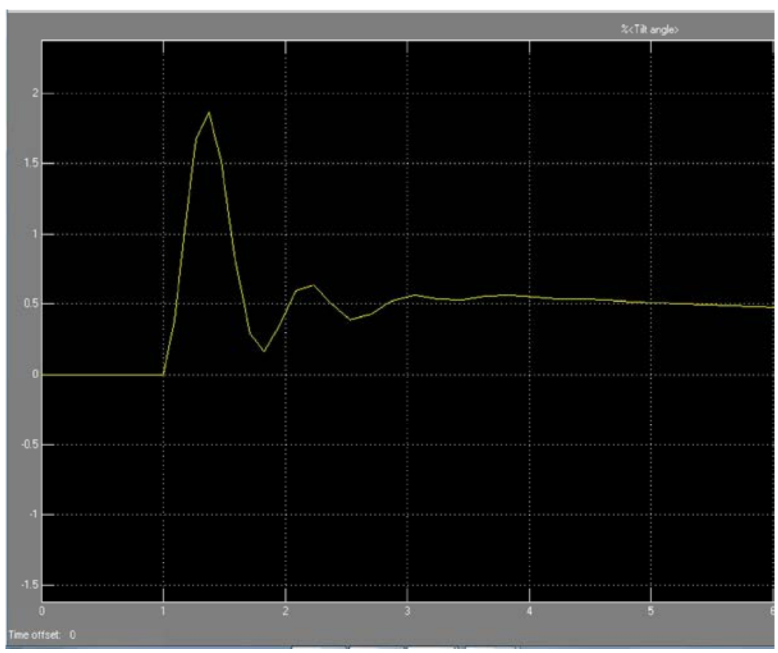

Fig. 6: LQR controller simulation.

**Speed Control of Lqr Based Robot Vehicle:** The poor dynamic characteristics and lower torque at lower speeds and low efficiency of induction motors are replaced by BLDC (Brushless DC motor)In BLDC motor the power loss occur in the stator and heat can be transferred through cooling system. Even though the DC motors have high torque capacity and smooth speed control and flux control the BLDC motor is used in various fields in industry like medical, aircrafts, military and instrumentation. The flexible construction, simple maintenance, low price and reliability are the major advantages of BLDC motor. The disadvantages of induction machines make the BLDC motors become more attractive option than induction motors.

The block diagram of the proposed speed control using PID controller is shown below.

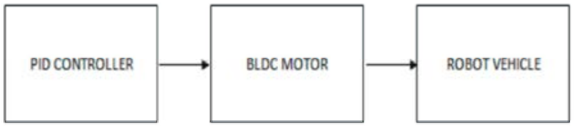


Fig. 7: Block diagram of speed control.

Table 1: PID parameters

| Pid Gains | Values |
|---|---|
| $K_p$ | 9 |
| $T_i$ | 0.04 |
| $T_D$ | 0.01 |

**Modelling of Bldc Motor:** Applying Kirchhoff's law for three phase stator loop windings,

$$v_x = R_x i_x + L_x \frac{di_x}{dt} + M_{xy} \frac{di_y}{dt} + M_{xz} \frac{di_z}{dt} + e_x \quad (10)$$

$$v_y = R_y i_y + L_y \frac{di_y}{dt} + M_{yx} \frac{di_x}{dt} + M_{yz} \frac{di_z}{dt} + e_y \quad (11)$$

$$v_z = R_z i_z + L_z \frac{di_z}{dt} + M_{zx} \frac{di_x}{dt} + M_{zy} \frac{di_y}{dt} + e_z \quad (12)$$

$e_x$,$e_y$,$e_y$ are functions of angular velocity.

$$e = K_e \omega_m \quad (13)$$

where $K_e$ is the back-emf constant. So we can represent BLDC motor in matrix form.

$$\begin{bmatrix} L_x & M_{xy} & M_{xz} \\ M_{yx} & L_y & M_{yz} \\ M_{zx} & M_{zy} & L_z \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} = \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} - \begin{bmatrix} R_x & 0 & 0 \\ 0 & R_y & 0 \\ 0 & 0 & R_z \end{bmatrix} \begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} - \begin{bmatrix} e_x \\ e_y \\ e_z \end{bmatrix} \quad (14)$$

For a surface mounted BLDC motor design the stator self-inductance are independent of the rotor position. Hence,

$$L_x = L_y = L_z = L$$

Mutual inductance will have,

$$M_{xy} = M_{xz} = M_{yx} = M_{yz} = M_{zx} = M_{zy} = M$$

And the resistance is also equal.

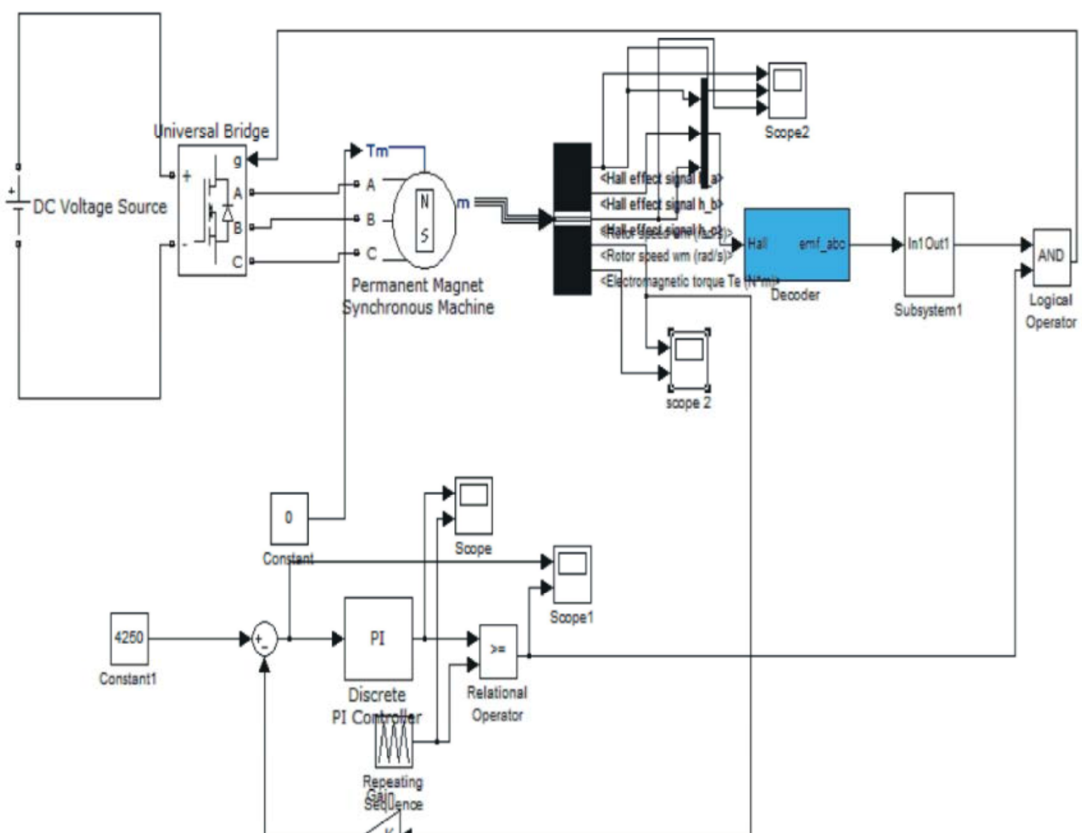


Fig. 8: Simulink diagram of Speed control of BLDC motor.

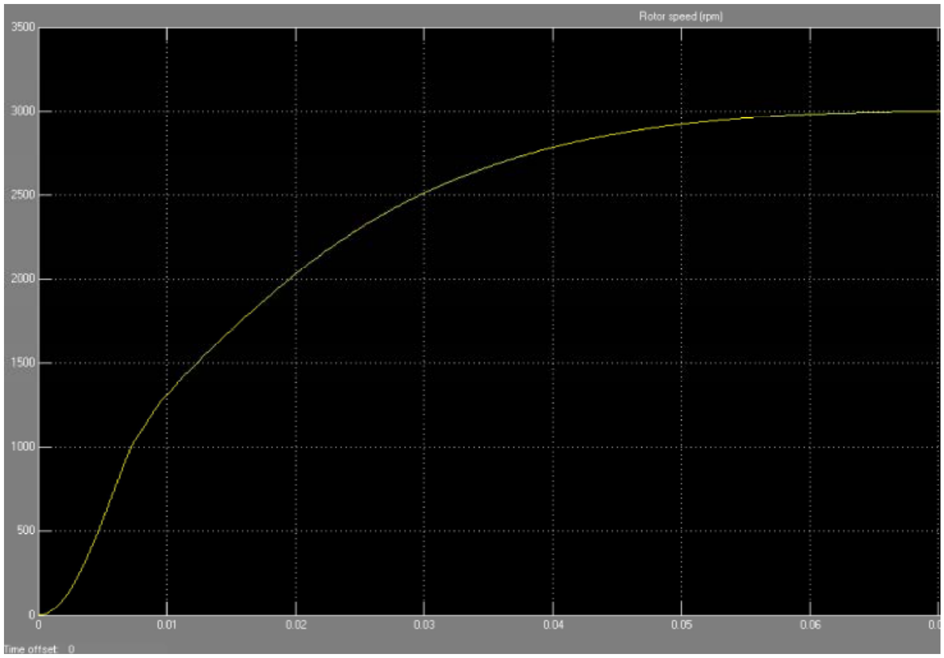


Fig. 8: Response of motor speed with time.

$$R_x = R_y = R_z = R$$

Equation (14) yields,

$$\begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} = \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix} - \begin{bmatrix} e_x \\ e_y \\ e_z \end{bmatrix} \quad (15)$$

The torque equation is expressed as

$$T_{em} = J\frac{d\omega_r}{dt} + B\omega_r + T_L \quad (16)$$

In terms of speed, current, back-emf the electromagnetic torque can be represented as,

$$T_{em} = \frac{1}{\omega_m}\left(e_x i_x + e_y i_y + e_z i_z\right) \quad (17)$$

The PID controller transfer function can written as,

$$G_{PID}(s) = K_p\left(1 + \frac{1}{T_i S} + T_d S\right) \quad (18)$$

By using Ziegler Nichols methods, we can find PID parameters.

$$K_p = 1.2\frac{T_0}{L_0} \quad (19)$$

$$T_i = 2L_0 \quad (20)$$

$$T_D = 0.5L_0 \quad (21)$$

## CONCLUSION

The paper covered overoll idea of the Modelling,design and simulation of LQR control system model for controlling a self balancing robot vehicle.LQR controller integrates all output states together to get the proper output value. The control signal is more accurate while comparing to PID.To design a speed controller for closed loop operation of the BLDC motor so that the motor runs very closed to the reference speed.The speed controlling is also implemented.The system increases the balance of robot cycle and also good speed control can be achieved. In future a complete automated robot vehicle can be designed using LQR method.

## REFERENCES

1. Sheng, Z. and K. Yamafuji, 1997. Postural stability of a human riding a unicycle and its emulation by a robot, IEEE Transactions on Robotics and Automation, 13(5): 709-720.
2. Distributed control for unmanned vehicles Jeffrey N. Callen Red Zone Robotics, Inc. IEEE Concurrency.
3. The Development of Self-Balancing Controller for One-Wheeled Vehicles Chung-Neng Huang Graduate Institute of Mechatronic System Engineering, National University of Tainan, Taiwan, China.

4. Design and implementation of pid based two wheeled self balancing mobile robot B.Malathi1, M.Ramchandran, PG student, Department of Electronics and Communication Engineering, SRM University, India 2 Faculty, Department of Electronics and Communication Engineering, SRM University, India.
5. Design And Development Of A Self-Balancing Bicycle Using Control Moment Gyro Pom Yuan Lam (B.Eng. (Hons.), NTU) A Thesis Submitted For The Degree. Of Master Of Engineering Department Of Mechanical Engineering National University Of Singapore 2012.
6. Huang, C.N., 2010. The development of self-balancing controller for one-wheeled vehicles, Engineering, 2: 212-219.
7. Hofer, K., 2005. Electric Vehicle on One Wheel, IEEE Vehicle Power and Propulsion Conference, pp: 517-521.
8. Unicycle.com(2010),'Unicycleparts',http://www.municycle.com.au/View.php?action=Page&Name=UnicycleParts(accessed 12/05/2010).
9. International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012). Design concepts for a hybrid swimming and walking vehicle Samuel N. Cubero a General Studies Department, Arts & Sciences, The Petroleum Institute, PO Box 2533, Abu Dhabi, United Arab Emirate.
10. http://www.segway.com.
11. Proportional Integral and Derivative Control of Brushless DC Motor Atef Saleh Othman Al-Mashakbeh, Department of Electrical Engineering Tafila TechnicaUniversity P.O. Box 179, Tafila – Jordan.
12. Anderson, B. and J. Moore, 1990. Optimal Control-Linear Quadratic Methods," Prentice-Hall, Upper Saddle River, 1990.