

Dynamic Modelling, Simulation & Control Design of Drive & Reaction Wheel Balancing Bot

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ABSTRACT: Stabilization of one wheel robot using drive & reaction wheel is an important research in present era. For this reason researcher chose to build a balancing Bot with unstable dynamics. A drive & reaction wheel balancing bot has been constructed at a reasonable cost, which facilitates modelling, simulation & control of bot. This research is about designing and balancing a single-wheel mobile robot that able to stabilize itself by using reaction wheel principal. The control strategies of a human riding a unicycle & inverted pendulum are studied first, and then dynamic model in 2D & 3D using Lagrangian approach which closely emulates the system is derived. A single wheel bot with mass & inertia properties similar to inverted pendulum & used as experimental guide line for designing control system. The research addresses aspects in the field of robotics, artificial intelligence & modern digital control system, but rather than specializing in any of these fields, it strives to combine these disciplines in unique application where interaction of these fields can be studied. This research approach was to not only design but also evaluate control system performance in sooth terrain without incurring large expenses. The robot has all its electrical and computational power on board, with ability to receive commands from a mobile to change its direction and speed. A linearized model was derived using Simulink & optimal control system using PID & Fuzzy Logic controller to stabilize the bot was designed and simulated.

KEYWORDS: OneWheel robot, Reactobot, Omnibot, Balancing bot.

I. INTRODUCTION

Design and control of dynamically stable single wheel robots is a growing area to study in research. The balancing robot which utilizes the inverted pendulum concept is being studied and researched intensively in order to develop effective control system that are able to control this naturally unstable system.

A significant but frequently overlooked problem is that statically stable single wheeled robot can be easily become dynamically unstable. Conventional statically-stable single wheeled robots if physically tall enough to interact with people, they must maximize their platform stability by lowering their centre of gravity. If the robot's centre of gravity is too high, or the robot's motion accelerates rapidly, the robot can tip over. Therefore, a wide and heavy base with low accelerations motion is applied for statically stable robot to avoid the robot tipping over. These conditions present a number of performance limitations and ill-suited for navigation in human environments.

To achieve effective interactions in human environments, drive & reaction wheel bot with human-like height, width and weight is the most suitable choice. The dynamic stability affords it advantages in manoeuvrability over statically stable robots and makes it a good candidate for operating in human environments. Besides, balancing on a single wheel allow the bot to move in any direction without turning.

This research is about designing and balancing a single-wheel mobile robot that able to stabilize itself by using reaction wheel principal. The control strategies of a human riding a unicycle & inverted pendulum are studied first, and then

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

dynamic model in 2D & 3D using Lagrangian approach which closely emulates the system is derived. A single wheel bot with mass & inertia properties similar to inverted pendulum & used as experimental guide line for designing control system. The research addresses aspects in the field of robotics, artificial intelligence & modern digital control system, but rather than specializing in any of these fields, it strives to combine these disciplines in unique application where interaction of these fields can be studied. This research approach was to not only design but also evaluate control system performance in smooth terrain without incurring large expenses. The robot has all its electrical and computational power on board, with ability to receive commands from a mobile to change its direction and speed. A linearised model was derived using Simulink & optimal control system using PID & Fuzzy Logic controller to stabilize the bot was designed and simulated.

II. PROBLEM STATEMENT

The aim of this project is design a mechanical system for the problem of balancing of one wheel robot by studying the methods and techniques involved in balancing an unstable robot on Drive wheel & Reaction wheel which allow it to be more robust and to overcome the incurred flaws in the previous models. Further the researcher will scrutinize the expenditure involved to fabricate a prototype including a variety of parts and software. The system should move & stand alone on single wheel.

Objectives of projects:

1. To design and control a single wheel self-balancing robot.
2. To include various interdisciplinary parts such as a PID-based controller, FUZZY LOGIC controller, Arduino controller
3. To design a complete control system with the state space model that will provide the base for controller design.
4. To Design and construct the hardware and mechanism of the balancing robot according to the desire specifications.
5. To design a 2D & 3D model of the single wheel self-balancing robot.
6. To apply Lagrange method to the system to derive the equations of motion for 2D & 3D.
7. To develop 3D solid model of single wheel self-balancing robot on Solid Works modelling software.
8. To stabilize the model utilizing state space equation of the system in a PID and Fuzzy Logic Controller in MATLAB software.
9. Develop program using MATLAB for controlling of single wheel robot using PID & FUZZY Logic controller.
10. Comparison of PID & FUZZY Logic controller then selecting optimum one for prototype.

Methodology for solving problem

1. System design.
2. Mathematical modelling (2D & 3D) using Lagrangian approach.
3. Solid modelling using SOLIDWORKS.
4. Simulation (Open loop)
5. Design of controller (PID & Fuzzy Logic) using MATLAB.
6. Validation of result using Simulink software.

III. MATHEMATICAL MODELLING

Requirements of System

- From Literature we have identified following requirements that our system should obey for proper balancing of one wheel robot.
- Sitting time of less than 5 seconds.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

- Body angle never more than 0.5 radians from the vertical.
- Working mechanical system.
- Standalone & moving system with reaction wheel.
- Choice of accurate sensor.

Assumptions

- ✓ The process of designing a Drive & Reaction Wheel Bot is an complicated process due to which a few assumptions are made in the system so as to simplify the system design. The following are the assumptions made,
- ✓ Any distortions in the system is neglected as the system is divided into three mains parts namely the drive wheel, reaction wheel and the body
- ✓ Friction is considered to be negligible.
- ✓ Slip for this model is not taken into consideration for drive wheel & floor.
- ✓ The value of static friction is sufficiently high so as to prevent sliding of the ball and also to avoid the motion of rotation of the ball about its axis.
- ✓ The Drive wheel makes constant contact with the ground and with no shoot or hindrances in the path of movement.
- ✓ Ground considered for the movement of this robot is considered to be flat so that YAW moment is restricted.
- ✓ Time delay in the relaying of the control is neglected

A. 2D Mathematical Modelling

The nature of this robot is similar to that of a human being riding on a classic mono- cycle. This is an unstable system that analysed separately considering two different dynamics: longitudinal (pitch) and lateral (roll).

The robot in analysis is composed of a Drive wheel, a body and reaction wheel. The wheel has the objective of balancing the system in the movements of pitch, while the reaction wheel allows balancing the rolling movements. It then assumes that the yaw movement is prevented because of the structure itself of the system, the following:

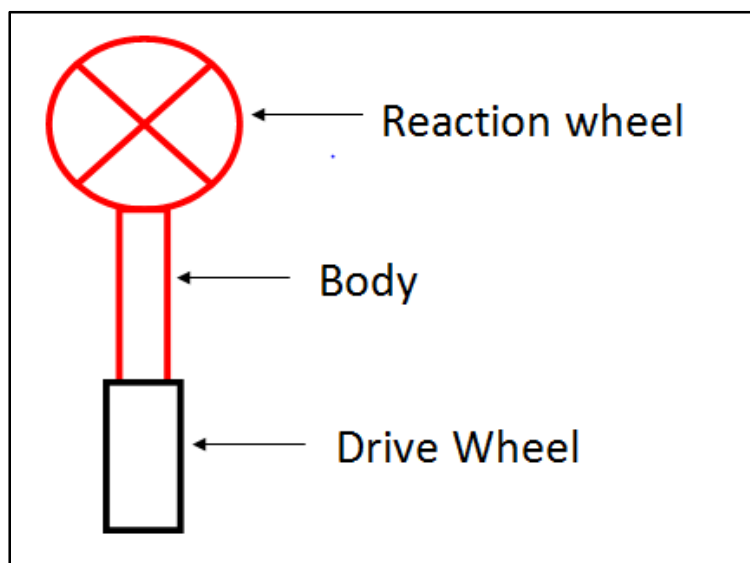


Figure 3.1: schematic diagram of drive & reaction wheel bot

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

3.1 Preliminary Considerations

For the study of the robot in question is used the mathematical model proposed in [Fig4.1]. Such dynamic model is housed applying the Lagrange approach to the mechanical system, assuming that the only motions available are the longitudinal and lateral. During the entire analysis there is the possibility of decoupling between the two movements, which allows to study the behaviour of the system in two different planes. Any coupling effects, they are to be considered negligible.

3.2 Longitudinal Equations of motion

For the analysis of the robot in its longitudinal movement it is been taken into account the following reference diagram

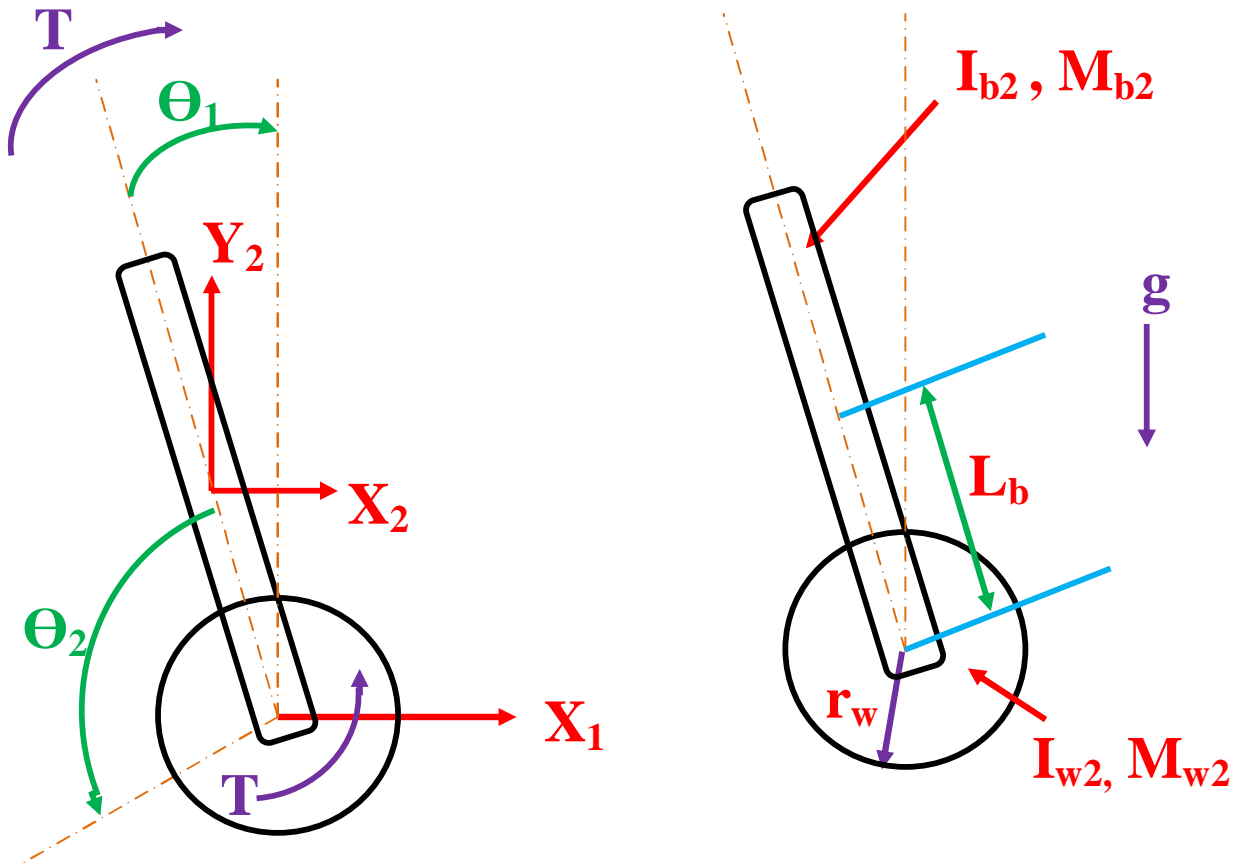


Fig. 3.2 Longitudinal Equations of motion

Notations:

- θ_1 = Angle between wheel & body
- θ_2 = Angle between body & vertical axis
- T = Applied torque from motor to wheel
- X_1 = Horizontal position of wheel
- X_2 = Horizontal position of body
- Y_2 = Vertical position of body
- M_{w1} = Mass of wheel

MB2 = Mass of body
IW1= M.I. of wheel w.r.t. CG
IB2 = M.I. of body w.r.t. CG
LB= Distance between center of wheel & CG of body
rw = Radius of wheel
g = Acceleration due to gravity

Langrangian Equation,

$$\frac{d}{dt} \left[\frac{d(K.E.)}{d\dot{\theta}_i} \right] + \left[\frac{d(P.E.)}{d\theta_i} \right] + \left[\frac{d(E.D.)}{d\dot{\theta}_i} \right] = M(t) \text{ or } F(t) \quad \text{External Exitation}$$

Θ_i = All generalized Co-ordinates,

M (t) = for torsional vibrations

F (t) = for linear vibrations

For longitudinal system EOM,

$$(M_{B2} r_w^2 + M_{W1} r_w^2 + I_{W1}) \ddot{\theta}_1 + (M_{B2} r_w l_B \cos \theta_2 + M_{B2} r_w^2 + M_{W1} r_w^2 + I_{W1}) \ddot{\theta}_2 - M_{B2} r_w l_B \dot{\theta}_2^2 \sin \theta_2 = T \quad (4.1)$$

$$(M_{B2} r_w l_B \cos \theta_2 + M_{B2} r_w^2 + M_{W1} r_w^2 + I_{W1}) \ddot{\theta}_1 + (2M_{B2} r_w l_B \cos \theta_2 + M_{B2} r_w^2 + M_{B2} l_B^2 + I_{B2} + M_{W1} r_w^2 + I_{W1}) \ddot{\theta}_2 - M_{B2} r_w l_B \dot{\theta}_2^2 \sin \theta_2 - M_{B2} g l_B \sin \theta_2 = 0 \quad (4.2)$$

3.3 Lateral Equations of motion

For the analysis of the robot in its lateral movement it is been taken into account the following reference diagram,

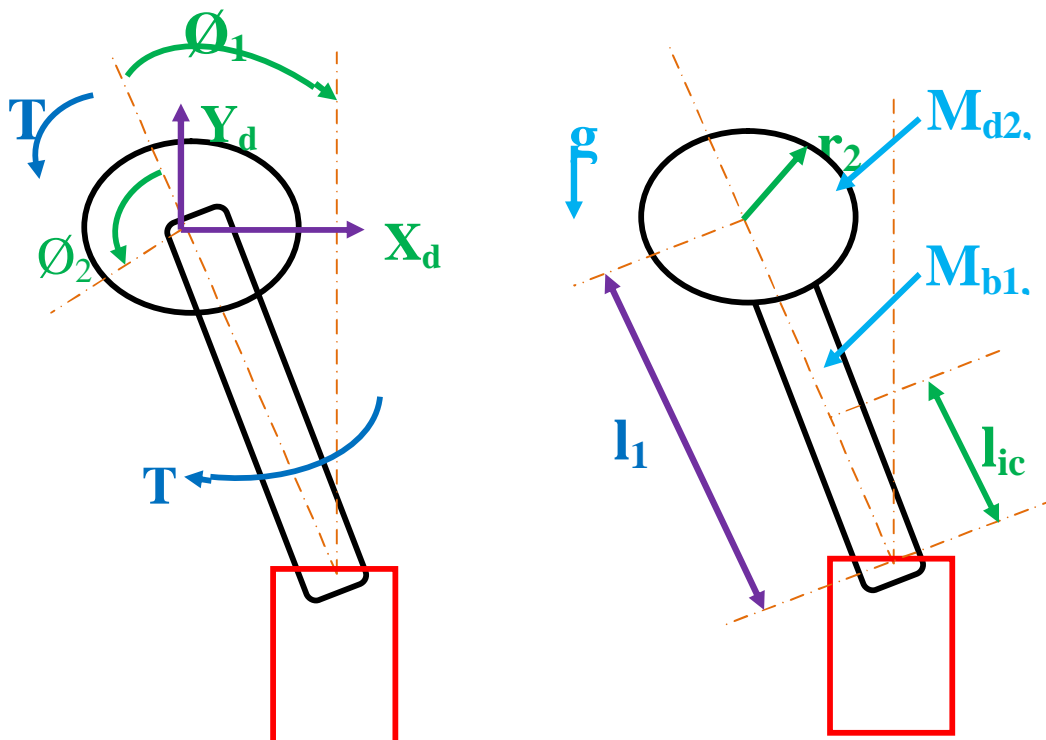


Fig. 3.3 Lateral Equations of motion

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

Notations:

- θ_1 = angle between body & vertical axis
- θ_2 = angle between disc & body
- T = applied torque from motor to axis of disc
- XD2 = the horizontal position of disc
- YD2 = the vertical position of disc
- MB1 = Mass of body
- MD2 = Mass of disc
- IB1 = M.I. of body w.r.t. point A
- ID2 = M.I. of disc w.r.t. its center
- l1 = distance between center of disc & A
- lic = distance between point A & CG of body
- r2 = radius of disc
- g = acceleration due to gravity

For lateral system EOM,

$$(I_{B1} + I_{D2} + M_{D2}l_1^2)\ddot{\phi}_1 + I_{D2}\ddot{\phi}_2 - (M_{B1}L_{ic} + M_{D2}L_1)g \sin \phi_1 = 0 \quad (4.3)$$

$$I_{D2}\ddot{\phi}_1 + I_{D2}\ddot{\phi}_2 = T \quad (4.4)$$

Above equations (4.1),(4.2),(4.3) & (4.4) are highly nonlinear equations, so to linearize this equations MATLAB is used and Simulink block is obtained to linearised this equations.

4.3.4 Motor Dynamics:

Here armature controlled D.C. motor is selected. The relation between input voltage supplied to motor and torque developed by motor along lateral axis,

$$T = \frac{KK_M}{R_M}(V_M - KK_E\dot{\theta}_1) \quad (4.5)$$

Where,

- K= Mechanical constant
- KM = Torque Constant of Motor (Nm/Amp)
- KE = Constant Of Electro Magnetic Motor
- Rm= Electric Resistant Of Motor
- Vm= Input Voltage

$\dot{\theta}_1$ = Velocity of Rotation Of Shaft

τ = Available Torque At Axis

Now substituting the equation (4.5) in (4.1),(4.2),(4.3) &(4.4) for both cases longitudinal & lateral;

$$(M_{B2}r_W^2 + M_{W1}r_W^2 + I_{W1})\ddot{\theta}_1 + (M_{B2}r_Wl_B \cos \theta_2 + M_{B2}r_W^2 + M_{W1}r_W^2 + I_{W1})\ddot{\theta}_2 - M_{B2}r_Wl_B\dot{\theta}_2^2 \sin \theta_2 = \frac{KK_M}{R_M}(V_M - KK_E\dot{\theta}_1)$$

Neglecting the whole term having $\sin \theta_2=0$ & $\cos \theta_2=1$, we get,

$$(M_{B2}r_W^2 + M_{W1}r_W^2 + I_{W1})\ddot{\theta}_1 + (M_{B2}r_Wl_B + M_{B2}r_W^2 + M_{W1}r_W^2 + I_{W1})\ddot{\theta}_2 + \frac{K^2K_MK_E\dot{\theta}_1}{R_M} = \frac{KK_MV_M}{R_M} \quad (4.6)$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

$$\begin{aligned} & (M_{B2} r_W l_B + M_{B2} r_W^2 + M_{W1} r_W^2 + I_{W1}) \ddot{\theta}_1 + (2M_{B2} r_W l_B + M_{B2} r_W^2 + M_{B2} l_B^2 + I_{B2} + M_{W1} r_W^2 + I_{W1}) \ddot{\theta}_2 \\ & - M_{B2} g l_B \theta_2 = 0 \end{aligned} \tag{4.7}$$

$$(I_{B1} + I_{D2} + M_{D2} l_1^2) \ddot{\phi}_1 + I_{D2} \ddot{\phi}_2 - (M_{B1} l_{ic} + M_{D2} l_1) g \phi_1 = 0 \tag{4.8}$$

$$I_{D2} \ddot{\phi}_1 + I_{D2} \ddot{\phi}_2 + \frac{K^2 K_M K_E \dot{\phi}_2}{R_M} = \frac{K K_M V_M}{R_M} \tag{4.9}$$

3.5 State Space Modeling:

For The Longitudinal Motion: For the longitudinal motion, the mathematical model in the state space is to be described by following equations: first of all defining state variables for state equations (4.6) & (4.7)

$$\begin{aligned} X_1 &= \theta_1 \rightarrow \dot{X}_1 = \dot{\theta}_1 \\ X_2 &= \dot{\theta}_1 \rightarrow \dot{X}_2 = \ddot{\theta}_1 \\ X_3 &= \theta_2 \rightarrow \dot{X}_3 = \dot{\theta}_2 \\ X_4 &= \dot{\theta}_2 \rightarrow \dot{X}_4 = \ddot{\theta}_2 \end{aligned}$$

Now state space model is given by,

$$\begin{pmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{pmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \left(\frac{K_7}{K_5} + \frac{K_6 K_1 K_7}{K_5 K_2 - K_6 K_1} \right) & \left(\frac{-K_6 K_3}{K_5 K_2 - K_6 K_1} \right) & 0 \\ 0 & \left(\frac{-K_1 K_7}{K_5 K_2 - K_6 K_1} \right) & \left(\frac{-K_3 K_5}{K_5 K_2 - K_6 K_1} \right) & 0 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \dot{\theta}_1 \\ \theta_2 \\ \dot{\theta}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \left(\frac{-K_4 K_6}{K_5 K_2 - K_6 K_1} \right) \\ \left(\frac{-K_4 K_5}{K_5 K_2 - K_6 K_1} \right) \end{bmatrix} V_M \tag{4.10}$$

For The Lateral Motion: For the lateral motion, the mathematical model in the state space is to be described by following equations: first of all defining state variables for state equations (4.8) & (4.9)

$$\begin{aligned} X_1 &= \phi_1 \rightarrow \dot{X}_1 = \dot{\phi}_1 \\ X_2 &= \dot{\phi}_1 \rightarrow \dot{X}_2 = \ddot{\phi}_1 \\ X_3 &= \phi_2 \rightarrow \dot{X}_3 = \dot{\phi}_2 \\ X_4 &= \dot{\phi}_2 \rightarrow \dot{X}_4 = \ddot{\phi}_2 \end{aligned}$$

Now state space model is given by,

$$\begin{pmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \\ \ddot{\phi}_1 \\ \ddot{\phi}_2 \end{pmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ \left(\frac{M_{B1} l_{ic} + M_{D2} l_1}{I_{B1}} \right) g & 0 & 0 & \left(\frac{K^2 K_M K_E}{I_{B1} R_M} \right) \\ - \left(\frac{M_{B1} l_{ic} + M_{D2} l_1}{I_{B1}} \right) g & 0 & 0 & - \left(\frac{K^2 K_M K_E}{I_{B1} R_M} \right) \left[\frac{I_{B1} + I_{D2}}{I_{D2}} \right] \end{bmatrix} \begin{bmatrix} \phi_1 \\ \dot{\phi}_1 \\ \phi_2 \\ \dot{\phi}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \left(\frac{-K K_M}{I_{B1} R_M} \right) \\ \left(\frac{K K_M}{I_{B1} R_M} \right) \left[\frac{I_{B1} + I_{D2}}{I_{D2}} \right] \end{bmatrix} V_M \tag{4.11}$$

B. 3D Mathematical Modeling

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

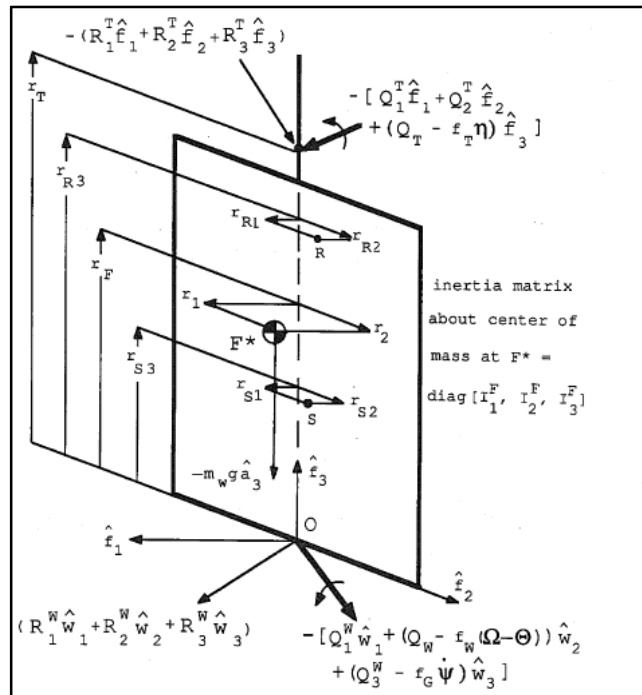


Fig 3.4 FBD of One

Wheel Robot

Notations:

- ϕ = Roll Angle
- Θ = Pitch Angle
- Φ = Yaw Angle
- $\bar{\eta}$ = Angular Velocity of reaction Wheel
- $\bar{\Omega}$ = Drive Wheel Angular velocity
- ρ = Angle of Reaction Wheel Relative to Frame
- σ = Angle of Drive wheel Relative to Frame
- m_w = Mass of Drive wheel
- r_w = Radius of Drive Wheel
- m_F = Mass of Frame
- r_1 = Distance of center of Mass of Frame Located in Front of Center Line
- r_2 = Distance of center of Mass of Frame Located in Side of Center Line
- r_F = Distance between wheel Axle & Center of mass
- m_T = Mass of Reaction Wheel
- r_r = Distance from Wheel Axle to Center of Mass of Reaction Wheel
- Q_w = Control Torque of Drive Wheel Motor
- Q_T = Control Torque of Reaction Wheel Motor
- Generalized Co-ordinates for 3D system:

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

There are seven co-ordinates,

$$x, y, \bar{\omega}, \phi, \varphi, \theta, \upsilon$$

As, θ, ϕ & their derivatives are small, so converting it to five co-ordinates

$$x, y, \bar{\omega}, \varphi, \upsilon$$

3.63D Lateral EOM by Lagrangians Approach:

$$(I_3^W + I_3^F)\ddot{\psi} + I_2^W \Omega_0 \dot{\phi} = -Q_T \quad (4.12)$$

$$\begin{aligned} & [I_1^W + I_1^F + I_1^T + (m_W + m_F + m_T)r_W^2 + 2r_W(m_F r_F + m_T r_T) + (m_F r_F^2 + m_T r_T^2)]\ddot{\phi} + I_3^T \eta_0 \dot{\theta} \\ & = [I_2^W + (m_W + m_F + m_T)r_W^2 + (m_F r_F + m_T r_T)r_W] \Omega_0 \dot{\phi} \\ & + [(m_W + m_F + m_T)r_W + (m_F r_F + m_T r_T)]g\phi \end{aligned} \quad (4.13)$$

$$I_3^T (\ddot{\psi} + \dot{\eta}) = Q_T \quad (4.14)$$

3.7 3D Linear EOM by Lagrangians Approach:

$$[I_2^W + (m_W + m_F + m_T)r_W^2] \dot{\Omega}_0 + (m_F r_F + m_T r_T)r_W \ddot{\theta} = Q_W \quad (4.15)$$

$$\left[I_2^F + I_2^T + m_F r_F^2 + m_T r_T^2 \right] \ddot{\theta} + (m_F r_F + m_T r_T)r_W \dot{\Omega} = I_3^T \eta_0 \dot{\theta} + (m_F r_F + m_T r_T)g\theta - Q_W \quad (4.16)$$

3.8 3D State space Modelling :

After doing state space analysis we get following state space matrix by using above five Lagrangian Equations (4.12),(4.13),(4.14),(4.15) & (4.16)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

$$\begin{bmatrix} I_{1,1} & I_{1,2} & 0 & 0 & 0 & 0 & I_{1,7} & I_{1,8} & 0 & 0 & 0 \\ I_{2,1} & I_{2,2} & 0 & 0 & 0 & 0 & I_{2,7} & 0 & 0 & 0 & 0 \\ 0 & I_3^T & I_3^T & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ I_{4,1} & I_{4,2} & 0 & I_{4,4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ I_{7,1} & I_{7,2} & 0 & 0 & 0 & 0 & I_{7,7} & I_{7,8} & 0 & 0 & 0 \\ 0 & I_{8,2} & 0 & 0 & 0 & 0 & I_{8,7} & I_{8,8} & 0 & 0 & 0 \\ 0 & I_{9,2} & 0 & 0 & 0 & 0 & I_{9,7} & I_{9,8} & I_{9,9} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \ddot{\phi} \\ \ddot{\phi} \\ \dot{\eta} \\ \ddot{\sigma} \\ \dot{\phi} \\ \dot{\sigma} \\ \ddot{\theta} \\ \dot{\Omega} \\ \ddot{\rho} \\ \dot{\theta} \\ \dot{\rho} \end{bmatrix} =$$

$$\begin{bmatrix} F_{1,1} & F_{1,2} & F_T & 0 & F_{1,5} & 0 & 0 & 0 & 0 & F_{1,10} & 0 \\ 0 & F_{2,2} & 0 & 0 & F_{2,5} & 0 & F_{2,7} & 0 & 0 & 0 & 0 \\ 0 & 0 & -F_T & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & F_{4,2} & 0 & -F_P & F_{4,5} & F_{4,6} & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ F_{7,1} & 0 & 0 & 0 & 0 & 0 & -F_W & F_W & 0 & F_{7,10} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & F_W & -F_W & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & g & -F_P & F_{9,10} & F_{9,11} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\phi} \\ \eta \\ \dot{\sigma} \\ \phi \\ \sigma \\ \dot{\theta} \\ \Omega \\ \dot{\rho} \\ \theta \\ \rho \end{bmatrix}$$

$$+ \begin{bmatrix} -1 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & -1 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} Q_T \\ Q_W \end{bmatrix} + \begin{bmatrix} 0 & F_T & 0 \\ K_{2,1} & 0 & 0 \\ 0 & -F_T & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ K_{7,1} & 0 & F_W \\ 0 & 0 & -F_W \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} g \\ \eta_0 \\ \Omega_0 \end{bmatrix}$$

(4.17)

4.5 3D Solid Modelling:

A 3-Dimensional model is prepared using Solid works 2014. This Model represents an overview of the actual model of the Drive & Reaction Wheel Robot.. This model was prepared in parts as it can be divided into three major parts,

- ✓ Body which is meant to carry the controllers , Battery , Sensors
- ✓ Drive Wheel which will carry the motors in turn connected to the wheel
- ✓ Reaction Wheel which will carry the motors in turn connected to the wheel

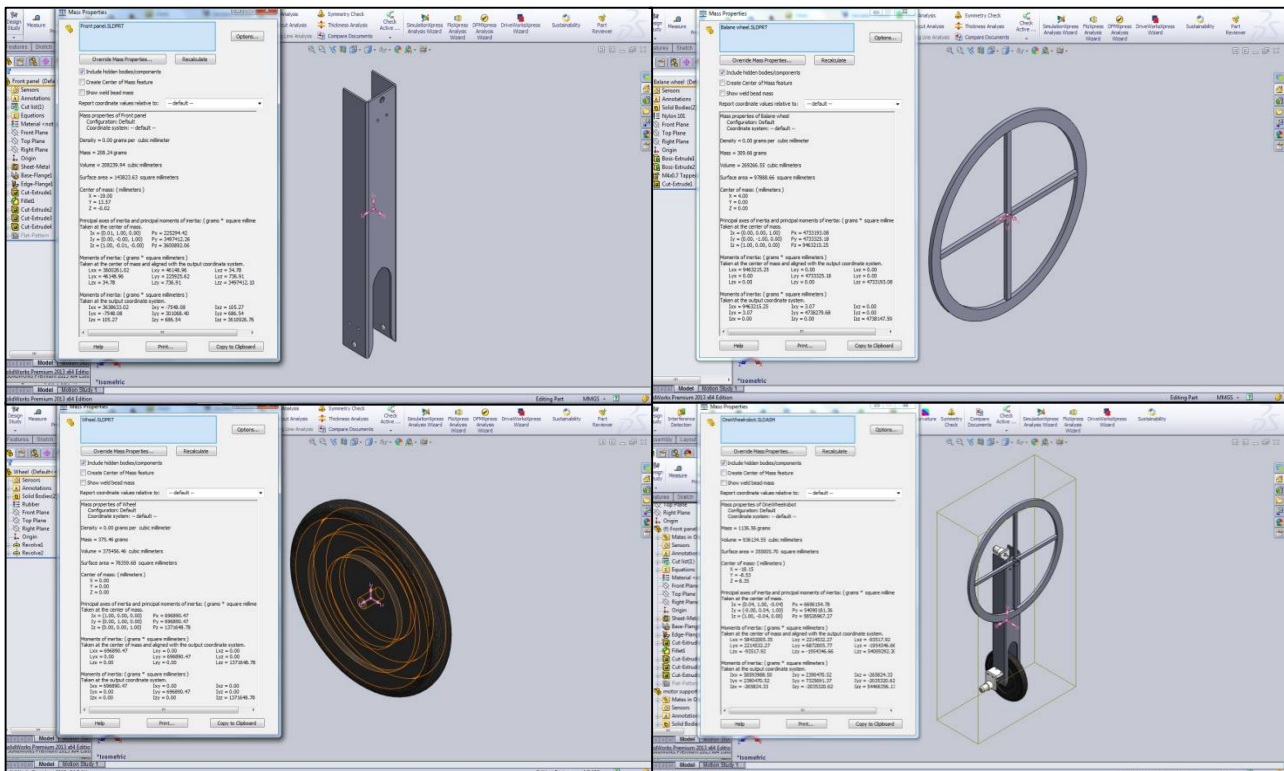


Figure 3.5 3D Model showing Drive & Reaction wheel Balancing Bot & main components.

From the above modelling we take all the inertia values for state space matrix directly from software.

IV. RESULTS

The equations of motion are represented in a state space model are simulated using MATLAB and the values of system matrix, input and output matrix is found. Further using this continuous-time state space model the transfer function is represented using the Matlab only and the result is represented in continuous-time transfer function. Then Proportional Integral Derivative (PID) were implemented and compared on a real time ONE WHEEL ROBOT & following results are obtained for different trials.

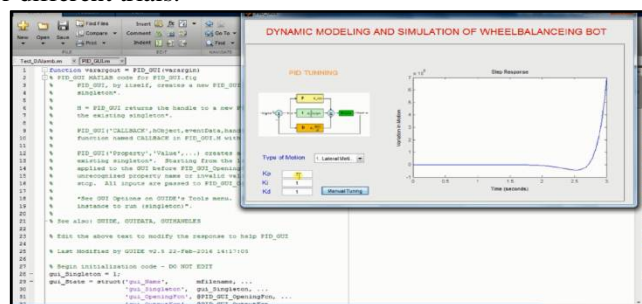


Figure 4.1 Graph of step response Vs time for Drive & Reaction Wheel robot using PID Controller.(Trial 1)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

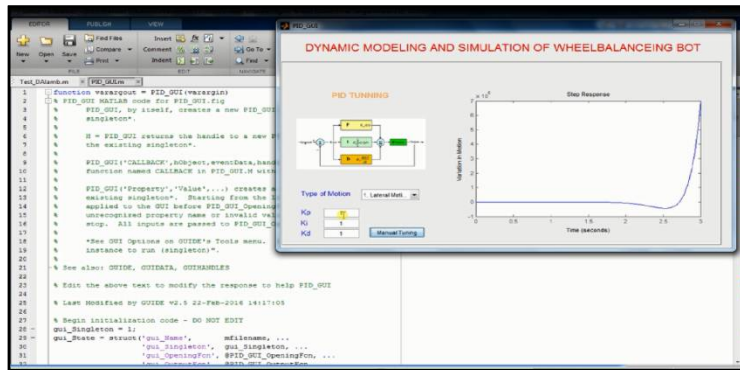


Figure 4.2 Graph of step response Vs time for Drive & Reaction Wheel robot using PID Controller. (Trial2)

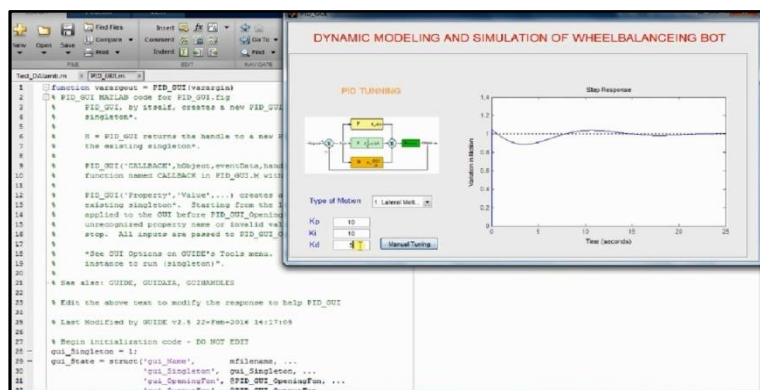


Figure 4.3 Graph of step response Vs time for Drive & Reaction Wheel robot using PID Controller. (Trial 3)

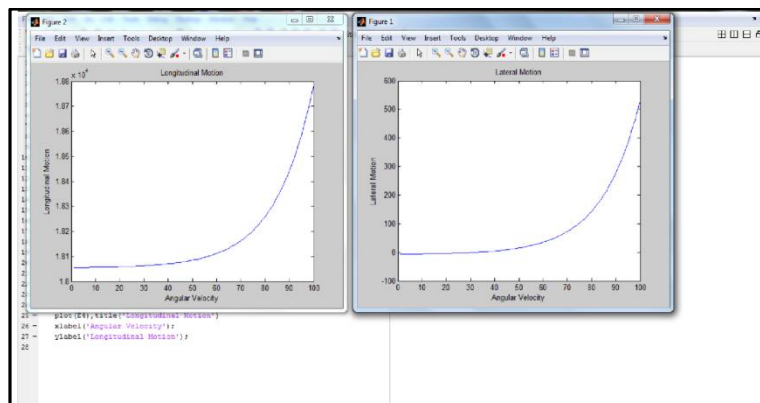


Figure 4.4 Graph of step Longitudinal &Lateral EOM for Drive & Reaction Wheel robot using PID Controller.

From Above graphs shows the response of the body position to an impulse disturbance under PID controller when the values of $K_p = 10$, $K_i = 10$ and $K_d = 5$.

The settling time of the response is determined to be 0.25 seconds, which is less than 5 seconds. Since the steady-state error approaches to zero in a sufficiently swift manner, no additional integral action is needed. The peak response,

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

however, is lesser than the requirement of 0.5 radians .Therefore the overshoot can be reduced by increasing the amount of derivative control. Hence at $K_d=5$ the proper response was achieved.

V. CONCLUSION

At the beginning of this project, various objectives were recognized for this project all of the above stated goals were achieved. Brief descriptions about the goals are as follows:

Attainment of the Equations of Motion: Equations of Motion of a generalized Drive & Reaction Wheel Balancing Bot have been derived in linearised form. Several assumptions were required during the derivation, and as such the equations do not give a perfect model of the system. However, the derived equations are believed to provide a fairly accurate model, as simulation results were similar to actual results.

Development of a Controller program to stabilise a Drive & Reaction Wheel Balancing Bot: A controller program has been developed in which successfully balances the Drive & Reaction Wheel Balancing Bot. Additionally, the controller is able to maintain balance when subjected to small disturbances, and also provides command tracking capabilities.

Design of the Drive & Reaction Wheel Balancing Bot is considered and also various parameters utilized and also various parts were considered such as the motors, wheels, microprocessors etc.

A 3D model was designed consisting the various parts imparting dimensions and material and collaborating them into an assembly Stabilization of the model utilizing state space equation of the system in a PID Controller in MATLAB software is performed but further the graphs depicting the results using FUZZY Logic Controller are yet to be derived. After which the comparison of PID & FUZZY LOGIC Controller will also be discussed.

REFERENCES

- [1] Robert E., and Richard S. "Dynamics of Multibody system", Fourth edition, Springer-Verlag, 1988.
- [2] Xu Y., and Au K., "Stabilization and path following of a single wheel robot", IEEE/ASME Transaction on Mechatronics, vol. 9, pp. 407-419, 2004
- [3] Au K. and Xu Y., "Decoupled dynamics and stabilization of single wheel robot", IEEE/PSJ International Conference on Intelligent Robots and Systems, 1999.
- [4] Seth B., Joydeep B. & Umasankar, "A Enclosed one wheel robot," B.Tech thesis IIT Bombay, July, 2008.
- [5] Reza O.S., "Nonlinear control of underactuated mechanical system with applications to robotics and aerospace vehicles", Ph.D. Thesis, MIT, February 2001
- [6] Issam A. Smadi, Yasutaka Fujimoto, "Three Dimensional Dynamical modeling of One-wheel Robot", Modeling, Identification, and Control - 2007, Ac tapress, pp 500-505
- [7] Aria A., PendarH., "Equations of Motion of a Single -Wheel Robot in a Rough Terrain", roc. IEEE Int. Conference on Robotics and Automation, 2005, pp 879 -884.
- [8] Amir A. Bature, SalindaBuyamin, Mohamed. N. Ahmad, Mustapha Muhammad, " A Comparison of Controllers for Balancing Two Wheeled Inverted Pendulum Robot", International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol:14, No:03-62, 146003-8383-IJMME-IJENS © June 2014 IJENS
- [9] A. Kadis, D. Caldecott, A. Edwards, M. Jerbic, R. Madigan, M Haynes, B. Cazzolato and Z. Prime, "Modeling, simulation and control of an electric unicycle", The University of Adelaide, Australia.
- [10] Kadam Shishirkumar Namdev, "Dynamic Modeling, Simulation and Control of One Wheel Robot", M.Tech thesis IIT Bombay, Jun, 2009
- [11] Fabian Kappeler, "Unicycle Robot", M.Tech thesis IITKharagpur, June 28, 2007