Dr. Andrew Rawicz
School of Engineering Science

Simon Fraser University
8888 University Drive
Burnaby, BC
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Re: ENSC 305/440 Functional Specification for a Virtual Reality Bicycle Trainer

Dear Dr. Rawicz:

Enclosed is a functional specification from V-Cycle describing the features of the V-cycle pro, our exciting new Virtual Reality Bicycle Trainer. We are designing a novel improvement in indoor cycling which incorporates virtual terrain feedback and allows you to use your own street bike for stationary exercise. This product is designed to be used by amateur and professional cyclists alike to improve their performance during the off-season.

Our functional specification provides details to our high level performance, and more specifically to our systems functionality. This document will be used by all members of the team in the testing stage, as well as for developing compatible subsystems that are easily integrated. This specification outlines targets for all members of the team to meet, ensuring a minimum acceptable level of performance.

The V-Cycle team consists of Dan Edmond, Mike Henrey, Lukas-Karim Merhi and Jack Qiao; students from the School of Engineering Science at SFU. If you have any questions, please contact Mike by email at mah3@sfu.ca.

Regards,

Lukas-Karim Merhi

Lukas-Karim Merhi
Chief Executive Officer
V-Cycle

Enclosure: *Functional Specification for a Virtual Reality Bicycle Trainer*

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cycle

Functional Specification

Executive summary

Indoor bicycle training is difficult to make fun and engaging, but may be the only option for the avid cyclist during the winter, or someone using cycling as a rehabilitation tool after knee injuries. Most indoor trainer do not allow the user to ride their own bike, and those that do fail to provide an experience that's engaging enough to maintain the user's interest. The *V-cycle Pro* by V-cycle will address these issues with the indoor bike trainer by allowing the user to cycle their own bicycle in one of our virtual custom terrain maps or anywhere in the world through a Google earth interface.

The device itself will fit any standard road bikes, and will use real-time elevation data to control the angle of the bike and the pedaling resistance. The proof-of-concept model will yield the following key features to make a riding experience that is as realistic as possible:

- Adaptable to standard road bikes
- Front-lifting mechanism to tilt bicycle, simulating hilly terrain
- Variable resistance mechanism for simulating the increased/decreased difficulty of riding on hilly terrain
- Passive side tilting mechanism, adding a balance component to the workout
- Dynamic turning, enabled with handlebars and side-to-side tilting
- Interactive software interface with the ability to ride anywhere in the world with Google Earth or on custom terrains

In addition to the interactive experience provided by our computer software package, users will be able to use the V-Cycle pro as a stand-alone unit with adjustments for incline and difficulty. These features will be integrated into our proof-of-concept model will an expected delivery date of April 13, 2010.

Safety is of paramount importance in all design phases of the V-Cycle Pro. The proof-of-concept model must meet the same strict safety standards outlined in this document as the production model. Our device will also adhere to ASTM, ISO, and CSA standards regarding fitness equipment and commercial appliances.

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Glossary

Standard road bike

- 610mm - 720mm radius wheel rims
- Conventional road tires with a smooth tread pattern, inflated to 80-100 PSI
- Mass of less than 15Kg [1]
- Max seat height 110 cm
- Wheelbase less than 110cm
- Quick release rear axle
- Bike is in an acceptable standard of upkeep (wheels trued, operational brakes, drive train oiled calibrated and greased, no stress fractures on frame or crankset, etc.)

Average user

- Body mass is between the 5th percentile of females and the 95th percentile of males all aged 20-39 in Canada [2]
- Height is between the 5th percentile of females and the 95th percentile of males all aged 20-39 in Canada [2]
- Familiar with simple bike repair and bike tools
- Owns their own standard road bike and performs regular basic maintenance
- Owns and fully utilizes a helmet

Un-experienced user

- Has not used the V-Cycle bike trainer for more than 10 hours

Experienced user

- Has used the V-Cycle bike trainer for at least 10 hours

Standard operating environment

- 15 – 25 degrees Celsius
- Indoors
- Stable, non-slip floor for using device

Critical error condition

- A condition where continued use of the device will result in physical harm to the user or machine

Non-critical error condition

- A condition where the device detects a configuration error or invalid information, but continued use will not cause any error conditions

All bike terminology used in this document is consistent with glossary items on Sheldon Brown's online resource at http://www.sheldonbrown.com/.

1. Introduction

The Virtual Reality Bicycle Trainer (V-Cycle Pro) is a bicycle trainer for use indoors in the off-season. Incorporating physical and visual feedback elements into the system provides the user with an exciting alternative to conventional exercise bicycles. With our device, both amateur and professional riders are able to enjoy training during the cold winter months, and obtain a realistic exercise routine while doing so. The requirements for the Bicycle Trainer are described in the following specification.

1.1. Scope

This document describes the functional requirements that must be met by functioning V-Cycle Pro units. These requirements are written to describe our proof-of-concept device, and may be adapted for a production device in the future. These requirements will be relied on during the design of the current V-Cycle Pro proof-of-concept and will also be referred to in future documentation.

1.2. Intended Audience

Our functional specification will be fully employed by all members of the V-Cycle team. Each member shall use the document as a basis when researching and implementing the subsystems they are responsible for. The project manager will use the specification to gage progress and whether integration is occurring properly. During testing and integration, this document will be applied to resolve design conflicts or performance related issues.

1.3. Classification

The following convention has been established for classifying the functional requirements and is applied throughout the document:

[S#-p]

Where # is the specification number
Where p is the priority of the specification and can have one of the following values:
A: Particular features required for safe operation
B: Denoted requirement for proof of concept model
C: Production only

2. System Requirements

The general requirements of V-Cycle Pro proof-of-concept model are presented below. Specific subsystem requirements can be found in the following sections.

2.1. System Overview

The V-Cycle Pro at its highest level can be seen outlined in Figure 1.

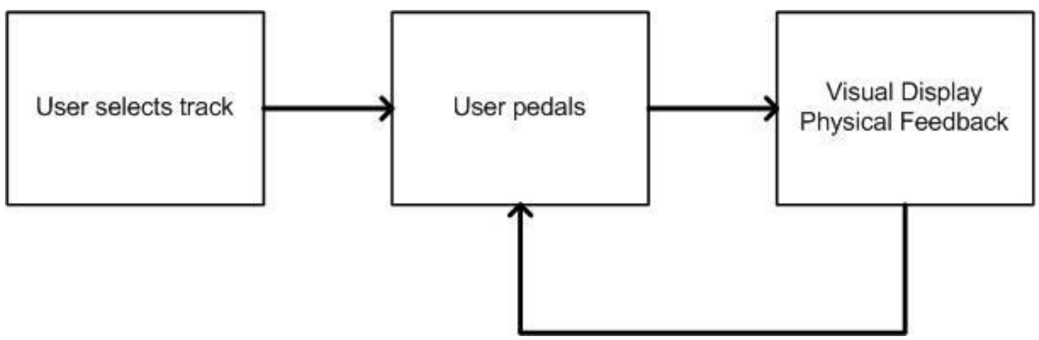

Figure 1: System Overview

For our proof-of-concept model, our system will be an integrated and operational product. The user will be able to place their own bike in our trainer, and perform indoor exercise while being stimulated by visual and physical feedback. The user interface will allow the user to select between Google StreetView locations, or one of our own custom "demo tracks." As they traverse the track, steering much in the way you would in a regular bicycle, the visual display will update based on the direction and velocity of the pedaling. In addition, the terrain presented will be reflected by the bike's longitudinal orientation; it shall tilt to reflect uphill and downhill pedaling. Finally the system shall incorporate a physics model that reflects realistic pedaling resistance for hills, and responds passively when the user leans to each side. A conceptual diagram of the device and its subsystems is shown in
Figure 2.

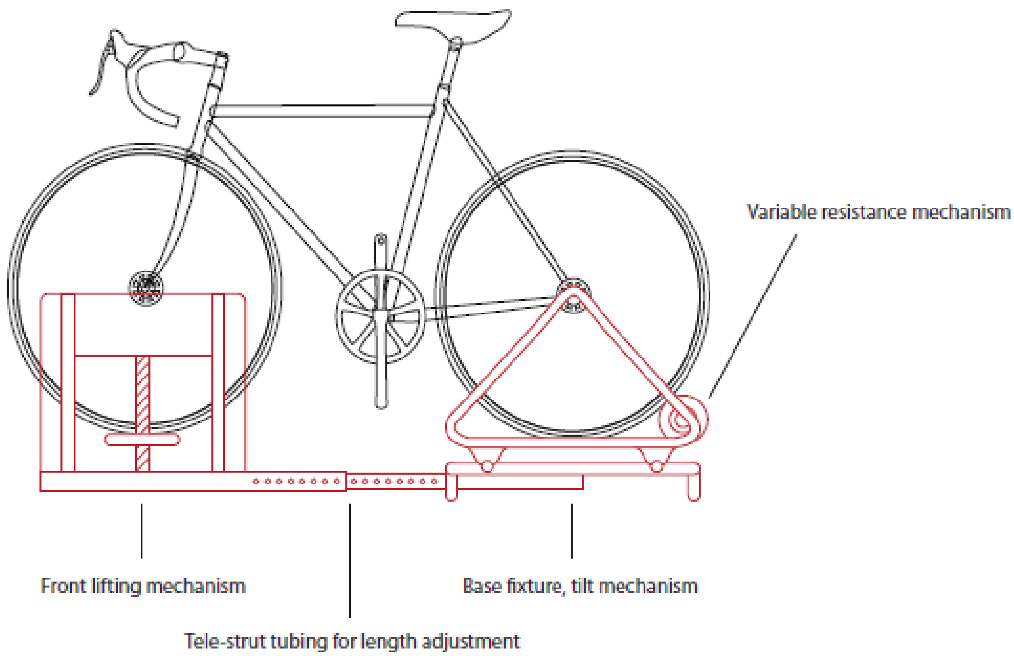

Figure 2: Conceptual drawing of the V-Cycle Pro

Because of the importance of the system requirements, we opted to perform a Quality Function Deployment (QFD) analysis on our system. The output of this analysis is the following House of Quality (HOQ). This HOQ has been of significant use for us as it provides a quantitative and qualitative measure of where our strengths and weaknesses lie, and what features our product has that differentiate it from the competition. Many of our system requirements are derived directly from the HOQ [3].

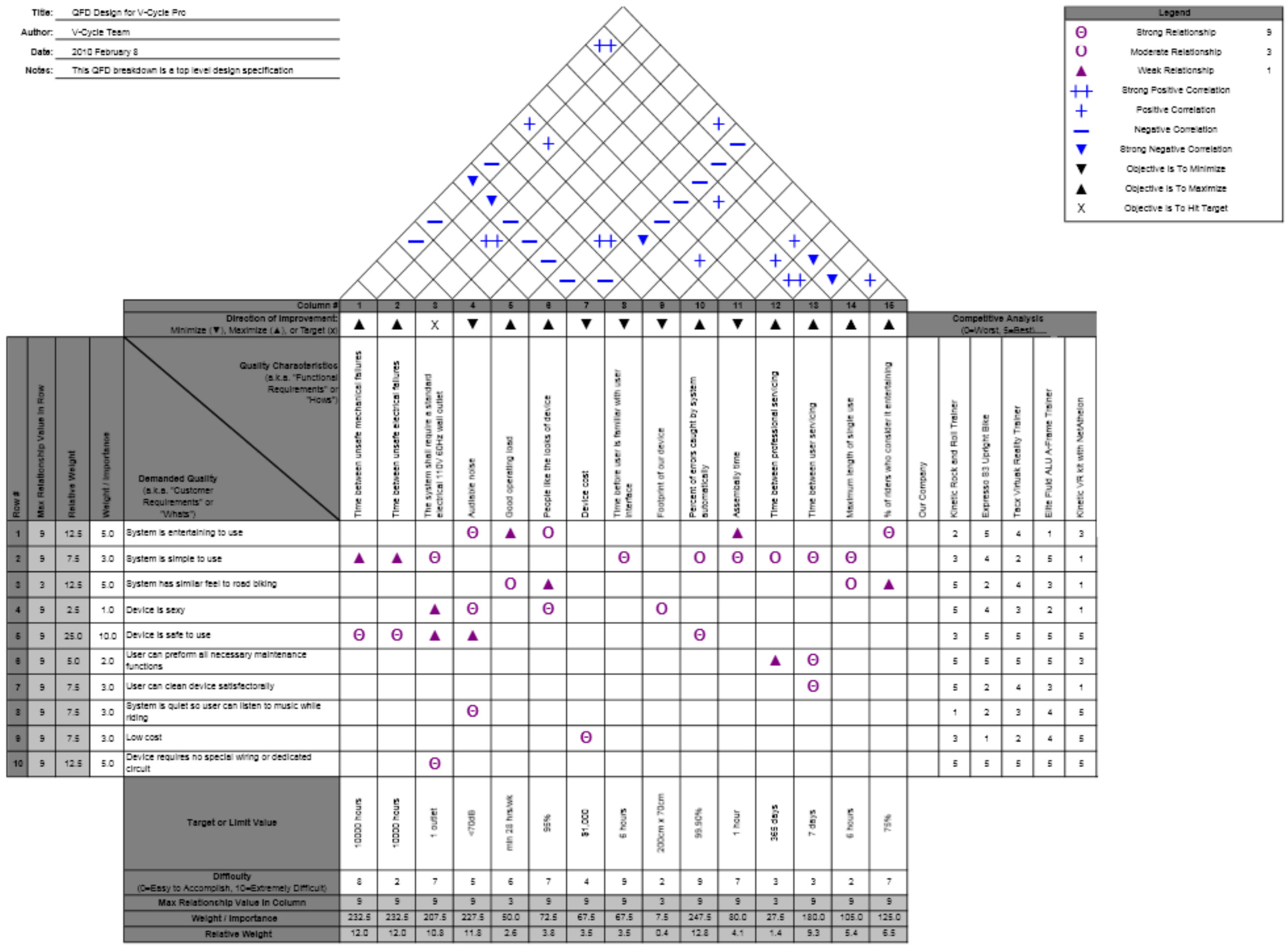

Figure 3: System Requirements House of Quality

The HOQ can be interpreted as follows. The customer's requirements are listed down the left side and on the right side they are compared with our competitor's offerings. Along the top, our product's general specifications are listed, and cross-referenced with the customer's requirements in the center according to the symbols in the legend. This allows us to see which of our functions will affect which consumer demands. Finally the inter-relations between our functions are shown in the triangular shaped region, so we can clearly see compromises and inter-dependencies during design.

2.2. General requirements

[S1-A] The system shall have an off state at which all components are inactive and power is off

[S2-A] The system shall have an idle state at which all components are inactive but power is on. The idle state will be at a position which allows the user to mount or dismount our device easily

[S3-A] The user shall be aware at all times when our system is moving or ready to move through the use of displays and LEDs indicating the system's status

[S4-B] The retail price of our system will be less than CDN$1000

[S5-B] The user will be able to use any standard street bike in our device

[S6-C] One user will be able to setup and adjust our system without additional help

[S7-C] After using our device, the user shall be able to ride their bike on the street without modifications to their bike

2.3. Physical Requirements

[S8-B] The length of our device shall not exceed 200cm

[S9-B] The height of our device (without bike) shall not exceed 80cm

[S10-B] The width of our device shall not exceed 70cm

[S11-B] Each part of our device will be movable by an average person

2.4. Electrical Requirements

[S12-B] The power supply will be sufficient to power all devices simultaneously

[S13-B] The power cord will have a length of at least 2m

[S14-B] Key test points shall be made available for testing and debugging purposes

[S15-C] The power supply will be useable with a wall supply of 110V, 60Hz AC. Using a second wall outlet for the microcontroller board is acceptable in the proof-of-concept model but not in the production model

2.5. Mechanical Requirements

[S16-A] The device shall be stable when used by the average user.

2.6. Environmental Requirements

[S17-A] The system shall operate normally within the standard operating environment
[S18-C] The system will be silent when off or idle
[S19-C] The noise of our device shall not exceed 80dB during operation

2.7. Standards

[S20-A] The system shall comply with standard ASTM F2276-09 regarding the design and manufacturing of fitness equipment.
[S21-A] The system shall comply with standard ISO 20957-1 and complementary standard ISO 20957-10 regarding general safety requirements and test methods for stationary training equipment.
[S22-A] The system shall comply with standard CSA C22.2 NO 68 regarding motor operated appliances, including exercise equipment, intended for use with nominal supply voltages of 600 V and less.

2.8. Reliability and Durability

[S23-B] The system shall perform under a normal load of at least 28 hours/week
[S24-C] The system shall be serviceable by trained technicians
[S25-C] The system shall be resistant to liquid spills (including sweat) and easily cleanable
[S26-C] The system shall be inspected daily by the user before use for wear
[S27-C] Simple maintenance shall be done weekly by the user

2.9. Safety Requirements

[S28-A] There will be no uncovered pinch points in our device
[S29-A] Limit switches will prevent any dangerous movements
[S30-A] Dangerous sections of the power system and electronics will be enclosed in a metal box and proper warnings posted
[S31-A] The device shall not overheat or catch fire
[S32-A] The device shall be able to detect critical conditions and shut off

[S33-A] The electronic components shall not cause any interference with other devices
[S34-A] The device shall be able to detect non-critical error conditions and respond appropriately

2.10. Performance Requirements

[S35-C] The device shall take no longer than 30 seconds to be in an operable state after powering on
[S36-C] The total time for any automatic mechanical movement shall take less than 4 seconds

2.11. Usability Requirements

[S37-B] The user shall be familiar with the computer interface within 6 hours of use
[S38-B] User movable parts shall be clearly identifiable with the use of labels or affordances
[S39-B] The user shall be able to remember their favorite settings and configurations
[S40-C] One user shall assemble the system in under an hour
[S41-C] The un-experienced user shall be able to configure their ride path and be ready to exercise in under 5 minutes
[S42-C] The experienced user shall be able to configure their ride path and be ready to exercise in under one minute
[S43-C] 80% of users shall find the user interface satisfying
[S44-C] System errors shall be clearly understood by the average user in 80% of cases
[S45-C] Configuration mistakes shall be clearly understood by the average user in 80% of cases

3. Front Lifting Mechanism

The front lifting mechanism will give the user a more realistic feeling of cycling on hills by raising/lowering the front tire. A concept drawing of this subsystem in action is shown in Figure 4.

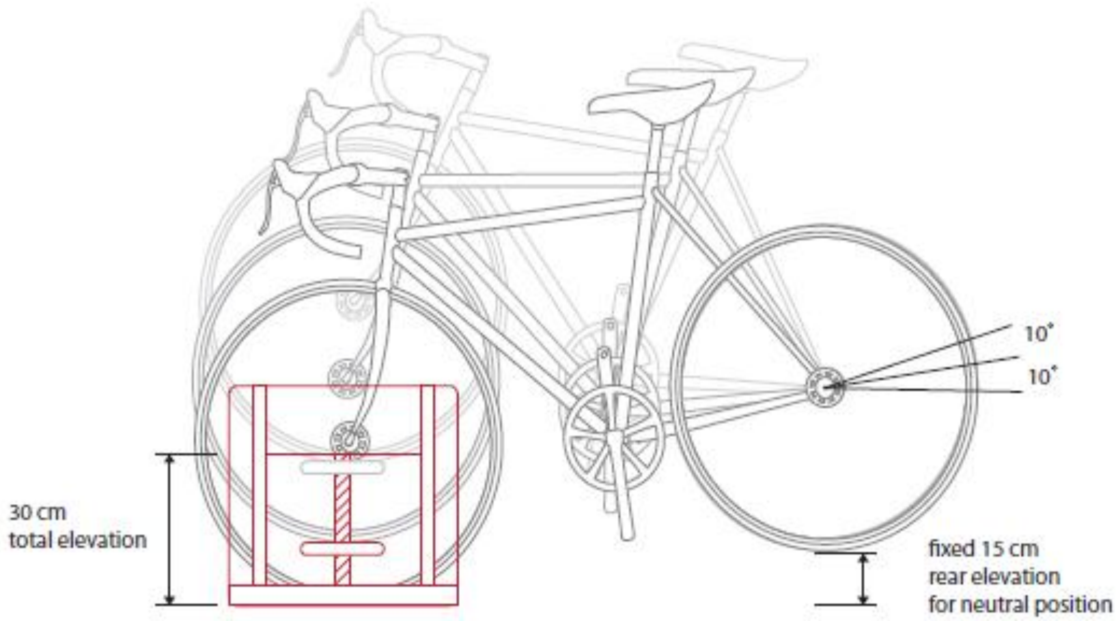

Figure 4: Concept Drawing of Front Lifting Mechanism

3.1. General requirements

[S46-B] The device will simulate high-frequency road texture (gravel, asphalt, mud, etc) by rapidly accelerating the front of the bike

[S47-B] The device will simulate low-frequency road texture (hills, valleys) by positioning the linear guide at appropriate positions

[S48-C] It will be easy for the user to attach and detach the bike from the lifting mechanism without assistance

3.2. Physical Requirements

[S49-C] The structure of the mechanism will be portable, and will in the trunk of a normal sedan

[S50-C] The device will be monolithic, with no separate parts required for operation

Mechanical Requirements

[S51-A] The structure of the device must maintain stability regardless of the bike's tilt and handle rotation
[S52-A] The device must be capable of supporting 130kg (user + bike), indefinitely at any elevation
[S53-B] The linear drive system shall be able to accelerate 130kg (user + bike), at 1G up to a speed of 10cm/s
[S54-C] The device will automatically adjust speed and acceleration to the person's weight, so as to maximize simulation performance

4. Side Tilting Linkage

The side tilting linkage is a passive linkage that enables the user to further engage the core muscles while riding. On a normal stationary bike, the rider has no side-to-side freedom, however as we are intending to replicate the knife-edge model of a road bike we are providing an extra degree of rotation for the user. A concept drawing of the side tilting linkage is shown in Figure 5.

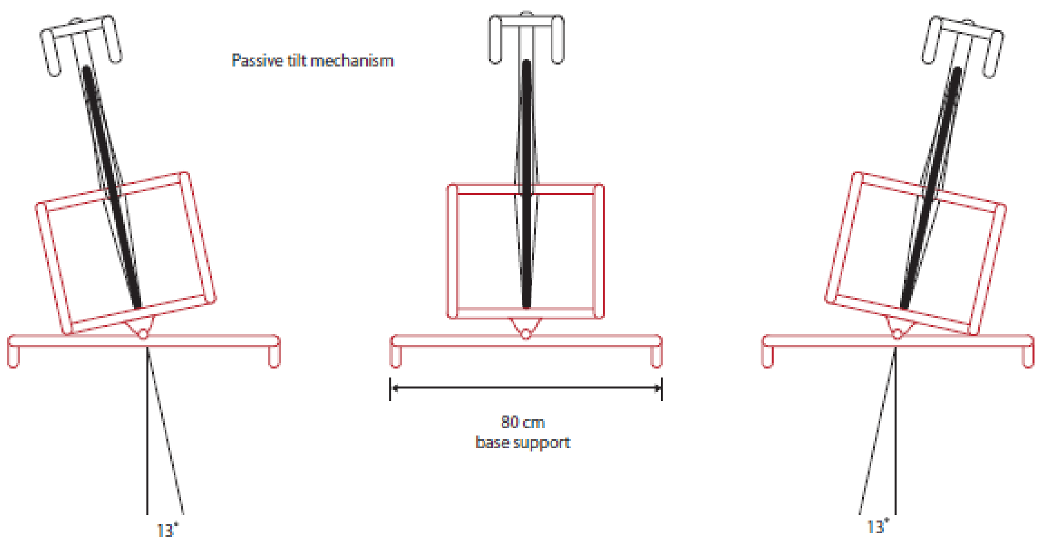

Figure 5: Concept Drawing of Side Tilting Linkage

4.1. General Requirements

[S55-A] The bike must not tip over as a result of the side tilting linkage
[S56-B] The linkage should provide the user with a means of engaging the core stabilizing muscles

[S57-C] The linkage should provide a resistance profile similar to what a user would feel while riding on the road

4.2. *Mechanical Requirements*

[S58-B] The linkage must be passive
[S59-B] The linkage should return to a natural position when no external forces are applied
[S60-B] The linkage should contain a damping and spring effect

4.3. *Physical Requirements*

[S61-C] The linkage should not weigh more than 5kg
[S62-C] The linkage shall be well integrated into the frame of the trainer and not look obtrusive

5. Variable Resistance Device

The variable resistance subsystem of the V-Cycle will give the user a realistic feeling of the terrain they're riding on by simulating the effect of grade on the difficulty of cycling. Ideally, it will also simulate a realistic velocity/wind resistance profile, a major shortcoming of passive magnetic flywheel bike trainers.

5.1. *General Requirements*

[S63-B] The variable resistance system will simulate the increased difficulty of cycling uphill
[S64-C] The variable resistance system will spin the rear wheel at the required speed when cycling downhill to simulate the decreased difficulty of cycling downhill
[S65-C] The variable resistance system will increase the difficult of cycling with increased velocity to simulate the effect of wind resistance
[S66-B] The power requirements of the variable resistance system will not necessitate the use of a dedicated power supply
[S67-B] Heat dissipation requirements of the variable resistance system will be carefully considered for safety and proper function of electrical components in the system

5.2. *Usability Requirements*

[S68-A] All moving components of the variable resistance system will be enclosed and out of reach of the user

[S69-A] All components of the variable resistance system that dissipate heat will be enclosed

6. Electronic Hardware

The function of the electronic hardware, precisely the microcontroller is to continuously monitor wheel speed and tilting coordinates, process that information, and actuate the motor for the elevation mechanism and variable resistance unit. Additionally, the microcontroller shall communicate serially with the computer software, and be able to run without computer input in standalone mode.

6.1. Electrical Requirements

[S70-A] All the electronics on the back platform and front platform must be able to tolerate vibrations under normal use

[S71-A] The microcontroller requires a DC power supply of 9V and 650 mA

[S72-A] The Motor requires a power supply of DC 80V and 5 A

[S73-A] All power supplies will be CSA approved and not exceed 1500 watts

[S74-A] All electrical components will comply with Institute of Electrical and Electronics Engineers (IEEE) standard

[S75-A] All electronic hardware will be enclosed to assure user safety

[S76-A] Heat produced by high current pass in the system will be dissipated safely

[S77-A] All electrical wiring will be insulated

7. User Interface and Visual Display

7.1. General Requirements

[S78-A] Display warnings when a mechanical failure condition occurs

[S79-B] Will display 3d terrain as well as Google street-view imagery for visual feedback

[S80-B] The visual display will match the tilt, turning angle, and elevation of the physical bike

[S81-B] Information on current speed, travel distance, and elevation profile will be displayed on-screen

7.2. *Usability Requirements*

[S82-B] The visual interface should be easily learn-able and usable without necessary prior-knowledge or training.

[S83-C] The visual display will be projected in stereoscopic 3d for full-immersion virtual reality simulation

7.3. *Software Requirements*

[S84-A] The software will never produce erroneous outputs to the hardware systems, even running on a slow computer with multiple applications running

[S85-B] The visual display software will run well on any modern PC with a video card, running windows XP, Vista, or windows 7. Minimum computer hardware requirements: 512 MB ram, 1 GHz processor, 10MB Hard disk space

[S86-C] The visual display software will run at a low resolution mode on less capable computers such as laptops

8. User Documentation

[S87-B] User documentation such as technical support, user manual, detailed installation guides will be available online on the V-Cycle website www.vcycle.ca in English

[S88-C] A video on the website will demonstrate how to install the apparatus step by step

[S89-C] The online documents will be written for the average user

[S90-C] All types of user documentations will be translated into different languages to satisfy product language requirements in international markets

9. System Test Plan

The system test plan can be generalized into 3 main steps: first testing the individual's modules, then testing combined modules and finally testing the whole unit together.

Detailed testing procedures for individual modules to be followed throughout implementation and design periods are as follows:

- The reed switch tachometer: This sensor will be tested to see that it accurately records revolutions per minutes/seconds, and that it properly calls an interrupt service routine (ISR) on the microcontroller with minor interrupt to the software.
- Serial communication interface: A test program will be written to verify hand-shaking communications between the computer program and the Arduino microcontroller
- 2D accelerometer: This sensor will be tested to see that it accurately tracks 2D position for measuring the bicycle tilt
- Elevation mechanism: The motor driver and stepper motor will undergo multiple tests with different loads exertion such as weight of biker and bicycle and steep terrain fluctuations
- 3D terrain and visual simulation: The program responsible to simulating 3D terrain will be run in multitasking operating system environments to confirm robustness of software
- Bike trainer platform stability and tilting mechanisms: The back wheel platform will be tested by using people of different weights to verify the strength of the plywood and durability of the skateboard tracks for the tilting mechanism.

Test plan for integrated modules is as follows:

- Microcontroller interface with sensors and computer program: A test program will be written to verify that the microcontroller is handling multiple ISRs and serial communication, and system control simultaneously
- Microcontroller interface with elevation platform and variable resistance: Verify that mechanical platform and variable resistance unit is adjusting to elevation data according to the 3D terrain delivered by the computer program, and that system response time is adequate.
- Verify that power supply sufficiently power multiple modules: A test bench program will be written to exert the greatest load on all the functional and adjustable parts simultaneously. Throughout the duration of this test, visual inspection of operation and temperature of components will be recorded to confirm the reliability and safety of the product. The current will be monitored throughout the test at key high current passes in the system. Power supply failures will also be tested.
- Safety and error handling testing will be of paramount importance for our device. Upon the first integration of the system, static loads will be used to determine safe operation

of the device under load. Stress tests will include testing the linear drive system for our front wheel with the fastest theoretical elevation changes, as well as proper operation of the safety limit switches.

Once the working proof-of-concept has been determined to be safe, the project manager Dan Edmond - a professional cyclist, will conduct detailed trials on the virtual reality bicycle trainer to optimize system parameters for the most realistic ride possible. Ease of set-up and usability of the software graphical user interface will also come into focus.

The typical usage scenario for the V-cycle is as follows:

- User locks bike into the bike trainer and places front wheel into the turntable riser ring
- User starts program to run simulation terrain on computer or chooses stand alone mode
- User decides to exercise as long as they feel fit to
- User terminates exercise and multiple exercise data will be stored for the next time they exercise

We will conduct trials of this typical scenario with other avid road cyclists to receive feedback on comfort, usability, and overall satisfaction.

10. Conclusion

The functional specification detailed in this document defines the operational and safety requirements of the V-Cycle. A working model meeting functional specifications with priorities A and B is currently undergoing the process of design, implementation, and testing with an expected delivery date of April 13, 2010.

11. References

[1] D. G. Wilson, *Bicycling science.* Cambridge, Mass: MIT Press, 2004.

[2] Statistics Canada: Canadian Health Measures Survey 2007-2009. [Online]. Available: http://www.statcan.gc.ca/pub/82-623-x/82-623-x2009001-eng.pdf [accessed Feb 8, 2010]

[3] D. G. Ullman, *The mechanical design process.* Boston, Dubuque, IA: McGraw-Hill, 2003.