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Design & Development of Self-Balancing Bike using Reaction Wheel

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Abstract:
This project is aimed on the design and development of a two wheeled prototype vehicle that is capable of balancing with or without a rider. The Autonomous bike will employ a control system to keep itself from falling over while stationary or in motion and will be able to attain an erect posture, it would be driven by a dc motor and a servo for steering control. Based on inverted pendulum concept, the goal of this project is to build a bike prototype capable of balancing itself using a reaction wheel. In order to maintain its self balance, the vehicle receives input from MPU-6050 sensor and calculates the tilt angle and reacts accordingly to maintain a vertically erect posture on its two wheels . Sensor data is first processed to get a noiseless data of the bike state then fed into a control system which outputs a signal to drive the motor coupled to the reaction wheel which generates a counter force to oppose the inclination of bike. The requirements include that the bike should be capable of balancing vertically without falling over.

Keywords: Self balancing bike, Reaction wheel, Gyroscopic sensor, PID control system.

I. INTRODUCTION

We want to use the development of a self-balancing bike towards several broad goals:
1. Gaining insight into the nature of control that maximizes fall avoidance.
2. Possible future self-driving bikes (like possible future self-driving cars).
3. Use of reaction wheels for maintaining center of gravity of bike by generating a counter force as opposed to the angle of tilt of bike.
4. Study of nature of Self balancing Autonomous 2-wheeled vehicles.

To this end, we want our bike to make use of reaction wheels the same concept which is equipped in earth orbiting satellites & space telescopes too for maintaining and adjusting altitude and for pitch, yaw and roll control in the vacuum of space. Autonomous 2-wheeled vehicle could provide balancing assistance without affecting the experience of riding a bike and this could provide great benefit. Such a system could be used as a teaching tool, as well as a physically therapeutic device. This problem of balancing a bike is common to a well-known inverted Pendulum problem. An inverted pendulum is a pendulum which has its center of mass above its pivot. The pendulum here is similar to a bike system. While a normal pendulum is stable, an inverted pendulum is unstable, and must be balanced in real time to remain upright. In this case, the bike is a rigid body which can rotate around its contact point with the ground hence forming an inverted pendulum. A bike motion has multiple degrees of freedom, but this project aims to stabilize is the angle of tilt around the point of contact with the ground relative to the direction of gravity which is only one of the degrees of freedom of bike.

II. BACKGROUND

A bike cannot withstand upright or maintain a stable erect posture wholely upon its two wheels without the riders assist. One of the most popular self-balancing robot bike, Murata Boy, which was developed by Murata in 2005. which employs a reaction wheel inside a robot which acts as a torque generator, in short an actuator for the balancing of the bike. The reaction wheel usually consists of a spinning rotor, whose spin rate is nominally zero. Its spin axis is fixed to the bike. Its speed is increased or decreased to generate reaction torque around the spin axis according to the requirement. Reaction wheels are mechanical energy storage systems and least expensive of all momentum exchange actuators. Its advantages are simplicity, low cost, and the absence of ground reaction. Its disadvantages are that its more energy consuming and cannot produce large amounts of torque. In Another different approach by Honda makes use of an automated steer-by-wire system. This system unfastens the handles from the front forks at speeds less than 3 mph. Thus, it badges the front wheel's control to the processor. The bike is efficient enough to sense the lean angles. This swipes the wheel to at least one or the opposite side, to neutralize any tendency tip over. It likewise fine-tunes the angles of the front forks. This drops the bike's center of gravity to recover stability. Honda's "Riding Assist" technology doesn't depend upon gyroscopes for balancing. It has an alternative mechanism that, uses tech resultant from the balancing schemes in its Asimo robot.

III. OBJECTIVE

For controlling the bike the challenges to be overcomed are: Balancing the two-wheeled bike wholely upon its two wheels without support from any external assist is one of the key challenges. A bike remains upright when it's steered in order that the bottom reaction forces exactly balance all the opposite internal and external forces, like gravitational if leaning, inertial or centrifugal if during a turn, gyroscopic if being steered, and aerodynamic if during a crosswind. Steering is supplied by a rider or by the bike itself under certain circumstances. One other way that a bike can be balanced is by applying appropriate torques between the bike and rider. This automatic balancing is generated by a combination of several effects that depend on the structure, geometry, mass distribution, and speed of the bike. Tires, suspension, steering damping, and frame flex also influence the balancing, in bikes. The most common technology employed in self-balancing bikes is all about two gyroscopes placed as low as possible. Principally, the gyroscope may be a rotating flywheel or a disk with a free axis of rotation. This is capable of taking over an arbitrary orientation. The gyroscope within majority of times stays in the balance thanks to its free axis rotation. As the axis is free, the balance remains unaffected with any quite tilting or moving. If you plan to drive the bike over, the gyroscope thrusts it back.

IV. MODELING SELF-BALANCING TWO-WHEELED BIKE

The two-wheel bike model is shown in the Figure a, in which m1 is the weight of the bike (including the DC motor), m2 is the weight of the flywheel, h1 is the height of the center of the gravity of the bike (excluding the flywheel), h2 is the height of the center of the gravity of the flywheel, I 1 is the moment of inertia of the bike, I 2is the moment of inertia of the flywheel, θ is the tilt angle of the bike compared to the vertical axis, and φis the angle of rotation of the flywheel.

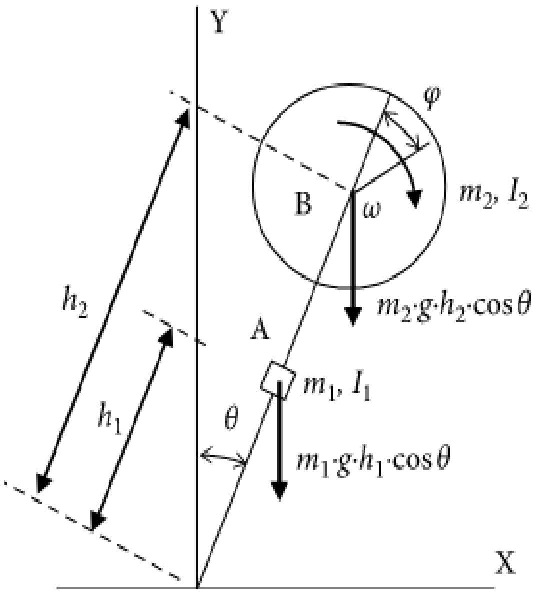


Figure.a. Self-balancing two-wheeled bike model

By considering & calculating these criteria the overall mechanical & technical development has to be made.

V. DESCRIPTION OF SYSTEM

The design of bikeis described below with consideration of physical complexity, power requirements, programming code complexity, cost, and closeness to resembling a bike. There are multiple number of motors and sensors required in this project. The reaction time and starting and stopping are also taken into special consideration. Power is also required which include the battery necessary to provide the system with continuous power supply. The battery is dependent on the weight of the model, number of motors needed for that design, and the torque demands of the motor(s) for the control system. The reaction wheel design employs a flywheel which rotates about an axis parallel to the frame of the bike. This design converts the bike as an inverted pendulum with a fixed pivot where the bike wheels meet the floor.

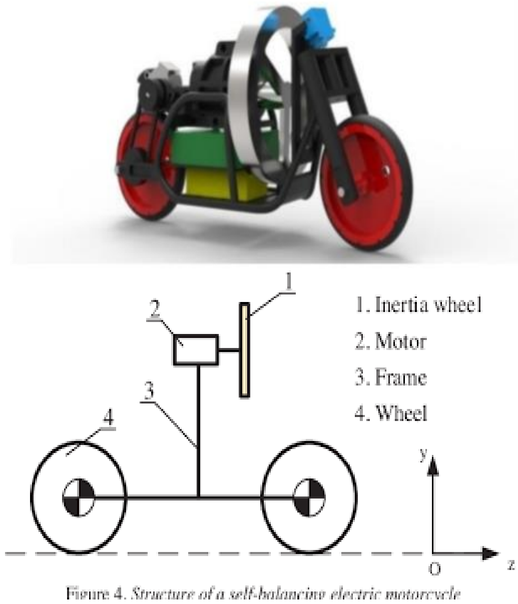


Figure.1. Mechanical model

As the bike falls to one side, a motor mounted on the bike exerts a torque on the flywheel, generating a reactionary torque on the bike, which restores the balance of the bike. There are several advantages of the flywheel design. This design is very stable giving the bike capability to balance even in a stationary position. Due to the simplicity of the design of the autonomous bike model, the controller would be relatively straightforward to implement. This design would also allow the bike to travel in a straight line with little or no deviations.

A.Control Overview

The control of the bike is simple and straightforward. This includes reading data from sensor, filtering the data, applying control algorithms on the data, and sending control signal to the actuators. All the filtering of data and generation of control signal is done by a microcontroller.

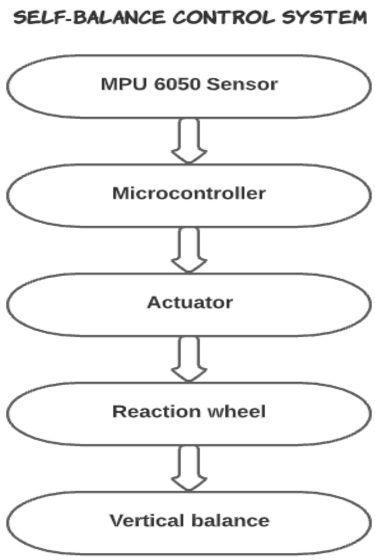


Figure.2. Process flow diagram

The Arduino Uno Rev3 (the selected microcontroller) reads the output of the accelerometer and the gyroscope module MPU-6050 via the 10-bit analog-to-digital converter. This collected value is used to calculate the tilt angle of the bike.

The measured angle is treated with a PID algorithm, and output generated is scaled to a corresponding voltage and fed to the motor controller. The motor controller then outputs a voltage to the DC motor. This motor geared down, and ultimately actuates the flywheel. The torque exerted on the flywheel, generates a reaction torque which is exerted on the bike.

B. Control Unit

The microcontroller selected to control the balance of the bike is the Arduino Uno R3 Board based on Atmel ATmega328P microcontroller chip.

Figure.3 .Arduino Uno Rev3 Microcontroller

The processing unit used is Arduino Uno Rev3board equipped with an ATmega328P which is an 8-bit microcontroller based on AVR RISC architecture. Itis the most popular of all AVR controllers as it is used in ARDUINO boards. It has multiple I/O (Input / Output) ports at 3.3V voltage level and also 5V voltage level, onboard ADC (Analog to Digital Converter) and PWM (Pulse Width Modulation) outputs for motor control. It also has I2C, SPI port which is used to communicate with other I2C or SPI enabled devices. It can be programmed easily which makes it extremely popular in robotics applications. Here it performs the following functions:

- Reading outputs of Gyro and Accelerometer sensor module via I2C port.
- Processing the input signals.
- Periodic recalibration of gyro.
- Display of angle & other data.
- Control of actuator unit.

C. Gyro & Accelerometer Sensor

Tilt angle sensing is the main part of this project and the most difficult part as well.

Figure.4. MPU6050 motion sensor

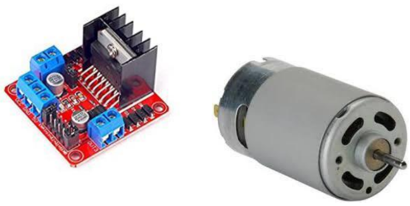
To measure the bike's angle, an accelerometer and a gyroscope is used, and their values are combined using a Kalman filter. Integrating the values of these two sensors proves useful when calculating the bike's tilt angle. Accelerometers are used to measure the angle with respect to gravity directly, but they are highly susceptible to noise. Gyros produce noiseless values, but they measure angular velocity. As a result, the gyro output is integrated to obtain a measurement of angular position or tilt angle. This integration gives an error known as drift, which is a drawback of the gyro. Integrating both sensors gives the output which is accurate tilt angle rather than value produced by one sensor only. This is done by the implementation of a filter, which combines the advantages and eliminates the drawbacks of each sensor. The output produced by Kalman filter after combining accelerometer and gyroscope data is smooth and noiseless.

D. Actuator unit

As the bikeinclines to one side, we need to apply a counter force as opposed to tilt angle to return the bike to vertical position. A reaction wheel pendulum type model is used for the balancing purpose. The components used are:

- High torque DC motor
- A reaction-wheel
- Motor driver L298N

The flywheel requires a large amount of power, so a fairly powerful motor and a gear reducer are required. In order to choose the motor, the designed frame and layout of components, are considered as well as the calculations to model a simple inverted pendulum, are given as an input into a V-REP simulation.This simulation gives values in determining the power, torque and velocity that the motor required. To meet these requirements, a High torque DC motor is used. A capacitor is connected across the motor which charges and discharges during the on and off time respectively, thus behaving like an integrator. The torque generated by the motor and the reaction torque generated by the reaction wheel is a function of the average value of current supplied. The tilt angle is considered and the reaction wheel is rotated proportionally to generate an equal and opposite torque to balance the bike. But just proportional controller overthrows the bike to another side which is not the required situation. To fix this issue we need to implement a closed loop control algorithm which can damp this periodic motion and make it stable at the vertical mean position after some time. This is where PID (Proportional Integral and Derivative) Controller comes in action.



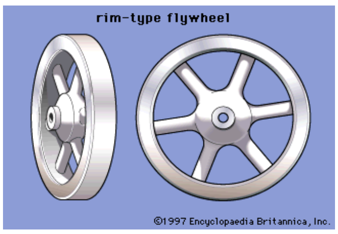


Figure.5. Actuator unit

E. PID Closed loop control system

A proportional–integral–derivative–controller (PID controller) is a control loop feedback mechanism. It is widely used in industrial control systems and a variety of other applications.

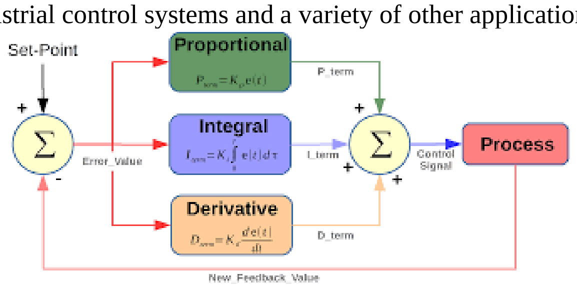


Figure.6 . PID Control system

In the self-balancing bike a PID control algorithm is used to generate the control output for the reaction wheel mechanism. The tilt angle of the bike with respect to the vertical axis is considered as an error in the system and fed to the proportional controller of the PID system. The difference in the tilt angle of the bike with last measured angle or the angular velocity is fed to the Differential controller of the PID system. The error is integrated over time and then fed to the integral controller of the PID system. Along with these errors, the angular velocity of the reaction wheel is also taken as an error. This is done as we have limitation of the angular velocity of the motor after which even if the power supplied to the motor is increased, there will be no significant change in the torque generated, which leads to no reaction torque. To overcome this saturation condition, the angular velocity of the reaction wheel is also taken as feedback from the system and fed to the controller. With a tuned PID parameters, an output is generated by the controller and this output generated by the controller is considered as an input for the reaction wheel motor torque and as equivalent amount of power is provided to the motor. Takes tilt angle of the bike as s ‘θ’and angular velocity of reaction wheel as ‘ω’, then the output of the controller will be:

$$PID = K_{p1} * \theta + K_{d1} * d\theta/dt + K_{i1} * \int \theta \, dt + K_{d2} * \omega$$

V. CONCLUSION

This paper is focused onto the bike using reaction wheel. The simplest PID controller is applied to balance the bike about the axis and to attain an excellent stability. There are ongoing researches for development of highlyfeatured control systems & control algorithms for the vertical balancing and to minimize effects of external disturbances, such as wind, sudden crash impact etc. and giving driving capabilities to the bike with straight line trajectory and a curved trajectory with maintained tilt angle such as to balance the centrifugal forces generated at the time of turning the bikeand providing the steering wheel mechanism along with an enclosed chassis as that of a car with air bags are currently being under development. bikes are sustainable and practical personal mobility solutions for all major kind of environments, However, many campus environments also experience traffic congestion, parking difficulties And so a self-balancing bike would be an optimal solution in such cases as it may encourage people to switch to self-balancing two wheelers and further there would be many research & design optimizations so as to develop a pollution free and enviornment friendly e-bike. This paper focuses on design & development of a safer, compact and enviornment friendly two-wheeled self-balancing vehicle which can become a mode of personal transport and stand out to be one of the safest version of two wheeled vehicles.

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