Self balancing vehicle

1. Introduction

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Research on two wheeled, self balancing vehicle is gaining momentum in many laboratories around the world and has made many developments based on it. Balancing carts are defined by their ability to balance on two wheels and spin on the spot similar to an inverted pendulum. It has been the subject of many researches around the world ever since people started investigating the concept of inverted pendulum system. Many forms and functions of a two wheeled cart have been developed and modified, due to its high manoeuvrability, two wheeled balancing cart has been investigated and developed to become a human transport machine. The Segway, Pegasus, and iBot models are such examples of the design of two wheeled balancing robot as a human transport machine.

Balancing of a two wheel cart is a non linear control problem which is quite complex to solve in a methodological approach due to two degrees of freedom, i. e. the balancing cart position and angle using only one control input force.

The control principle simply involves driving the wheels of the cart in the direction where the body is falling. It has the same principles as balancing a broom stick on the palm of a hand, a person balancing the stick moves the hand in the direction that the stick is falling

The scope of this thesis is to design a controller and develop the hardware for the two wheeled cart such that the cart can stay in an upright position while the cart is in a static position or moving.

Apart from the above, the thesis will look into the suitability and performance of different types of linear state space controllers namely the Linear Quadratic Regulator (LQR), pole placement controller and state observer design in balancing the system.

1. 2. Literature Review

The wide application of technology derived from the very concept of inverted pendulum has lead to many researches being carried out by many researchers and robot enthusiasts around the world. This chapter provides a review on some vital topics related to the balancing of a two wheeled robot as well as some of the existing human transporters,

1. 2. 1. Segway

The Segway PT is a two-wheeled, self-balancing electric vehicle invented by Dean Kamen. It is produced by Segway Inc. of New Hampshire, USA. The working of the Segway is based on a new technology termed ‘ dynamic stabilization’, i. e. it uses the body’s movement to enable the Segway to perform its function.

For instance, to move forward or backward, the rider has to lean in the required direction, similarly, for left-right movement, the ‘ Leansteer’ frame is turned in the required direction. The dynamics of Segway PT are also based on the concept of the inverted pendulum. It consists of electric motors powered by Valence Technology and phosphate based lithium ion batteries, two tilt sensors and 5 gyroscopes. The servo drive motors rotate the wheels forward or backwards as needed for balance or propulsion.

1. 2. 2. Self Balancing Scooter

Trevor Blackwell built a self-balancing scooter similar to the Segway HT that was completed in 2002. There are two models of the scooter built by Trevor Blackwell and the control system of the vehicle are summarized below,

Model 1:

The scooter is powered by Remote Control (RC) car battery packs. The packs provide a power source that can support the high discharge rate demanded by the motors. The control system of the vehicle is run from an 8-bit Atmel microcontroller using Proportional Derivative (PD) control with feedback from a piezo electric rate gyroscope. The gain parameters can be tuned by hand while actually using the vehicle. The motors are controlled by the Pulse Width Modulation (PWM) signals from the motor driver. Steering is done by making one wheel go faster than the other. Because all the mass is centered between the wheels, it can spin around quite quickly. The steering system adds and subtracts a small percentage of power from the motors depending on the current speed of the vehicle

Model 2:

This model is an improvisation of the first model. It is designed to be much smoother, lighter and faster than the first model. Roboteq dual channel motor controller used in the first model is replaced with an OSMC (Open Source Motor Controller) driving each wheel independently. The OSMC can supply from 13V to 50V at 160A continuous and 400A peak while the major advantage stems from the processing time which is in the order of one or two milliseconds compared to tens of milliseconds with the previously used Roboteq motor controller. The gyroscope system used in the first model is replaced with a gyroscope/accelerometer assembly that has significantly less noise and less susceptible to vibrations. This model includes a Bluetooth connection such that the scooter can be driven remotely while balancing.

1. 2. 3. JOE le Pendule

Felix, Grasser (2002) built a revolutionary two-wheeled vehicle called the JOE. It consists of two coaxial wheels with each wheel coupled to a DC motor. This configuration enables the vehicle to do stationary U-turns. The control system consists of two state space controllers which drives the motors so as to keep the system in equilibrium while in motion. In order to reduce cost as well as danger for the test pilots a scaled down prototype carrying a weight instead of a driver was built (Grasser et al). The implemented control system is the pole placement control. JOE's performance can be further enhanced by varying the pole placement in real time depending on the states and inputs of the system. The implementation of these controllers can be seen in papers published by Nakajima et al. (1997), Shiroma et al. (1996), Takahashi et al. (2001) and Grasser et al (2002).

1. 2. 4 LegWay & EquiBot

Steve Hassenplug's Lego based LegWay uses two Electro-Optical Proximity Detectors to balance and detect and follow lines. This robot uses Infrared Proximity detectors to deduce the tilt angle of the robot. Another robot similar to the Legway is the Equibot by Dan Piponi. Equibot is a balancing robot which is like a small scale segway. It is based around an ATMega32 RISC Microcontroller. It has just one sensor: the Sharp infrared ranger. This is positioned facing downwards to measure distance to the floor and as a result tilt angle is obtained. The output from this device is used to decide which way the robot is leaning and hence stabilize the system.

1. 2. 5 nBot Balancing Robot

The nBot balancing robot by David P. Anderson is another two wheeled balancing robot that has been developed in the recent past, the concept of balancing this robot could be applied to this two wheeled balancing cart project, for the nBot the wheels are driven in such a way as to stay under the robot’s center of gravity, hence, the robot remains balanced. The nbot consists of two feedback sensors: a tilt or angle sensor to measure the tilt of the robot with respect to gravity, and also consist of encoders on the wheels in order to measure the position of the base of the robot. The position and motion of an ‘ inverted pendulum’ based machine such as the nBot are defined by four variables. They are the position, the velocity, the tilt angle and the tilt rate. The measurements from these four variables are summed and fed back as a motor voltage which is proportional to torque, hence is used to balance and drive the robot.

1. 2. 6 EDGAR

A student project at the University of Adelaide under the guidance of Dr. Ben Cazzolato resulted in EDGAR, the Electro-Drive Grav-Aware Ride. EDGAR’s design draws up the successes and failures of the Segway PT and various other attempts of producing self balancing scooters which use different automatic control methods. Angular feedbacks from the gyroscopic sensor and PWM output to motors are used in a control system to achieve balance in EDGAR. The microcontroller used is the Wytec MiniDRAGON+ development board; the microcontroller receives the information from sensors, interprets the information and then sends commands to drive the system to maintain balance.