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Modelling, Simulation & Control Design of Omnibot Using Reaction Wheel Principle

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Abstract : *Stabilization of Omnibot 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 modeling, 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 Langrangian 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 controller to stabilize the bot was designed and simulated.*

Keywords– *Reactobot, Omnibot, Single Wheel Robot, One Wheel Robot, Self-Balancing bot*

I. INTRODUCTION

Design and control of dynamically stable Omnibot 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 center of gravity. If the robot's center 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 maneuverability 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 Omnibot 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 Langrangian 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 linearized model was derived using Simulink & optimal control system using PID controller to stabilize the bot was designed and simulated.

II. PROBLEM DEFINATION

The aim of this project is design a mechanical system for the problem of balancing of Omnibot 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.

2.1 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, 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 Langrange 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 Controller in MATLAB software.
9. Develop program using MATLAB for controlling of Omnibot using PID controller.
10. Comparison of controller then selecting optimum for prototype.

2.2 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) using MATLAB.
6. Validation of result using Simulink software.

III. MATHEMATICAL MODELLING

3.1 Requirements of System

- From Literature we have identified following requirements that our system should obey for proper balancing of one wheel robot.
- Settling time of less than 5 seconds.
- Body angle never more than 0.5 radians from the vertical.
- Working mechanical system.
- Standalone & moving system with reaction wheel.
- Choice of accurate sensor.

3.2 Assumptions

The process of designing a Drive & Reaction Wheel Bot is a 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

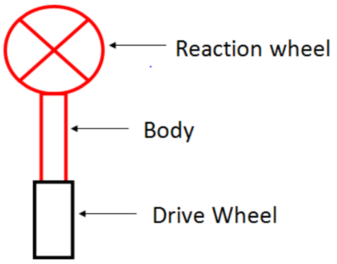


Fig. 3.1.Schematic diagram of drive & reaction wheel bot

3.3 Preliminary Considerations:

- For the study of the robot in question is used the mathematical model proposed in [Fig2.1]. 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 studying the behavior of the system in two different planes. Any coupling effects, they are to be considered negligible.

- 3.4 State Space Modelling:

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 (6) & (7)

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

Now state space model is given by,

$$\begin{pmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{pmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \left(\frac{K_7}{K_5} + \frac{K_6K_1K_7}{K_5K_2 - K_6K_1}\right) & \left(\frac{-K_6K_3}{K_5K_2 - K_6K_1}\right) & 0 \\ 0 & \left(\frac{-K_1K_7}{K_5K_2 - K_6K_1}\right) & \left(\frac{-K_3K_5}{K_5K_2 - K_6K_1}\right) & 0 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \left(\frac{-K_4K_6}{K_5K_2 - K_6K_1}\right) \\ \left(\frac{-K_4K_5}{K_5K_2 - K_6K_1}\right) \end{bmatrix} V_M \quad \text{.........(3.4.1)}$$

For the lateral motion, the mathematical model in the state space is to be described by following equations:

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

Now state space model is given by,

$$\begin{pmatrix}\phi_1\\ \phi_2\\ \phi_1\\ \phi_2\end{pmatrix}=\begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ \left(\dfrac{M_{B1}l_{ic}+M_{D2}l_1}{I_{B1}}\right)g & 0 & 0 & \left(\dfrac{K^2K_MK_E}{I_{B1}R_M}\right)\\ -\left(\dfrac{M_{B1}l_{ic}+M_{D2}l_1}{I_{B1}}\right)g & 0 & 0 & -\left(\dfrac{K^2K_MK_E}{I_{B1}R_M}\right)\left[\dfrac{I_{B1}+I_{D2}}{I_{D2}}\right]\end{bmatrix}\begin{bmatrix}\phi_1\\ \phi_2\\ \phi_3\\ \phi_4\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \left(\dfrac{-KK_M}{I_{B1}R_M}\right)\\ \left(\dfrac{KK_M}{I_{B1}R_M}\right)\left[\dfrac{I_{B1}+I_{D2}}{I_{D2}}\right]\end{bmatrix}V_M$$
…………………………………………… (3.4.2)

IV. 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

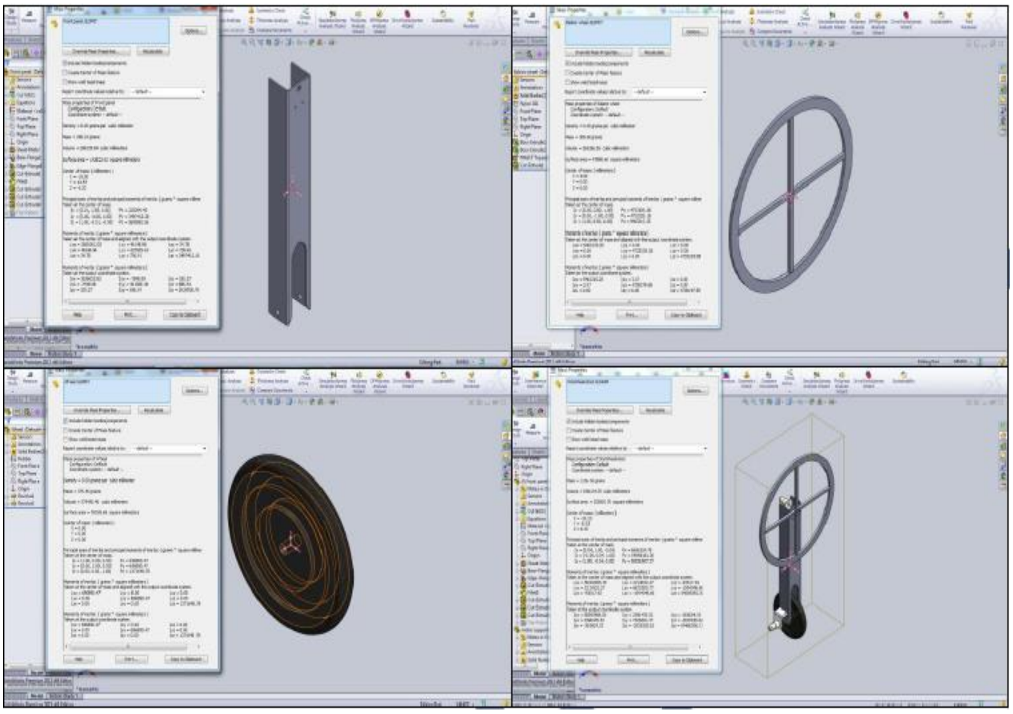


Fig. 3.2: 3D Model showing Drive & Reaction wheel Balancing Bot & main components.

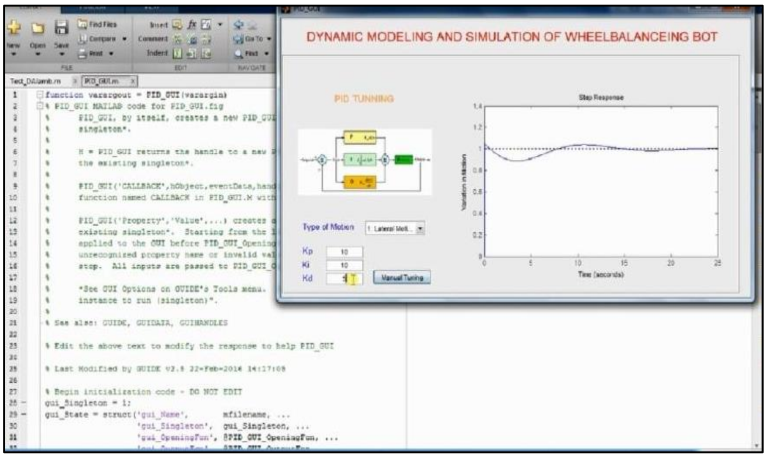
From the above modelling we take all the inertia values for state space matrix directly from software.

V. RESULTS

The equations of motions of 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 Mat lab only and the result is represented in continuous-time transfer function. Then Proportional Integral Derivative (PID) were implemented and compared on a real time Omnibot & following results are obtained for different trials.

From below graphs shows the response of the body position to an impulse disturbance under PID controller when the values of Kp =10, Ki =10 and Kd =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, 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 Kd=5



the proper response was achieved.

Fig. 5.1: Graph of step response Vs time for Drive & Reaction Wheel robot using PID Controller.

VI. 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 linearized 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 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 & graphs are drawn to depict balancing.

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