Virtual Cycling Reality

By

Bryant Johnson

Chongxin Luo

Gregory Knox

Project Proposal for ECE 445, Senior Design, Spring 2016

TA: Luke Wendt

10 February 2016

Project No. 47

Contents

Part I

Introduction

1 Statement of Purpose

The age of Virtual Reality (VR) is fast approaching, but VR experiences are currently beyond the reach of the average consumer. 3D goggle systems and hardware designed to interact with them are prohibitively expensive for the average consumer at $1500 for an oculus rift pc bundle. The Virtual Cycling Reality (VCR) Project seeks to bring the power of VR into the homes of the average consumer. This will be accomplished by creating a 3D video game world in which the user can bike. This world will come to life through a system of sensors, a fan based environmental feedback system, and by harnessing the power of the user's smart phone, coupled with a head mounted display. While other existing virtual biking experiences, such as CycleOps and The Virtual Bike, also attempt to bring a cycling experience into the home, they rely on 2D display measures and lack the environmental feedback that the VCR Project will provide.

2 Objectives

2.1 Goals

- Provide smooth virtual world for the user to experience.
- Track user head movement precisely.
- Accurately sense cycling speed and turning, with low latency user feedback.

2.2 Functions

- Measure rider speed.
- Detect handlebar rotation.
- Track head motion in three degrees of freedom.
- Interpret sensor data and use to update the virtual world.

2.3 Benefits

- Allows the fun of biking during any weather or season.
- Provides a more physically interactive way to virtual bike ride.
- Users can experience and explore a unique world.

2.4 Features

- Fan based wind feedback system.
- Variable resistance simulates different terrain types.

Part II

Design

3 Block Diagrams

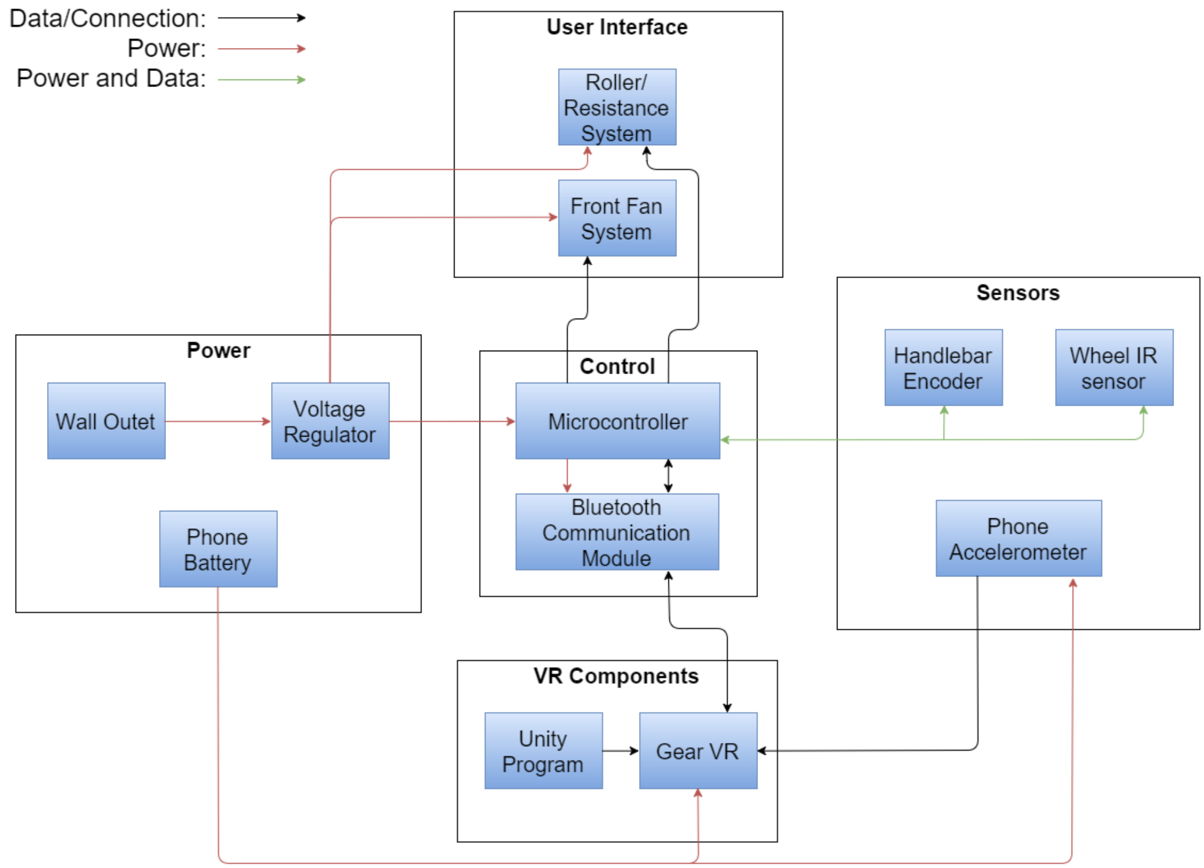

Figure 1: Block Diagram for Virtual Cycling Reality Project

4 Block Descriptions

Shown in Figure 1 above is the Block Diagram for the Virtual Cycling Reality project. The diagram contains five main blocks, which are Power, Control, User Interface, VR Components and Sensors. Each block can be implemented individually, and connecting the blocks in the end will achieve all functionality listed previously. The implementations and functionality of each block are being discussed in the sections below. (whats the functionality, where takes the input, where output goes).

The breakdown of this design splits the work into modules which involve power circuit, sensor/microcontroller design and software engineering. All three technical areas of focus matches with the areas of specialties of project members, which each member is able to put their area of interests into the maximum use.

4.1 Power

4.1.1 Voltage Regulator

Power for this project will be acquired directly from the wall outlet. A stepdown transformer will convert the line voltage from 1 V ac to 24 V ac. A bridge rectifier will convert the ac voltage to dc and a fixed voltage switching regulator will provide the final 12v output. A buck converter is also necessary to power the Fan System. The buck converter is controlled with a PWM signal from the microcontroller. This outputs the full 12v at 100% duty ratio and decreases linearly to 0v at 0% duty ratio. The buck converter will be constructed from discrete components and will require a power MOSFET and a high-side gate driver.

4.2 Control

4.2.1 Microcontroller

The microcontroller in this project acts as the connecting bridge between sensors and the simulation. An Arduino Uno will be used for for this section of the design. The power source for this unit comes from the voltage regulator and will be operating at 12 V. It takes input from the wheel IR sensor and the handlebar encoder. After probing the sensors the data collected will be sent Gear VR module using the Bluetooth Communication Module (BTCM). In the case of a changing terrain in the simulation the Gear VR module will send a new resistance value to the microcontroller via the BTCM. In response, the microcontroller then sends a corresponding signal to the Roller/ Resistance system in order to change the pedalling resistance, thus providing feedback to the user.

4.3 User Interface

The User Interface module contains all components that interact with the user. The User Interface system has two major functionality. First of all, it gives a platform for user to use physical actions to control simulation characters. Secondly, it gives the user physical feedback according to the simulation environment. The User Interface system contains two main components, which are the front fan system and the rollers/resistance system. The user experiences these systems through riding a bike. The bike is being modified in order to achieve all functionality for this project.

4.3.1 Front Fan

The fan control system gives realistic physical wind feedback to the user, which plays an important role in the immersive simulation system. The fan system will be constructed from up to six 120mm 12v dc computer fans. The fans will be placed together to give a stronger and wider air movement. The microcontroller controls fan speed based on the speed of the rider in the simulation. Section 4.1.1 discusses more on the buck converter.

4.3.2 Roller/Resistance System

The Rollers/Resistance system is located on the rear wheel of the bike, and it gives direct feedback to user from the simulation. The rear dropout of the bike is supported by a bike stand while the roller system is applied to the rear wheel. The roller system is incorporated on the bike stand as a part of the bike trainer. The resistance works by moving a magnet in proximity to a metal roller. The position of this magnet is controlled by a steel cable which will be moved using a servo controlled by the microcontroller.

4.4 VR Components

The VR Components for this project contains two main parts, the software part of the VR Components is supported with Unity3D program, and the hardware part of the VR components is supported with Gear

VR.

4.4.1 Gear VR

Gear VR is being used as the head mount display for this project. It provides the user with a 3D virtualization environment. The processing power of Gear VR is supplied by an Andriod phone (Galaxy S6). The mobile processor takes inputs from on chip phone accelerometer, and microcontroller via Bluetooth. All sensor input information will be used as controller input for the Unity Program. The corresponding field of view will be displayed onto the phone screen.

4.4.2 Unity Program

As the software side of the project, a VR simulation is built with the Unity3D program. User will experience a simulation of riding a bike in the virtual environment, all physical inputs from the bike will be transformed into control inputs, and the certain simulation elements such as the slope and resistance will be used as the output to the bike for user feedback. The simulation program will be running on the smart phone directly.

4.5 Sensors

There are total of three sensors being used in the project in order to track the user's physical movement. The sensor signals are being integrated into simulation inputs.

4.6 Handlebar rotary Encoder

In order to effectively measure the angle of the handlebars, a handlebar rotary encoder will be placed on the head tube of the bike. The voltage reading from the rotary encoder will be probed by the microcontroller in order to calculate the degrees of rotation of the handlebar. The voltage readings will need to be tuned to ensure that voltage ranges read can be quantized into approximate handlebar positions.

4.7 Phone Accelerometer

The built in accelerometer on the smart phone is being used to track the user's head movement. Its input directly feeds into the Unity Program, which is being used to control the simulation field of view. Due to the limitation of the accelerometer, only rotation movement will be support, the linear movement will not be support for the VR experience.

4.8 Wheel IR Sensor

The IR Sensor is installed on the bike stand. The IR sensor functions to record the speed of the rear wheel, the sensor inputs is being used as control input for the simulation as well as the control input for the front fan system. The IR sensor contains both IR emitter and IR receiver, four IR reflecting tapes are installed on the wheel spokes. The sensor voltage reading peaks when the IR reflecting tape passes in front of the the receiver. The frequency of IR sensor peaks will be used to calculate the speed of the bike.

Part III

Components Requirements, Testing Verifications, and Tolerance Analysis

5 Components Requirements Testing Verifications

Components Requirements	*Testing Verifications*
Voltage Regulator 1) Voltage regulator must operate at a maximum input voltage of 36 V and supply 12 V ±5% for a current up to 1.4 A. 2) Buck converter must be able to supply load up to 14 W at 12 V output.	1) Attach 8.5 Ω power resistor as regulator load. Next, attach oscilloscope probe across the load. Then, supply 36V to regulator from DC supply. Ensure voltage remains between 12.6V and 11.4V. 2) Attach a 10.3 Ω power resistor to the converter output. Next, attach oscilloscope probes across the load. Then, supply the converter with 12V. Drive gate driver with PWM signals from 50% to 100% duty ratio. Ensure no components go about 50°C.
Microcontroller 1) Able to drive I/O pins to logical 1 and 0. 2) Able to accurately read analog voltages between 0 V and 5 V with +/-15 V variance.(Digital range of arduino = 0-1023) 3) Latency for a signal sent from the microcontroller to the phone should have a round trip time less than 30 μs.	1) I/O ports should display 5 V for logical 1 and 0 V for logical 0 with +/-0.5 V variance. 2) Using a voltage source we will manually supply the pins of the arduino with the correct voltage and compare against reading from the microcontroller. 3) Comparing time stamp between when the micro controller sends a signal to the phone, and when the phone sends an acknowledgement message back to the microcontroller.
Bike Controller 1) Able to support user with maximum of 120kg body weight. 2) Able to support maximum biking speed of 30km/h.	1) A heavier member of the group will test ride the bike with safety features on, additional weight will be added to the member until the total weight reaches 130kg. 2) Use bike speedometer to measure speed of the bike, the speed of the bike will be increased gradually until reaches 35km/h.
Roller/Resistant System 1) Able to apply a minimum of 3 different resistance levels to the rollers.	1) Different resistance levels will be set, and weight will be added to the bike pedal until it moves. The difference of weight between resistance levels should be minimum of 2.5kg.

Front Fan Unit 1) Rotation speed has approximate linear relationship with input PWM duty ratio +/-20%. Max rotational speed is 1200 rpm.	 1) By writing a test routine on the microcontroller and by probing the sense pin from the fans, we can compare to the expected rotational speed based on the input voltage to the actual. The sense pin outputs square waves which will be read on osilliscope.
Unity Program 1) Achieve reasonable simulation performance, with minimum of 30 frames per second.	 1) the Unity Program will be ran independently on the smart phone with frame rate recording.
Gear VR 1) Achieve extensive use up to 1 hour without major discomfort for the user. 2) Smart Phone battery should be able to achieve 1 hour of usage with full charge.	 1) Several volunteers will be asked to use the simulation for extensive period of time (1 hour), any discomfort and disorientation side effects will be reported and modified. 2) The smart phone will be fully charged, and run the simulation for 1 hour.
Handlebar Encoder 1) Front handle bar able to support maximum rotation of 120 degrees in both directions. (clockwise and counter clockwise) 2) Able to accurately sense small rotations of the handlebars with +/- 5 degrees.	 1) Sensors detect accurate reading at maximum rotation angle. Verified with a protractor. 2) Digital reading from the microcontroller will be compared with physical measurements from a protractor.
Phone Sensors 1) Detect three degrees of freedom head movements. (Yaw, Pitch and Row) 2) Stay within reasonable error range after 1 hour of continues use. The error range is +/- 10 degrees with respect to default orientation.	 1) A group member will wearing the Gear VR head set and performing Yaw, Pitch and Row rotations. 2) A group member with a measuring stick attached to the helmet will start the simulation with facing forward in the simulation and physically. After extensive use of 1 hour, the member will facing forward in the simulation, and the angle of error of physical facing direction will be measured.
Wheel IR sensor 1) Detect correct IR signal pulses correctly. 2) Able to calculate correct speed for the bike +/- 2 km/h. 3) Minimum speed detection achieve 3 km/h. 4) Maximum speed detection achieve 30 km/h.	 1) Measure voltage output from the IR sensor with voltage meter. 2) The speed of the bike will be measured by bike speedometer, it will be compared with microcontroller speed output. 2) The bike will be keep at speed of 2 km/h (measured by bike speedometer), the microcontroller speed output will be read, and should be able to output current speed with +/- 2 km/h error 4) The bike will be keep at speed of 30 km/h (measured by bike speedometer), the microcontroller speed output will be read, and should be able to ouput current speed with +/- 2 km/h error

6 Tolerance Analysis

To meet reliability goals, the latency for the microcontroller system needs to be kept under reasonable limit. For any VR experience, a total system latency of $50 milliseconds$ will feel responsive, but still noticeable laggy, and 20 milliseconds or less will provide the minimum level of latency deemed acceptable. Despite the latency due to mobile processor rendering, the latency of the microcontroller signal processing needs to be limited under 50 miliseconds. The latency of the sensor signal plays an important part. Both smart phone accelerometer and handlebar encoder output are read constantly, however the rear wheel IR sensor requires at least two IR reading peaks in order to calculate the speed of the bike. The IR sensor systems need to specifically designed in order to meet this requirement. The diameter of the bike rear wheel is $0.66\,meters$ ($25''$ Bike), therefore the circumference of the wheel is $c = \pi * Diameter = \pi * 0.66\,m = 2.07\,m$. Given a minimum initial speed of $5\,km/h$, the rotational speed of the wheel is $\omega = c/v = 2.07/5000 = 0.00105\,hr/rotation = 1.49\,s/rotation$. This gives total amount of 30 reflecting positions on the wheel in order to give out IR readings every $50\,milliseconds$. Therefore, the spokes of the rear wheel will be put into use, and each spoke will be used as an IR reflecting position for the IR sensor.

Part IV

Cost Analysis

7 Cost Analysis

7.1 Labor

Labor	**Cost**
Wage Per Hour * 2.5	\$78.75
Hours Per Week (hours)	20
Number of Weeks (Weeks)	16
Number of Workers (Person)	3
Total	\$75,600.00

7.2 Parts

Component	***Cost***	***Manufacture***
Bike	\$109.97	Dynacraft
Samsung Galaxy S6	\$467.99	Samsung
IR Reflective Tap	\$28.99	3M
IR Reflective Sensor	\$9.99	Parallax
Servo (SW-0231MG)	\$36.95	Savox

Gear VR	$99.99	Samsung
Spare lumber	$30.00	N/A
Arduino Uno	$24.95	Aruduino
Bluetooth Adapter (nRF8001)	$19.95	Adafruit
Bike Stand	$44.99	FDW
Fan (4 pack)	$12.99	Coolermaster
Passive RLC Components	$5.00	N/A
Rotary Encoder (Keyes KY - 040)	$2.03	Keys
High side driver (IRS2124STRPBF)	$2.31	Infineon Technologies Americas Corp.
Voltage Regulator (Active-Semi ACT4514SH-T)	$0.72	Active-Semi
Transformer (90-T40F3)	$8.25	White Rodgers
N channel power mosfet(FQP30N06L)	$0.95	Fairchild
Total	$906.11	

7.3 Grand Total

Components	$906.11
Labor Cost	$75, 600.00
Grand Total	$76, 506.11

8 Schedule

Week	**Task**	Member Responsible
2/8/2016	Prepare project proposal for submission	Chongxin
2/15/2016	Order necessary components VR: Create base simulation program Power: Create initial power converter design	Greg Chongxin Bryant
2/22/2016	Control: Create microcontroller control flow	Greg
2/29/2016	Assemble base bike controller Power Begin breadboard assembly and testing for voltage regulator VR: Finalize Unity program	Greg Bryant Chongxin
3/7/2016	Control: Write code to read from sensors VR: Begining writing drivers for smartphone	Greg Chongxin
3/14/2016	Finalize first pcb design	Bryant
3/21/2016	Control: Microcontroller Bluetooth communication Power: Fan assembly and testing	Greg Bryant

3/28/2016	Control: Sensor communication with Smartphone Power: Testing and debugging	Greg Greg
4/4/2016	Add sensors and microcontroller to bike Control: Testing and debugging	Bryant Greg
4/11/2016	Prepare for mock demo Finalize bike controller with VR	Bryant Chongxin
4/18/2016	Optimize design and Resolve issues	Greg
4/25/2016	Prepare final paper Prepare for final presentation	Chongxin Bryant
5/2/2016	Finish final paper Final presentation Lab Checkout	Chongxin Greg Bryant