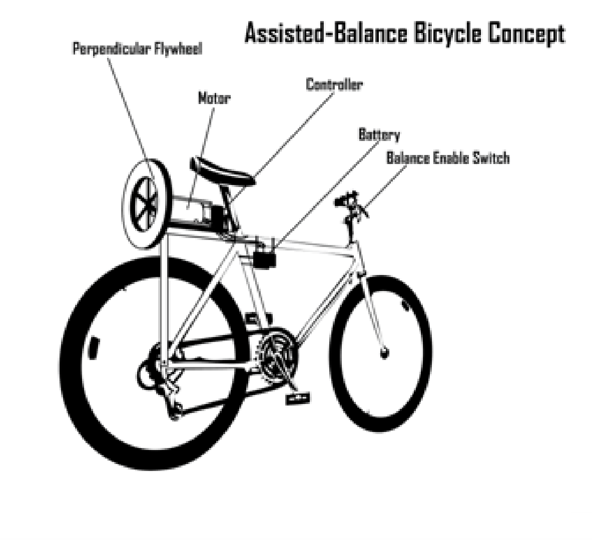
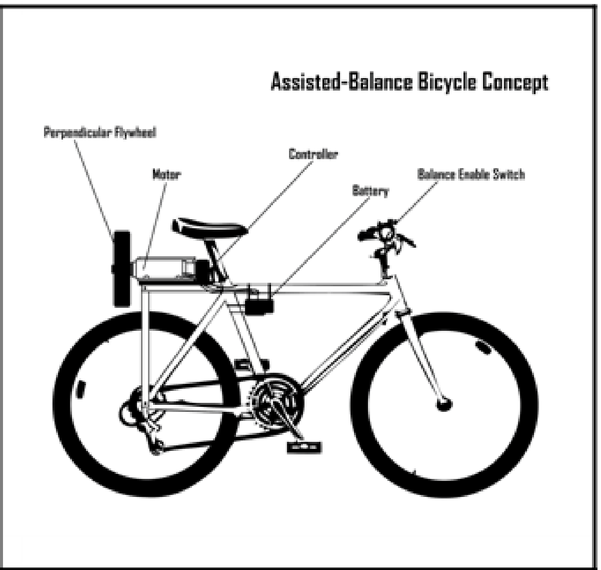
Assisted-Balance Bicycle



Rear-Angle View



Side View

Proposal September 21, 2010

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I. Introduction

The most difficult part of learning to ride a bicycle for many people is creating enough momentum through pedaling in order to allow the bike to stabilize itself. Once a rider learns how to mount a bicycle and distribute his or her weight, the rest is up to the natural physics of the wheels, seat, pedals, brakes and handlebars. Imagine if this most difficult task was eased by taking away the necessity of stabilizing oneself.

Understanding the physics of a bicycle is much more in depth a problem than one might think considering how common the device is in everyday life. When a bike is falling out of balance, it is as if the bicycle is making a circle to the side of the fall, pulling the bike towards the center of that circle, sometimes referred to as the "circle of fall." In order to keep from falling into the circle of fall (i.e. crashing), the rider has to create a counter-pull out of the fall. There are two ways a rider can create this counter-pull to overcome the fall. One choice is to quickly speed up the bicycle. The other is to quickly tighten (shorten) the radius of the circle of fall. Experienced riders instinctively do both as required. What we propose to do is create the counter-pull necessary to allow for the rider to remain upright.

When someone learns to ride a bike using training wheels, they teach themselves how much force is required to propel themselves forward, how hard one must brake to stop, and also the general mechanics of the steering of a bike. There is a giant step from here to learn to balance oneself while accounting for those other factors once the training wheels have been removed. Our balance-assist can create the intermediary step and allow the rider to become more confident in their ability to control the bike and ultimately learn to ride the bike with no assist. We plan to have certain degrees of assist so that, as one progresses, they may be able to have less of a counter-pull automatically generated so that they may be able to compensate themselves.

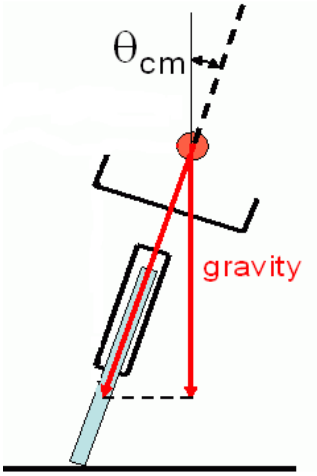
Beyond teaching someone how to ride a bicycle, the balance assist also has application in rehabilitation of people with inner ear problems (which can cause a deficiency in the ability to self-balance) or other debilitating injuries and also in aiding the elderly who have lost their confidence in their ability to self-balance.

As a senior design project, this project encompasses many areas of engineering. General dynamic physics is involved in determining the motion of a bicycle. The problem of balancing a bicycle is directly comparable to the classic nonlinear control systems problem of the inverted pendulum. There is a great mechanical aspect of this problem in devising mounting methods and mass distribution of our balance assist. Lastly, there is a project management aspect of the project that involves time-management, money-management, and teamwork that are all well accounted for by our proposal.

II. Bicycle Physics

The primary principal that allows a falling object, such as a bicycle, to have its position and angular acceleration changed by an accelerating flywheel is something that is called “coupled forces”. This essentially means that as long as the flywheel is fixed to the bicycle, the moment, also called torque, which is generated by the angularly accelerating flywheel, is transferred to the angular acceleration of the bicycle which is then used to rotate the bicycle back to the vertical position. There are many variables that must be calculated to determine what angular acceleration of the flywheel is need to counteract the falling motion of the bike due to gravity including the torque created by the bicycle falling as well as the moment of inertia of the flywheel.

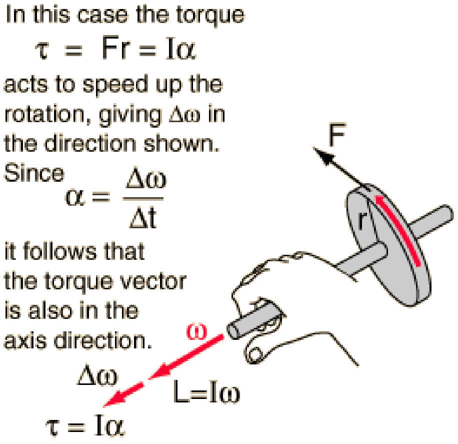
To calculate the torque of the bicycle falling we must first calculate the center of gravity, also known as center of mass, of the bicycle. The reason for this is because the force of the gravity pulling the bicycle down can be represented by a single force that is applied to the object at its center of mass. This is not so simple a task when trying to calculate the center of mass for an oddly shaped object such as a bicycle. However, we can easily calculate the center of mass of simple geometric shapes such as discs and rods. This is helpful due to the fact that a bicycle is essentially made up of two discs and a few rods. Therefore, the process to find the center of mass for a bicycle becomes fairly simple. All that has to be done is to find the center of mass of all the individual pieces of the bicycle. Then, those individual centers of masses can be added up using weighted averages to find the center of mass of the entire bicycle. Once that is done, the radial arm from the ground to the center of mass where the gravity acts on is known, and the torque of the falling bicycle can be calculated.



Once the torque for the falling bike is known, that force can then be compensated for by accelerating the flywheel. The torque of the bicycle and the torque created by the flywheel are related by the equation

$$M_b \times {R_b}^2 \times \alpha_b = M_f \times {R_f}^2 \times \alpha_f$$

where M_b is mass of the bicycle, R_b is radius from the ground to the center of mass of the bicycle, α_b is the angular acceleration of the bicycle, and the terms on the right side of the equation are the mass, radius and angular acceleration of the flywheel. It thus becomes a matter of calculating the necessary variables to determine how much angular acceleration of the flywheel is needed to move the bike. As can be seen by the equation above, the primary variables we need to control to keep the flywheel angular acceleration as low as possible to keep it within the limits of the motor are to keep the center of gravity of the bicycle as low as possible, have the ratio of the center of mass of the bicycle to center of mass of the flywheel as large as possible without overweighting the motor, and making the radius of the flywheel as large as possible.


In this case the torque

$$\tau = Fr = I\alpha$$

acts to speed up the rotation, giving $\Delta\omega$ in the direction shown. Since

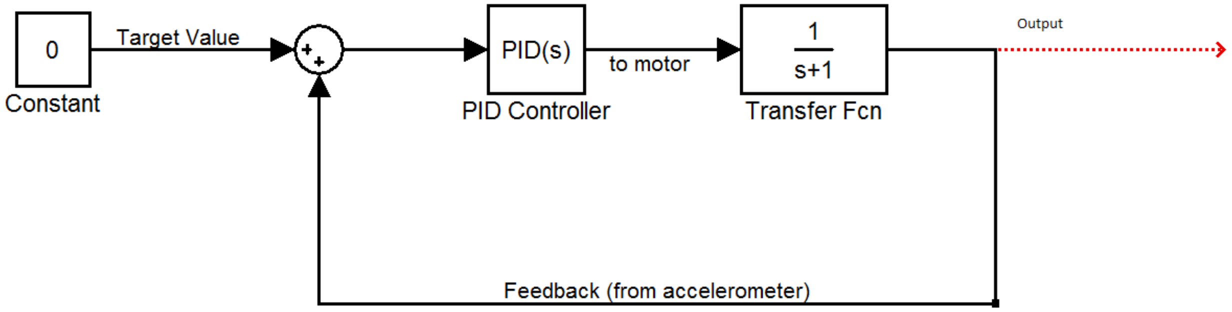
$$\alpha = \frac{\Delta\omega}{\Delta t}$$

it follows that the torque vector is also in the axis direction.

Using the above principle and concepts we can approximately model the falling of a bicycle and the effect that an angularly accelerating flywheel attached to the body of the bicycle will have on the bike. It is therefore possible to create a counter moment to the bicycle falling using a flywheel while keeping the values within the capabilities of the motor and the stress limits of the materials for the flywheel.

III. Balancing Control System Theory

The goal of the control system is to balance the bicycle using feedback from the accelerometer. This creates a closed loop control system, which is controlled by a PID controller. There are two inputs into the system, the desired value of zero (a completely balanced system) and the feedback from the accelerometer. These two inputs are added together to get an error, which is inputted into the PID controller. The output from the PID controller determines the voltage applied to the motor, which affects the speed and acceleration of the flywheel, thus balancing the bicycle.



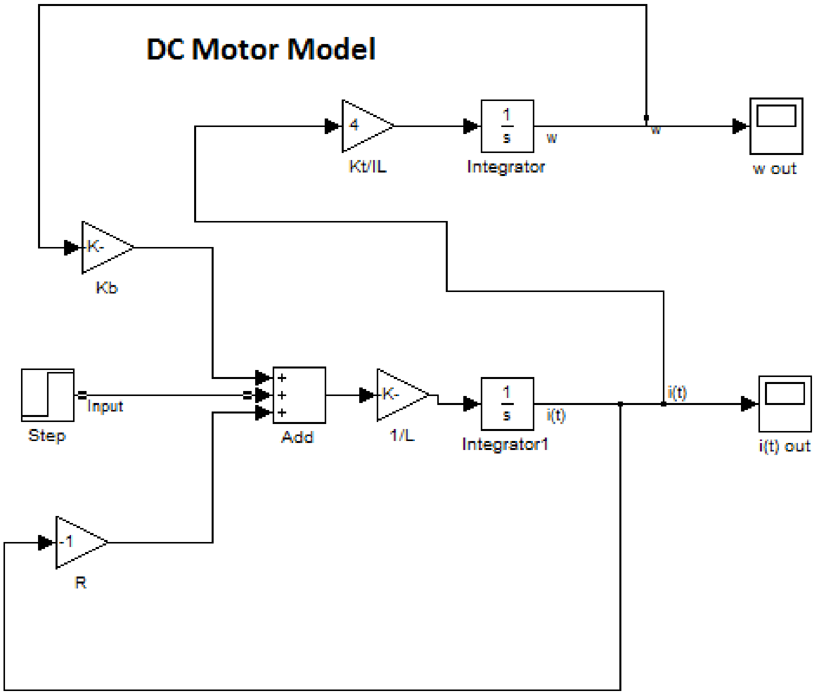
To model the control system, SIMULINK was chosen. SIMULINK is a component of the MATLAB package and is used to build systems from a block component level. This allows the user to create a complete system within SIMULINK using standard blocks used in control system theory. SIMULINK also has a PID tuner, which will automatically tune the gains for the P,I, and D parts of the controller. If an accurate model of the plant can be obtained or designed, this is an extremely effective tool that allows the user to look at the rise time, overshoot, etc. to find a controller that will suit the application best.

Also, SIMULINK allows the user to model certain components using differential equations. For example, a DC motor can be broken down to two differential equations:

$$\frac{d\omega(t)}{dt} = \frac{K_T}{I_L} i(t) \quad \text{and} \quad \frac{di(t)}{dt} = \frac{1}{L}[V_s - Ri(t) - K_b\omega(t)]$$

where K_T, I_L, R, L, and K_b are parameters of the motor.

From these equations, one can create a model using integrators, adders, and gain blocks. Thus, is on can obtain the motor parameters, one can create an accurate model of a motor within MATLAB and use the computational power of the program to do some useful analysis.



To model the control system in SIMULINK, an external simulated input had to be created. This input represents the external forces on the bicycle, such as a person leaning or simply gravity working on the system. This was added to the force created by the angular velocity of the motor to create the feedback portion of the system, which will be actualized by the accelerometer in the physical system. For the external input, several different patterns were created to try to accurately simulate some forces that might occur during physical testing.

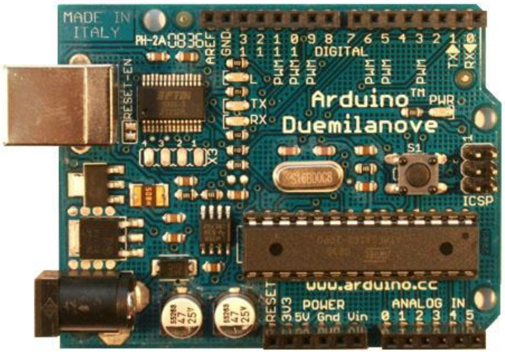
IV. **Physical Hardware**

Hardware List

- Arduino Duemilanove Microcontroller
- Memsic 2125 Dual Axis Accelerometer
- Bosch Cordless Drill Motor/Batteries/Charger
- Bike
- Mounting Hardware
- Flywheel

Microcontroller

For the brain of our entire system, we have chosen the Arduino Duemilanove model microcontroller. It has 14 digital I/O pins and a 16 MHz clock which we feel is sufficient for our purposes. The small size and price point of $30 also make it a very good choice. One of our group members happened to already have one of these.



Accelerometer

We decided on an accelerometer as the input to our control system. By serially interfacing it with our microcontroller, it is relatively easy to read out angles based on the positioning of the accelerometer. This will tell us when the bike is leaning and correction is needed. We selected the Memsic 2125 dual axis accelerometer available at Radio Shack for $33.

Motor/Batteries/Charger

The flywheel in our design requires a powerful motor to accelerate it left or right. This provides the counteractive force to stabilize the bike. The motor has to be reversible in order to spin the flywheel both ways. The motor needs to be DC and battery powered. Considering all these requirements, a cordless drill seemed to be the most viable option. It is powerful, reversible, battery powered, and comes with a charger. We selected the Bosch 18 volt 1/2 inch Compact-Tough Lithium Drill/Driver. This drill can spin up to 1600 RPM, and it has 500 in-lbs of torque. It has two lithium-ion batteries rated at 1.3 Ah capable of charging in less than 30 minutes. This drill was purchased from Amazon.com for $150.

Bike/Mounting Hardware

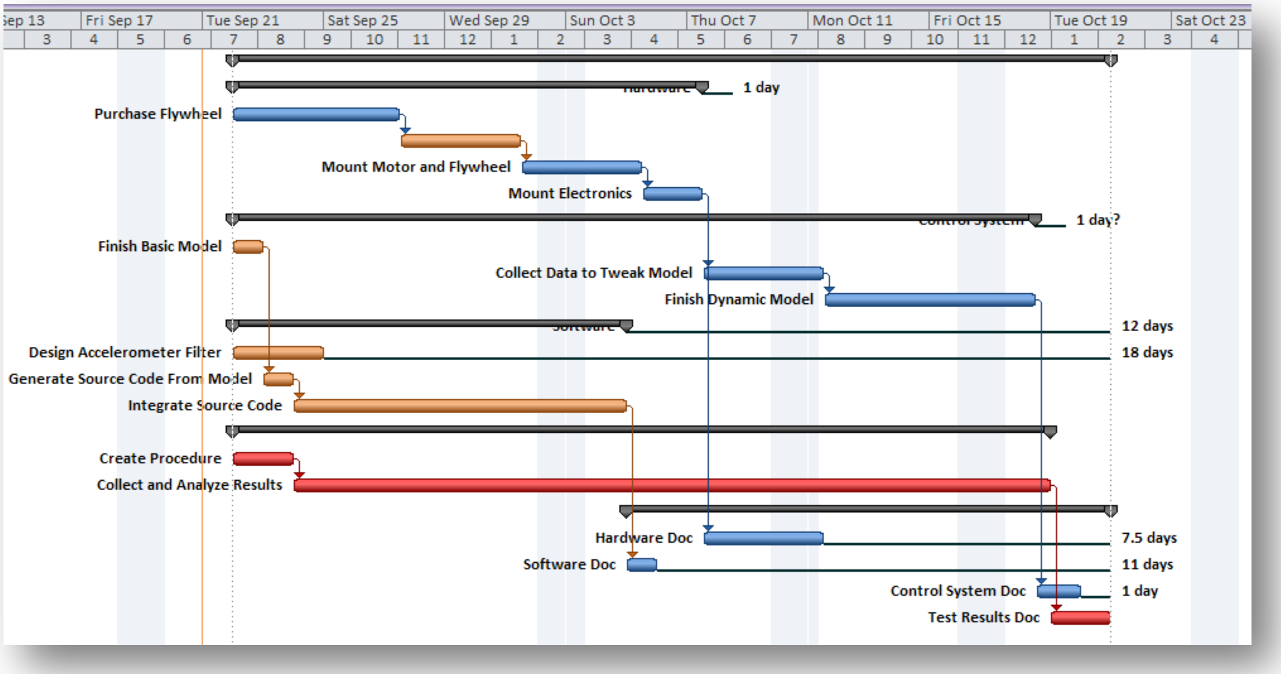
While our system theoretically is scalable, we are initially concentrating on stabilizing a child. Therefore, we selected a child's bike for our prototype design. We acquired two bikes at no cost for us to experiment with. However, we later discovered that a former graduate student had worked on a self-stabilizing bike previously. We decided to use this bike since it was already equipped with mounts for the hardware. It has a wooden surface mounted behind the seat that would be perfect for the microcontroller, accelerometer, motor, and flywheel to sit. There is also another wooden mount under the seat that we are considering for the battery.

Flywheel

The flywheel is one of our most crucial components. It also happens to be one of the hardest to obtain. Since our requirement for it is so specialized, it is easier to construct our own flywheel than to search for the perfect one. Currently, our plan is to use a small bicycle wheel. The bicycle wheel has the perfect place in the center to attach a rotating shaft. Plus, the wheel is very light in the center. We are going to add weight evenly distributed around the outside of the wheel until we get our desired torque to stabilize the bike.

V. Timeline

Our goal is to produce a working product by October 20, 2010. A detailed Gantt chart of the tasks to reach that goal can be seen in the figure below. The Gantt chart can be broken down into 5 main sections. These sections are hardware, software, control system, testing, and documentation. With this structure, it will be easy to build upon the schedule while maintaining an orderly timeline.



VI. Bill of Materials

Item	Price
Motor/Batteries/Charger	$153.49
Flywheel and Shaft	$50*
Accelerometer	$32.99
Microcontroller	$29.99
Mounting Hardware	$45*
Bike	$50*
Developmental Expenses	$100
Total	**$461.47**

*Cost has been estimated

The bike and mounting hardware were obtained at no cost to us. However, we have estimated the costs to give an idea of how much it would cost to recreate our system. We also accounted for any reinforcements we may have to make to the equipped mounting hardware on the bike. The flywheel and shaft have yet to be obtained so their costs have also been estimated. This is a very conservative budget. There will most likely be unforeseeable expenses incurred. Fortunately, a gracious donor, Mr. and Mrs. Stringfellow, have donated our entire budget plus a little extra to us.

VII. Conclusion

To summarize, we propose to create a balance-assist for a bicycle that can be used on any standard bike. The applications are in learning to ride a bike, aiding the disabled, and aiding the elderly. Using control systems theory, we will mount a flywheel to a reversible motor, feedback accelerometer angle data into our control system, and output compensated motor commands to correct for the lean associated with a falling bike. Our design encompasses many aspects of engineering, primarily those listed in the senior design requirement as defined by Accreditation Board for Engineering and Technology (ABET).