Electronic Automatic Transmission for Bicycle

Team 4 – Tianqi Liu, Ruijie Qi, and Xingkai Zhou

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TA: Hershel Rege

1 Introduction

1.1 Objective

Nowadays, an increasing number of people are commuting by bicycles in US, data shows that the number of bicycle commuters has increased 62% from 2000 to 2013 and this number is even higher in big cities: 408% for Portland, OR; 301% for San Francisco, CA; 498% for Washington, D.C. [1].

With the development of technology, bicycles that equipped with the transmission system including chain rings, front derailleur, cassettes, and rear derailleur, are more and more popular.

However, inexperienced bikers are usually confused about how to choose the optimal option of gears. As a result, they would suffer from inefficient gear ratio and exhaust themselves quickly. Besides, it is inconvenient for a rider to shift gears manually under some specific conditions such as braking, accelerating or trying to balance the bike.

Bicycle changes gears by pulling or releasing a metal cable connected to the derailleur. Thus, we could achieve automatic gear changing by hooking up the cable to a servo. Our goal is using sensors to electronically determine the optimal gear under conditions detected by sensors and choose the corresponding gear by pulling or releasing the steel shift cable in the bike. We plan to focus on the shifting of rear derailleur. In shorts, we would like to make an electrical automatic transmission for bicycle so that a biker can ride without manually changing gears. Besides shifting automatically, we plan to add a manual mode to our device as well. With the manual mode activated, the rider could override the automatic system and select the gear on its own. With this system, riders are able to focus more on skills other than shifting gears and ride more conveniently and more comfortably.

1.2 Background

We found out another group did electronic bicycle shifting in Spring 2016, but they didn't have an automatic gear shifting function and didn't have the sensor set-up like ours. In the commercial area, both SRAM and SHIMANO have electronic shifting products, but these products integrate the servo motor inside the derailleurs, and they have a price tag over $1000. Only professionals or rich enthusiasts can have a hand on them. Our system could potentially serve as an add-on device at acceptable price to all bicycles with mechanical rear derailleur transmission. To use our device, the user just need to detach the cable linking to the rear derailleur from the shift levers on the bike handle, and attach the cable to our device.

Our design won't necessarily directly compete with current commercial product, but we could let more people have a taste of electronically controlled bicycle shifting with a low-price tag.

1.3 High-Level Requirements

- Our system must be able to determine the optimal gear under the conditions described by sensors. Qualitatively speaking, our system should select lower gears when the cadence/speed goes down or pedal pressure goes up, and select higher gears when the cadence/speed goes up or the pedal pressure goes down.
- Our system must be able to pull or release the steel shift cable accurately enough to shift one gear up or down. In the beginning we will implement a simple 3-speed transmission, to decrease the difficulty level.
- Our system could have a manual mode described in the Objective section as well. Since the mounting/unmounting process of our device will take some time. So this functionality offer the user an option to take control over the transmission if he or she misses the fun of switching gears. Also, it would make our testing process easier.

2 Design

Our design mainly contains 4 modules: power supply, control unit, sensing unit, and servo module. The power supply provides all the electrical power consumed by our device. The control unit gathers data from the sensing unit, processes user inputs and sends downshift/upshift signal to the servo module. The sensing unit measures the rider's cadence, the bicycle's speed, and the pressure applied to the pedals. The servo module pulls or releases the shift cable to move the rear derailleur and shift gears.

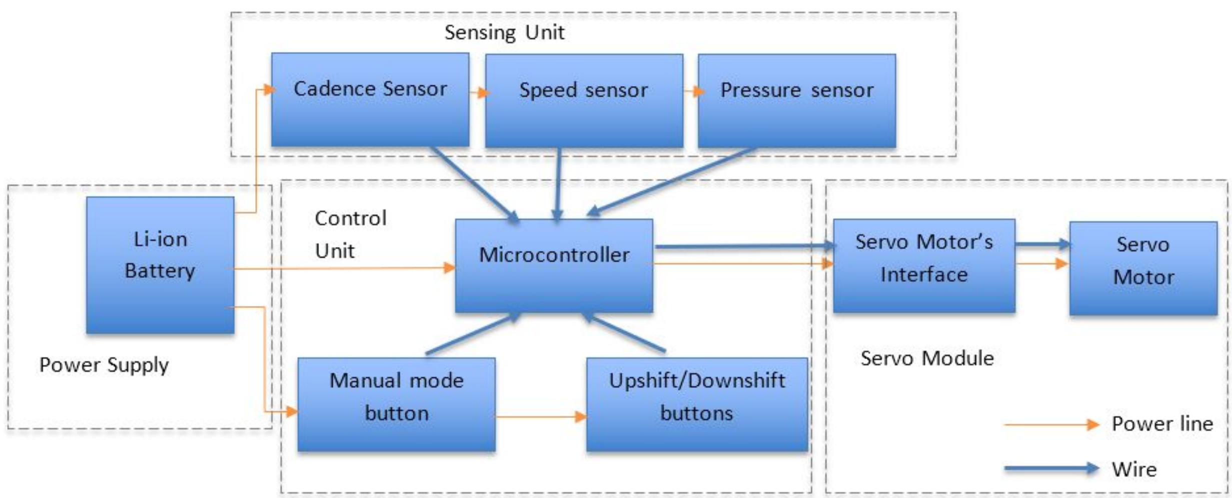

Figure 1. Block Diagram

2.1 Power supply(Li-ion battery)

The power supply contains a Li-ion battery and it provides power to all components.

We plan to use a 5V Li-ion battery or a larger battery with a 7805 voltage regulator, which can convert 7 to 35 V battery to a 5V power source.

Requirement: The battery must be able to store enough charge to power the entire system for at least 1 hour.

2.2 Sensing unit

In this part, we will have one cadence sensor, one pressure sensor on the seat and two pressure sensors on the paddle. All the results shall be passed to microcontroller. The control unit will use those data to decide when and how to switch the gear.

2.2.1 Cadence sensor

We will use 3144 5V Hall Effector as cadence sensor. One of those affordable sensors costs less than $1, including the small magnetics piece. And the output pin can be connected with microcontroller as digital input. This sensor should be placed at the crankset so that it can measure the true cadence and pass it to the microcontroller.

Requirement: The cadence sensor should be able to measure the cadence in accuracy of 3rpm.

2.2.2 Speed sensor

This sensor would use the same hardware as the cadence sensor(3144 5V Hall Effector) and connects to the microcontroller in the same way. However, it should be connected to the bicycle's wheel and since the diameter of bicycle wheel is known, the microcontroller could convert the frequency and get the speed.

Requirement: The speed sensor should be able to measure the speed of bike in accuracy of 1m/s.

2.2.3 Pressure sensors

We plan to insert a RFP602 thin film pressure sensor into the seat and two on the paddle. The pressure sensor is a resistor with resistance varying based on force applied on it.

Requirement: Could stay unharmed under 100KG pressure. Accuracy should be within 1 KG. Reliably output for at least 1000 rounds.

2.3 Servo module(integrated interface and servo motor)

This module receives signal from the control unit and mechanically actuates the shift cable.

We will use SPMSA5030 servo, which could offer 3.8 kg-cm, and pulling the cable of our transmission only takes 2.3 kg. So this sevo should be capable of switching the gear.

Requirement: Have enough power(>> 2.3KG) to pull the cable of rear derailleur. Can be powered by 5V voltage source.

2.4 Control Unit

In this part, it combines data from sensing unit and user input and outputs upshift/downshift signals to the servo module.

2.4.1 Microcontroller

For the microcontroller we will use ATmega328 28-pin PIPD version. This 8 bit microcontroller chip contains 32KB ISP flash memory and 23 general purpose I/O lines. To power the microcontroller, we need one 10k Ohm resistor, two 10uF capacitors, two 22pF capacitors, and a 16MHz clock crystal.

Requirement: Operate reliably for 2 digital input, 3 analog input and 1 digital output with 5V power source. Also, it should be able to connect with laptop using serial to USB connector.

2.4.2 Buttons

One should be toggle switch and the other two should be push buttons.

Requirement: Safe to operate while riding the bike. Suitable for 5V circuit.

2.5 Risk Analysis

The control of the servo could be a risk to the completion of this project. One problem could be the durability of the servo. A servo that is strong enough(>>2.3 KG) to pull the shift cable and hold the tension is a critical requirement, since otherwise the servo wouldn't physically to able to shift gears and the entire system would fail. Another problem could be how accurate could we control the servo. To be more specific, when the control unit tells the servo to shift up a gear, would it exactly shift up 1 gear or would it be slightly off? Even if the chain is slightly off its supposed position, it can grind with the cassette or chain rings, creating noises and inefficient transmission. That's why accuracy is also important.

Another risk to our project is on the software side. We need to ensure that the software algorithm could find the optimal gear based on data collected from various of sensors. If the algorithm is not good, it would jeopardize the usability of our project. The first thought is that we could study how experienced riders choose their gears. However, this could make us put tons of time into experimenting and potentially waste our time. Another method is to use mathematical calculation to select a gear that could keep our rider rides at an ideal range of cadence given the speed of the bicycle. No matter which method we choose, or we combine them, eventually we should carry out an algorithm that is good enough to decide the optimal gear.

3 Ethics

According to the IEEE Code of Ethics #5 [2], our product should not injure any people nor their property. Although we tried very hard in the design process, there are still several potential hazards that worth noticing.

First, changing bike gear at unexpected time might cause injury to the bike rider's knees and feet ankle. When the bike rider is riding in full speed, he or she might put all the body weight on the paddle. If the gear is changed in that situation, the sudden glitch will apply a counter force on one leg and might cause pain on that knee and ankle. To avoid such danger, we will implement pressure sensors on the seat and both paddles. Our microcontroller will avoid switching gear when the bike rider put all his or her body weight on one paddle.

Second, the lithium-ion battery on bike might explode and cause harm to the bike rider. A bike should have the ability to function under unfavorable weather conditions, including raining. Moisture in the environment could potentially cause a shortcut and result in battery burning or even explosion. Thus, we will follow the IP54 standard in design and manufacture process [3], which means the device exclosure should provide protection against dust and water spray.

Another harmful situation is bike crushing. The physical impact on battery could cause a short circuit inside the battery cell, overheat the neighboring part of the battery and propagate to a fire or even explosion. One of the possible solution is to put the battery inside the down tube of bike frame, which is the strongest part of the bike.

References

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