Design and Fabrication of Automatic Balancing Bicycle

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Abstract:

This paper reports to design and build a bicycle prototype that is capable of driving and balancing without a rider. The Automatic Balancing bicycle will employ a control system to keep itself from falling over while in motion, and be propelled by a motor. The goal of this project was to build a two-inline-wheel bicycle prototype capable of balancing itself using a reaction wheel. This robotic bicycle is able to drive and also come to a complete stop without losing its balance. In order to maintain balancing, the robot reads sensor input to detect tilt angle and correctly reacts to maintain a steady vertical position. Sensor data is fed into a control system which outputs a balancing torque to a motor spinning the reaction wheel. The requirements include that the bicycle should be capable of accelerating, driving in a straight line and stopping without falling.

Keywords: Flywheel Balanced bicycle,Gyroscopic effect, Balancing control, 3 axis-accelerometer

1. INTRODUCTION

Bicycles are a common form of exercise, recreation and transportation used by billions. They can also serve to provide physical therapy, as they are a low impact form of exercise that can train balance, strength, stamina and coordination. Though one may consider riding a bicycle to be a fairly simple task, this is not the case for many people. This includes young children, adults who have never learned to ride a bicycle, injured people, or people suffering from developmental or cognitive disabilities. A system that could provide balancing assistance to a bicycle rider without otherwise affecting the experience of riding a bicycle could provide great benefit to these groups of individuals. Such a system could be used both as a teaching tool, and as a physically therapeutic device.

This problem of balancing a bicycle is analogous to what is known as the invertedPendulum problem. An inverted pendulum is a pendulum which has its mass above its pivot .The pendulum can be anything forms a simple mass and rod, to a full system. While a normal pendulum is stable, an inverted pendulum is inherently unstable, and must be actively balanced to remain upright. In the case of a bicycle, the bicycle is a rigid body which can rotate around its contact point with the ground. Although a bicycle motion has multiple degrees of freedom, the particular type of motion which this project aims to stabilize is this tilt angle around the point of contact with the ground relative to the direction of gravity.

2. BACKGROUND

A bicycle is inherently unstable and without appropriate control, it is uncontrollable and cannot be balanced. There are several different methods for balancing of robot bicycles, such as the use of gyroscopic stabilization by Beznos et al. in 1998 Gallaspy in 1999, moving. of the Centre Of Gravity (COG) or mass balancing by Lee and Ham in 2002, and steering control by Tanaka and Murakami in 2004. A very well-known self-balancing robot bicycle, Murata Boy, was developed by Murata in 2005. Murata Boy uses a reaction wheel inside the robot as a torque generator, as an actuator to balance the bicycle. The reaction wheel consists of a spinning rotor, whose spin rate is nominally zero. Its spin axisis fixed to the bicycle, and its speed is increased or decreased to generate reaction torque around the spin axis. Reaction wheels are the simplest and least expensive of all momentum-exchange actuators. Its advantages are low cost, simplicity, and the absence of ground reaction. Itsdisadvantages are that it consumes more energy and cannot produce large amounts of torque.In another approach proposed by Gallaspy the bicycle can be balanced by controlling the torque exerted on the steering handlebar. Based on the amount of roll, a controller controls the amount of torque applied to the handlebar to balance the bicycle. Advantages of such a system include low mass and low energy consumption. Disadvantagesinclude the ground reaction force it requires andits lack of robustness against large roll disturbance.

3. OBJECTIVE

Challenges over controlling the bicycle: Balancing the two wheeler bicycle without support of any extra legs or wheels is one of the biggest challenges for human also from long time.

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A bicycle remains upright when it is steered so that the ground reaction forces exactly balance all the otherinternal and external forces it experiences, such as gravitational if leaning, inertial or centrifugal if in a turn, gyroscopic if being steered, and aerodynamic if in a crosswind. Steering may be supplied by a rider or, under certain circumstances, by the bike itself. One other way that a bicycle can be balanced, with or without locked steering, is by applying appropriate torques between the bike and rider similar to the way a gymnast can swing up from hanging straight down on uneven parallel bars, a person can start swinging on a swing from rest by pumpingtheir legs, or a double inverted pendulum can be controlled with an actuator only at the elbow. A bicycle remains upright when it is steered so that the ground reaction forceexactly balance all the other internal and external forces it experiences, such as gravitational if leaning, inertial or centrifugal if in a turn, gyroscopic if being steered, and aerodynamic if in a crosswind. Steering may be supplied by a rider or, under certain circumstances, by the bike itself. This automatic balancing is generated by a combination of several effects that depend on the geometry, mass distribution, and forward speed of the bike. Tires, suspension, steering damping, and frame flex can also influence it, especially in motorcycles.

4. DESCRIPTION OF SYSTEM

In order to meet the design requirements, potential designs for controlling the balance of the bicycle were developed and will be explained in this section. The three designs are described below with particular attention given to how well they meet the selection criteria: physical complexity, power requirements, programming code complexity, ease of turning/steering, math complexity, deviation from a straight line, cost, and closeness to resembling a bicycle.

The level of difficulty is related to the number of motors and sensors required, the reaction time required, and starting and stopping. Finally, power requirements include the battery necessary to provide the system with 10 continuous minutes of power supply (the original power supply requirement; it has now been changed to 5 minutes). The required battery is dependent on the weight of the model, number of motors needed for that design, and the torque demanded of the motor(s) for the control system.

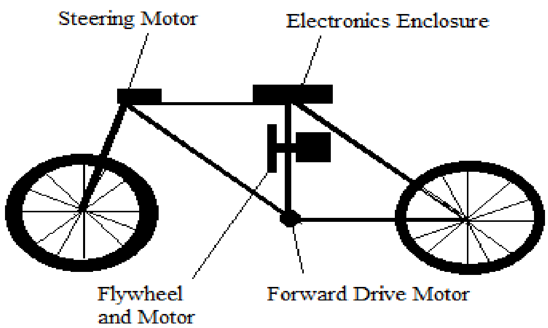

Fig.4.1: Conceptual design: Automatic balanced bicycle using flywheel

The flywheel design employs a flywheel which rotates about an axis parallel to the bicycle's frame. This design models the bicycle as a pendulum with a fixed pivot where the bicycle wheels meet the floor. As the bicycle begins to fall to one side, a motor mount to the bicycle exerts a torque on the flywheel, causing a reactionary torque on the bicycle, which restores the bicycle's balance.

The flywheel design has several advantages. This design is very stable: the bicycle can balance even in a stationary position. The mathematical model of this system is the least complex of the considered designs. Due to the simplicity of the design, the model would most likely be the closest to reality of the three designs. As a result of the relative math simplicity and the ease of starting and stopping, the controller would be relativelystraightforward to implement. This design would also allow the bicycle to travel in a relatively straight line with only small deviations.

One of the main disadvantages of this design is that it does not likely permit easy steering, especially for higher speeds, considering that the PID gains will be optimized for straightline travel. Also, the frame would have to be altered, causing the design to look less similar to a bicycle than others.

The final design of the Automatic balancing bicycle is described in this section. Each subsection explains one part of the design, including control overview, balance system, propulsion and steering system, and bicycle frame. All components discussed in this section.

4.1.OVERVIEW

Based on the design requirements, there were two options for what bicycle frame to use for this project: a child-sized bicycle or a smaller frame built from scratch. In the end, it was decided to build a small scale frame from scratch due to cost considerations and space considerations. Due to the high mass of a child-sized bicycle, the flywheel motor and associated controller required to balance it would be large and costly, and would not fit within the budget of this project.

The whole bicycle is constructed with the help of aluminium angles and arrangements to mount drive motor and keeping electrical circuitry. The cycle is low-lying so as to make its centre of mass low.

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Flywheel is made of mild steel, and it is sufficiently heavy enough to provide enough reactionary torque in the high torque motor attached to the vertical aluminiumangles.The flywheel is mounted on an axis parallel to the length of the bicycle. As the bicycle tilts, a motor applies a torque to the flywheel, which applies a reactionary torque on the bicycle to re-balance. A microcontroller implements a PID control algorithm based on the measured tilt angle to determine the required torque for the motor to apply to the flywheel.

4.2. CONTROL OVERVIEW

The control of the bicycle is divided into two parts: balancing controlled by a microcontroller and steering and propulsion remotely controlled by an operator. The two control systems are described in further detail below, and the entire system is illustrated in a fig.

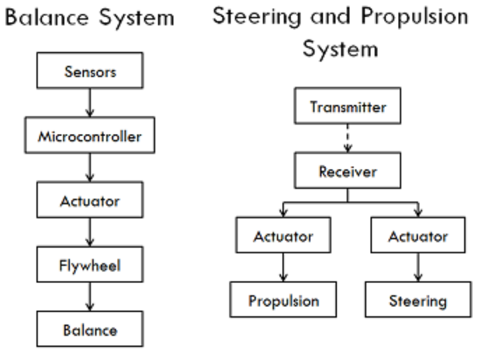


Fig.4.2: System block diagram

The AT mega 16 (the selected microcontroller) reads the output of the accelerometer and the gyroscope via the 12-bit analog-to-digital converter, and interprets the resulting values as a measurement of the bicycle's tilt angle. The measured angle is implemented into a PID algorithm, and outputs a corresponding voltage to the motor controller. The motor controller then outputs a voltage to the DC motor, which is geared down, and ultimately actuates the flywheel. A torque is exerted on the flywheel, and a reaction torque is exerted on the bicycle. This means in all aircraft with exception of agricultural and small general aviation airplanes, where the installation of a movable landing gear would increase the costs beyond the requirements of the aircraft category. Landing gear extraction is a primary operation and always its actuation has high redundancy.

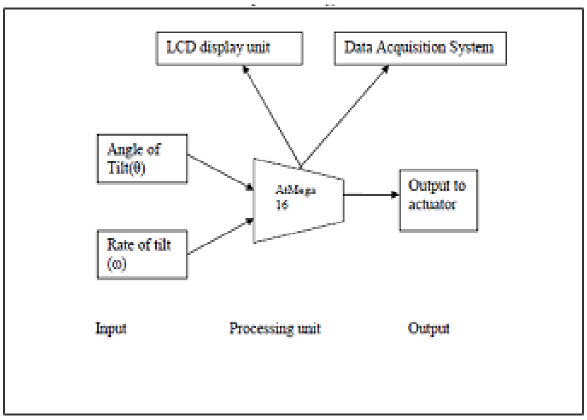
4.3. MICROCONTROLLER UNIT

The microcontroller selected to control the balance ofthe bicycle is the AT mega 16.

Fig.4.3:ATMega16

The processing unit used is Atmel ATMega16 microcontroller unit which is a versatile EEPROM. It has four I/O (Input / Output) ports, onboard ADC (Analog to Digital Converter) and PWM (PulseWidth Modulation) outputs for motor control. It can be programmed easily with minimum hardware requirements which make it extremely popular in robotics applications. Here it performs the following functions:

- ADC conversion of outputs of Rate Gyro and Accelerometer.
- Processing the input signals
- Periodic recalibration of gyro
- Display of angle & other data.
- Control of actuator unit



4.4. ANGLE SENSOR

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

- Triple Axis Accelerometer ADXL335
- Dual Axis Gyroscope IDG500

To measure the bicycle's tilt angle, it was decided to use an accelerometer and a gyroscope, and to combine them using a complimentary filter. Integrating these two sensors proves useful when calculating the bicycle's tilt angle. Accelerometers may be used to measure the angle with respect to gravity directly, but they are highly susceptible to noise.

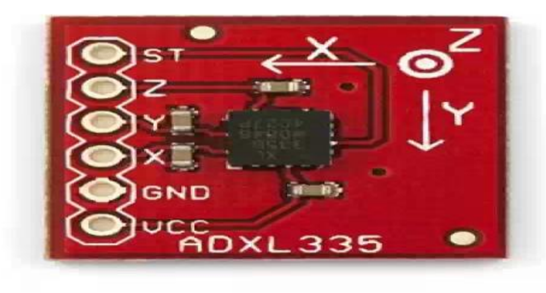


Fig.4.4: Triple Axis Accelerometer ADXL335

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Gyros are less susceptible to noise, but they measure angular velocity. As a result, the gyro output must be integrated in order to obtain a measurement of angular position. This integration yields an error known as drift, a drawback of the gyro. Integrating both sensors allows one to easily combine the output of each sensor in order to obtain a more accurate angle reading. This is accomplished through the implementation of a filter, which combines the advantages of each sensor and eliminates the drawbacks of each sensor.

4.5. ACTUATOR UNIT

As the bicycle tilts, we need to apply a restoring force to return the robot to vertical position. A reaction wheel pendulum model is followed for the balancing purpose. The components used are:

- High torque 24V DC motor
- A metallic reaction wheel
- Motor driver L293D

To supply sufficient power to the flywheel, a fairly powerful motor and a gear reducer are required. In order to choose the motor, the designed frame and layout of components, as well as the calculations to model a simple inverted pendulum, were input into a MATLAB simulation using Simulink. This simulation allowed the team to determine the power, torque and velocity that the motor needed to supply. To meet these requirements, we use High torque 24V DC motor.

The capacitor connected across the motor charges and discharges during the on and off time respectively, thus behaving like an integrator. The torque generated by the motor is a function of the average value of current supplied to it. It seems to be obvious that once we have angle we can rotate the flywheel with acceleration proportional to it, but that won't do the job. If that is done what actually will happen is that when there is a tilt the bike will cross the mean position and reach the other side till the same tilt angle. To fix this we need some kind of algorithm that can damp this periodic motion and make it stable at the mean position after some time. This is where **PID (Proportional Integraland Derivative)** Controller comes to use.

5. CONCLUSION

This paper is highly concentrated on the bicycle using reaction wheel pendulum. Tilted information to roll axiscouldis attained through the sensor integration of complementary filter between gyroscope and accelerometer. The simplest structured PID controller has been applied to roll direction joint.As future works, robust controller for the roll axis to minimize external disturbances effects, and „S curved trajectory are under research.Sustainable and practical personal mobility solutions for campus environments have traditionally revolved around the use of bicycles, or provision of pedestrian facilities. However many campus environments also experience traffic congestion, parking difficulties and pollution from fossil-fuelled vehicles. It appears that pedal power alone has not been sufficient to supplant the use of petrol and diesel vehicles to date, and therefore it is opportune to investigate both the reasons behind the continual use of environmentally unfriendly transport, and consider potential solutions. This paper presents the results from a year-long study into electric bicycle effectiveness for a large tropical campus, identifying barriers to bicycle use that can be overcome through the availability of public use electric bicycles.

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