DESIGN OUTLAWS

January 10, 2002

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: Process Report for the *Ranger* Electric Bicycle

Dear Dr. Rawicz:

The attached document, *Process Report for the Ranger Electric Bicycle*, describes the development of the Ranger from concept to completion, including sections detailing design justifications, problems encountered, and experience gained.

Our resulting proof-of-concept device incorporates an electrically powered motor, LCD and push button user interface, full speed control, and a variety of safety features. We have succeeded in making the *Ranger* a viable alternative to conventional electric bicycles, while adding minimal extra cost. This report discusses the final operation and design of our product, the true development costs versus projected costs, the resulting project timeline, and the future of the *Ranger*.

Our primary goal was to create a prototype for demonstration, in order to create public awareness of emerging electric vehicle options and to publicize the field of engineering along with the work that is being accomplished at SFU. We have accomplished the engineering work and have made plans to demonstrate at high schools and in competitions this Spring, in keeping with our primary objective. Our secondary fiscal goal was to develop new electric vehicle technology that may be incorporated into established commercial vehicle designs. We have proved our concept, and are now at liberty to take the project to the next step.

If you would like to contact us following our arranged demo, please do not hesitate to email outlaws-ensc@sfu.ca or contact me directly at (604) 320-0701.

Sincerely,

Eric Hennessey
Technical Lead and Marketing Manager
Design Outlaws

Enclosure: Process Report for the *Ranger* Electric Bicycle

PROCESS REPORT FOR THE *RANGER* ELECTRIC BICYCLE

Project Team	***Design Outlaws*** Rhiannon Coppin Eric Hennessey Samuel Hu Eric Keung
Contact Personnel	Rhiannon Coppin acoppin@sfu.ca
Submitted to	Dr. Andrew Rawicz Steve Whitmore *School of Engineering Science* *Simon Fraser University*

Date Issued	January 10, 2001
Revision	2.0

Table of Contents

1 EXECUTIVE SUMMARY....1

2 CURRENT PROJECT STATUS....1

2.1 WORKING FEATURES....1
2.1.1 Primary Features....2
2.1.2 "Bells and Whistles"....2
2.2 INPUT AND OUTPUT SUMMARY....2
2.2.1 Input....2
2.2.2 Output....2
2.3 USER SCENARIO....3

3 DEVIATION FROM FUNCTIONAL SPECIFICATIONS....3

4 DEVIATION FROM DESIGN SPECIFICATIONS....4

4.1 SYSTEM OVERVIEW....4
4.2 POWER....5
4.3 SPEED SENSOR....5
4.4 BRAKE SENSOR AND LIGHT....6
4.5 TILT SENSOR....7
4.6 USER INTERFACE....8
4.7 MICROCONTROLLER....9
4.8 MOTOR CONTROLLER....10
4.8.1 Design....10
4.8.2 Testing Our Design....11
4.8.3 PWM Design....11
4.9 BATTERY CHARGE MONITOR....13
4.10 SAFETY....13

5 FIRMWARE....14

6 IMPROVEMENT STRATEGY....14

6.1 MOTOR AND BATTERY....14
6.2 BATTERY REGENERATION....14

7 BUDGETARY AND TIME ISSUES....15

7.1 TIME FRAME....15
7.2 BUDGETING....17
7.3 SOURCES OF FUNDING....19
7.4 TEAM DYNAMICS....19

8 MEMBER EXPERIENCES....20

8.1 RHIANNON COPPIN – PROJECT MANAGER....20
8.2 ERIC HENNESSEY – TECHNICAL LEAD AND MARKETING MANAGER....21
8.3 ERIC KEUNG – HEAD OF R&D....22
8.4 SAM HU – LEAD SOFTWARE ENGINEER....23

9 FUTURE PROSPECTS OF THE RANGER....24

10 ACKNOWLEDGEMENTS....24

11 APPENDIX....25

List of Figures

Figure 1: The *Ranger* Electric Bicycle 1
Figure 2: Original System Design........ 4
Figure 3: Revised 24V to 5V Power Converter Circuit........ 5
Figure 4: Speed Sensor Mounted on the *Ranger* 6
Figure 5: Mounted Brake Sensor (at handlebar brake lever)........ 6
Figure 6: User Interface 8
Figure 7: System ProtoBoard (not Mounted)........ 9
Figure 8: PWM Circuit Diagram 12
Figure 9: Added OK Flag Path 13

1 Executive Summary

Design Outlaws have toiled unremittingly to produce the next phase of electric bicycle technology: electric bicycle cruise control. We have dubbed our working prototype “the *Ranger*” in esteem of it as a viable commuting alternative. We have implemented several features we deem necessary for user satisfaction and user safety, within budget and only slightly over the desired project timeline. This report details the features we implemented and those we decided to leave to future product releases, and investigates issues and impediments that delayed completion of the project.

2 Current Project Status

2.1 Working Features

The completed *Ranger* is represented in Figure 1.

Figure 1: The *Ranger* Electric Bicycle

From the figure, you should be able to pick out the pertinent features of our system. The “brains” of our system is the 5V logic board, interfaced with both analog and digital I/O. The board is normally mounted inside the black plastic housing (though shown resting on the back of the bicycle), which also holds the two 12V/5Ah batteries and the motor, at the back of the vehicle. Two sets of wires emerge to interface with both the speed encoder and the brake light, which are located also at the back of the vehicle. A 25-conductor parallel printer cable emerges, and leads to the user interface, which is mounted between the handlebars. The user interface is an LCD panel, buttons, LCD ON switch, motor ON switch, and brake sensors (which are not visible in this photo).

This working prototype implements the following features:

2.1.1 Primary Features

- Cruise control – The motor kicks in under 'safe' conditions (see *Safety* section) to bring the user to their digitally-set desired speed, within +/- 2km/hr.
- Top speed (motor only) of 22 km/hr on flat terrain, and capability to propel (motor only) bike and 65kg passenger up a 4% grade.
- Compliance with Canadian Electric Bicycle Legislation (refer to Appendix A)
- Motor On/Off switch
- Control Circuit On/Off switch
- LCD display with MODE, UP, and DOWN buttons
- User pre-settable speed (in increments of 5km/hr)
- Current speed display (to +/- 1km/hr)
- A series of safety checks (detailed in *Safety* section) to prevent unsafe or unwanted operation of the motor.
- Novel brake sensors, placed for safety at the user interface to the braking system

2.1.2 "Bells and Whistles"

- Battery charge display (in 8% blocks between 21.5 and 24V)
- Total trip distance display, accurate to +/- 1km/hr.
- Integration of brake sensors with 'brake light'

2.2 Input and Output Summary

The *Ranger* employs the following input (sensor) and output (actuator) devices:

2.2.1 Input

1) Speed encoder (digitally interfaced)
2) Brake sensor (mechanical spring contact – microswitch)
3) Tilt sensor (mercury tilt sensor, digitally interfaced)
4) Kill switch (mechanical contact)
5) Interface On/Off switch (mechanical contact)
6) MODE, UP, DOWN buttons (mechanical contact)

2.2.2 Output

1) Motor output (mechanical torque on bicycle wheel)
2) LCD interface
3) Brake light (mounted at back of bike)

2.3 User Scenario

In order to engage the motor, a number of parameters must be satisfied. A user must flip the motor ('kill') switch to the on position. They must also turn on the LCD display with its 'ON' switch, get into the 'SPEED' mode, and set a Target Speed above 0 km/hr. The battery must also be in working order (i.e. charged enough), which the user can check in the 'BATTERY' mode on the LCD display. (Modes are toggled with the "MODE" button). The brakes must not be engaged. The user must start pedaling, and achieve a speed above 3km/hr before the motor will kick in to bring them to the set 'Target' speed, as specified by Canadian law.

If the bike tips over, the tilt sensor disables the motor. If the user engages the brakes, the motor is disabled and the brake light turns on. Once stopped, the user must begin to pedal and achieve a speed above 3km/hr to engage the motor again. By setting the desired speed to 0 km/hr, the motor will not be engaged.

If the user interface is turned off, or if the motor switch is switched to 'OFF', then the motor is again not engaged.

3 Deviation from Functional Specifications

Several quantitative design parameters do not match our specifications. These are summarized in Table 2.

Table 1: Functional Deviations

Parameter Functional Specification	Parameter in Real System
"*Top speed of 30 km/hr on flat terrain or 15 km/hr up a 7% grade*"	Top speed of 20km/hr on flat terrain or 1km/hr up a 4% grade. This parameter was defined by the motor output, and our system works for this motor, though it was designed for the ideal legal motor (500W).
"*Display will be mounted such that it is viewable under various lighting conditions and from different viewing angles*"	The display is mounted in a black plastic casing, and is water-resistant. The LCD as it is would be difficult to view in direct sunlight, but as a proof-of-concept device, we felt it sufficient to mount it attractively within our means and budget.
"*Electrical wiring compliant with appropriate Canadian and US standards*"	We could not locate appropriate standards. The maximum power we use is 24V/15A

	from two lead acid-gel batteries. The power leads between the batteries and the wall charging circuit were part of the kit we acquired, and therefore we assume that the wiring is legal. Our add-ons use 5V below 0.6A.
"Battery charge indicator will be valid to ±5 %"	Battery charge indicator is valid to ±8 %
"The device will comply with CSA regulations."	We could not locate the appropriate CSA regulations, but we have ensured we meet the Transport Canada electric vehicle requirements. This is a required step in bringing our project to a manufacturable state.

4 Deviation from Design Specifications

4.1 System Overview

Our deliverables closely match our original design. Figure 2 is the original design system diagram at the highest level. The remainder of this section deals with the individual system components.

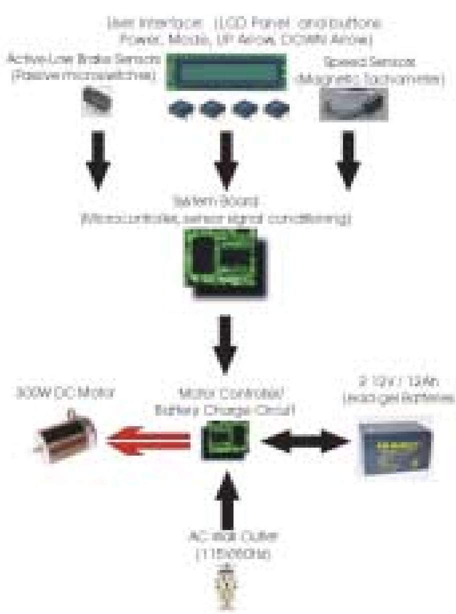


Figure 2: Original System Design

DESIGN OUTLAWS

4.2 Power

The power from the motor is provided by two 12V/5Ah lead-gel acid batteries, which are rechargeable through a North American wall outlet. The charging circuitry and batteries are part of the motor kit we acquired.

Our additional circuitry, which is an analog/digital mix, is powered by a +5V source, which is stepped-down from our 24V battery. Suspicious that the 5V supply circuit we originally built (using the LT1173 as specified in our Design Specification) was not supplying enough current, we switched to using a Maxim™ technology-based Voltage Regulator, as another group (Eric Haberger's) was using it and had found no problems in running their 5V logic from this source. The circuit diagram, including part names and numbers is shown in Figure 3. The inductor is a Delevan™ ferrite core.

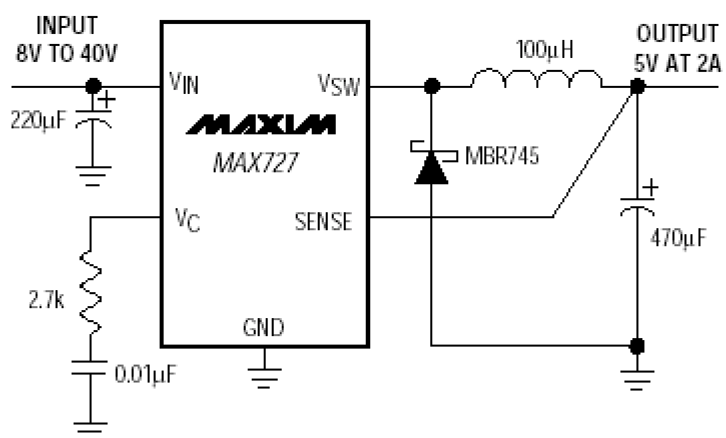


Figure 3: Revised 24V to 5V Power Converter Circuit

Re-wiring this circuit as the power supply (limited internally by the MAX727 package to 2.6A) was simple and quickly completed, thanks to Eric Haberger for temporarily donating the parts.

4.3 Speed Sensor

The mounted speed sensor is shown in Figure 4.

DESIGN OUTLAWS

Figure 4: Speed Sensor Mounted on the *Ranger*

This is a magnetic induction speed sensor, which induces 'electrical' contact when the terminals are in close proximity. To digitally interface this signal with the PIC microcontroller, we needed to create an active-low signal. The design and implementation of the speed encoder was simple and quickly completed.

4.4 Brake Sensor and Light

The brake sensor mounted nicely on the large hard-plastic mountain-bike style brakes, using cyanoacrylate to adhere a plastic extension to the movable portion of the hand-brake, and to adhere the body of the microswitch to the immobile portion of the brake. This sensor hid inconspicuously, and has a sizable room for error in its mounting. The brake sensor mounted on the left handlebar is shown in Figure 5.

Figure 5: Mounted Brake Sensor (at handlebar brake lever)

The microswitches are wrapped in shrink tubing, and are wired using the “common terminal” and the “Normally Closed” (NC) terminal. Two leads were thus taken from each switch, and one lead from each were soldered together within the user interface plastic casing (see section 4.6). This created a single continuous path that is conductive until the user presses the brake handle.

The brakes were mounted at the handlebars rather than at the wheel to ensure that a misalignment of the caliper would not interfere with this legal safety requirement. Also, if the brake line is cut or becomes loose, the brake sensor still functions at the handlebars, whereas it would not if it were mounted at the wheel. By wiring the brake sensors as a short, any accidental cut in the line results in a ‘false positive’ rather than a system failure.

The brake light is a donated bicycle LED setup. We removed the battery and the switching mechanisms (in order to use just the LEDs and the case), and soldered a 500Ω resistor to one of the leads to limit the current. We use one line from the brake sensor (which is wired on the other line to 24V) to trigger an inverter. Thus, a high (24V) condition does not trigger the brake light, while a low condition does.

This feature was simple to implement, though there was a complication. The brake switches are also wired in the ‘safety’ circuit interfaced to the original motor board. The situation may arise where one line from the brake switches is floating (due to the nature of the connections, see the ‘Safety’ section). Using a comparator to compare the lines, one of which is always at +24V, provided the quick and simple solution.

4.5 Tilt Sensor

We only decided to incorporate a tilt sensor into our electric bicycle design after issuing our design specification. Thus, our functional specification did not make a tilt sensor a requirement, nor stipulate the rules of its operation, and the design of the tilt sensor was not outlined in our design specification. Though not an absolutely necessary safety feature, given the small amount of additional work required to implement this system input coupled with the possibility of a collision before the user has a chance to apply the brakes or switch the motor off, we decided to implement this additional safety precaution.

As our electric bicycle design does not require a consistent user input for the motor to operate we thought it wise to incorporate a tilt sensor that automatically shuts the motor off if the user is dislodged from the bicycle or becomes severely unbalanced, which would be characterized by the bicycle tipping. We decided a mercury tilt switch was the best product for our needs. It is a simple on-off device, where a ball of mercury in a vacuum enclosed by glass establishes an electrical contact between the two leads of the device when the device is tilted approximately 90 degrees from vertical in any direction.

As discussed in the Safety Section (4.10), any break in a particular electrical path results

DESIGN OUTLAWS

in the immediate lowering of the OK flag, which signals the microcontroller to stop powering the motor. Thus if the bike happens to tip over, the ball of mercury will be displaced, breaking the electrical contact of its leads and stopping the motor operation.

4.6 User Interface

Figure 6 shows the current user interface mounted between the handlebars on the presentation bicycle. The three red buttons on the large black case are UP, MODE, DOWN, as marked with text and arrows, and the small white switch is the ON/OFF control for the logic board and the LCD. The silver switch is an additional cut to motor operation, but allows the LCD to continue providing the user with feedback.

Figure 6: User Interface

The plastic casing takes in wires from the brake sensors and the motor ON/OFF switch (the “kill” switch), and packages these with the user interface wires into a 25-conductor parallel printer cable, which connects to a short ribbon cable that is interfaced to the system board.

Included in the interface region is a label, in both French and English, affixed to warn the user that this is a motorized vehicle, in accordance with Canadian legislation. This label is not shown in the photo, as it is mounted on a section of the lower bicycle frame.

We felt it necessary to provide the user with several ‘outs’ during operation of our vehicle, and wanted these options to be easily accessible to either right- or left-handed people. For this reason we raised the "Kill switch" and made it relatively large so that a hand sweep could turn flip it down. The "OFF" position for both switches in vertically lower than the "ON" position, and all buttons are located in the central area between handlebars, at an angle viewable by most users. The labels and LCD output should be visible to a user of average vision, and the pushbuttons are large enough to be accessible to most users.

As a prototype, the user interface must be friendly and easy to interpret. We feel that we fulfilled the objectives we set out for the user interface, and propose that improvements could be made in consultation with a user interface expert, and a larger budget.

4.7 Microcontroller

We are using the PIC16F870-I/SP to implement our speed decoding, LCD output, input (button) handling, and motor control output (speed adjustment) as part of our feedback control system. We felt this part was large enough to handle our memory and processing needs, with an appropriate number of I/O, which is split into three 8-bit PORTS. This part has Pulse-Width Modulation (PWM) output capability, but unfortunately the PORT that contains this pin was required to implement other I/O, whose timing requirements prevent the use of this feature. Some improvisations were needed for the PWM motor control, which are detailed in section 4.8. Figure 7 is a snapshot of the finished proto-board, which mounts inside the battery and motor housing.

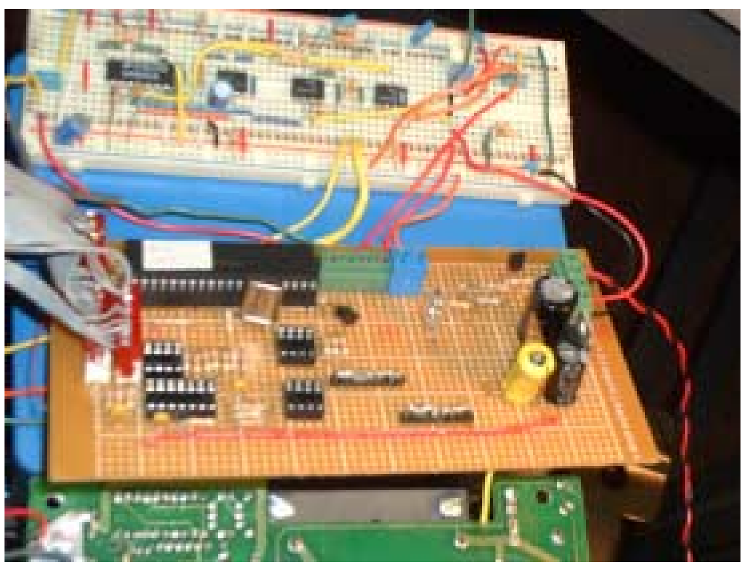


Figure 7: System ProtoBoard (not Mounted)

We ordered 3 of these parts at the outset, and managed to kill 2 of them within 2 days, approximately 3 days before our proposed demo date. To make matters worse, no local supplier had these chips, and Digikey, whom we bought them from before, was out of stock. To prevent re-coding our program for a different chip, we needed to get more of this part to continue development with backup chips, and we were forced to order 15 chips from Future-Electronics, a wholesale outlet. In the future, we would start development with microcontrollers that are locally available (Active carried a similar part that would require slightly altered code), or buy even more than we thought necessary at the outset. The best solution is to find a part that is available locally, or check how many each of its distributors have in stock. A very frustrating part of this course is realizing that everything has to be ordered from the States, or from back East – very little is available at our retail outlets, which are limited to Active, RP, and Lee's.

For future implementations of this course, a useful tutorial would be to list and explain the various sources for parts. The students should understand what type of parts the school carries (via Fred), what type of parts are available at the local Retail outlets (and give a list of phone numbers, addresses, website), and which companies are available for orders, and which are available to give useful samples. In industry, a student would be dealing with an established set of distributors and vendors that have relations with the student's company. ENSC340 students should not suffer, as we did, for lack of experience in parts sourcing.

4.8 Motor Controller

4.8.1 Design

The first step in designing the motor controller was to verify the operation of the motor given that it was safe to do so. An 'OK' flag powered the gate of a power MOSFET, which went high under the conditions that the current and voltage transients are limited to a safe range, the battery is not charging, and the bike moving at a minimum speed (set by the manufacturer's control circuit to 5km/hr). We trick the in-place circuitry into thinking the bike is moving at the minimum speed by fabricating a false back-EMF using a power supply. This trigger allows the OK flag to go high, and thus the motor engages.

Our next step was to test Pulse Width Modulation (PWM) control of the motor. This was accomplished by applying a positive alternating voltage to the gate of the MOSFET while ensuring that the OK flag was high. We broke the connection between the OK flag and the MOSFET, and attached wires from these points into our breadboard.

This is where we ran into our first problem: If the wire to the MOSFET is not connected to anything, it acts like an antenna and picks up small voltage fluctuations due to electromagnetic interference. These voltages were large enough to turn the power MOSFET on, starting the motor when it was not necessarily safe to do so. This gave us quite a scare the first time, and we quickly unplugged the battery. After turning on one time unexpectedly, we found that the battery terminals were shorted through the motor controller, and isolated it to a blown MOSFET. This occurred because the motor protection was bypassed, causing the MOSFET to sustain damaging currents. We ordered five new ones, replaced the dead MOSFET, and experienced no further problems.

4.8.2 Testing Our Design

To test PWM control of the motor we effectively wanted to 'AND' together the OK flag and the PWM signal. We first tried using a PNP transistor with the OK flag and the PWM signal attached to the emitter and base, respectively, through appropriate voltage divider resistors. This setup gave us nothing but problems, as leakage currents allowed the PWM signal to partly pass to the gate of the MOSFET even when the OK flag was low, and the motor behaved sporadically, often remaining on when it should be inactive.

Our next test used another power MOSFET instead of the PNP transistor, in order to mitigate the problem with leakage currents. Despite solving this problem, we still observed some sporadic motor behavior, with the OK flag passing through to the gate for both high and low PWM states and the motor remaining on at low power even when the OK flag went low. Based on our observations, we suspected this was due to parasitic capacitances.

Next we tried using a comparator circuit, which worked very well except for the fact that when both the OK flag and the PWM signal were low, the comparator output would be high, turning the motor on. This could only be fixed by setting the PWM low voltage to above 1V, which is only possible with the function generator and not possible in our circuit. The comparator circuit effectively proved PWM control of the motor was possible, so we next had to design this control into our circuitry.

We decided to use the PWM reset pin, controlled by the microcontroller (through a DAC and a comparator so that the PWM is held in reset if the DAC is set to a low voltage). With this design, if the OK flag, going to the microcontroller, goes low, the PWM will stop functioning which will cause the motor to cease operation.

4.8.3 PWM Design

Originally, the PWM used for motor control was going to be implemented through the PWM output pin inherent to the microcontroller we chose (PIC16F870-I/SP). Timing complications with dual processes attempting to use the same output PORT (and a lack of alternate I/O pins) made use of the built-in PWM impossible for our implementation. Time-Division Multiplexing of the output PORT was suggested as a solution, but this is a complex software operation, and would be difficult to debug.

The other option was to build a separate external PWM circuit. This hardware-based PWM accepts 3 bits of digital data from the microcontroller and convert the value to a square wave with a duty cycle between 0% and 100%.

We built a cheap and cheerful PWM using a simple design with basic ICs and discrete components. We found a reference design for a PWM that varies its output duty cycle based on an analog input voltage. This design, which we adapted to our circuit (shown in Figure 8), is implemented using two 555 timers. The first timer implements an astable oscillator, generating a continuous pulse train of variable frequency. The second timer implements a monostable one-shot, and is triggered by this variable-frequency pulse train. The output from this second timer is thus a pulse-width modulated signal, mapping back to the analog voltage controlling the first timer. The analog voltage is generated by a hand-made D/A, using 3-single bit active-high output pins from the microcontroller.

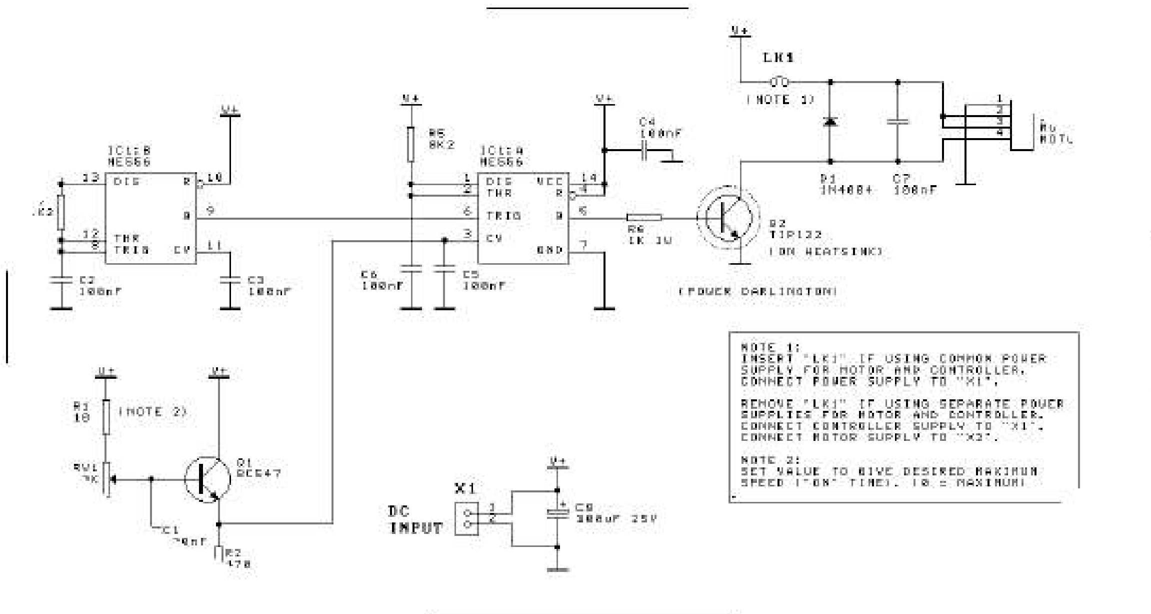


Figure 8: PWM Circuit Diagram

Due to the non-linearity of the PWM voltage-to-duty-cycle mapping, there was a large gap between the highest and second-highest bit states (i.e. between 111 and 110, the duty cycle drops from 100% ~ 55%). We devised two solutions to this problem: we could either make the DAC non-linear to compliment the PWM's non-linearity, or we could limit the DAC output voltage range and limit ourselves to only the lower end of the PWM's output. It soon became apparent that there was no trivial method to map the DAC to match the PWM non-linearity, and so the latter solution was implemented. The final solution allows us to modulate the output waveform between 32% ~ 100% duty cycles.

As a final design step, we had to ensure that one output state is reserved for shutting off the motor (i.e. no waveform driving the MOSFET) and so an additional comparator was added to compare the output of the DAC to a set value of 3V, which we have defined as our lowest output state. The output of this comparator hold the first timer in reset, and thus maps any analog output below 3V to zero.

This design allows seven distinct motor speeds to be maintained.

4.9 Battery Charge Monitor

We were able to create a battery charge monitor with a resistor-divider network stepping down the battery voltage to a range beneath 5V. This voltage is present at the microcontroller's ADC, and is mapped in program-space to percentages between 0-100%. 20.5V represents the low-end of battery-charge for four 6V lead-gel batteries in series. We therefore mapped 24V to 4.8V and 20.5V to 4.1V at the A/D input. This feature enables the user, through a separate MODE on the user interface, to easily monitor the state of battery charge while in transit.

4.10 Safety

The motor will only operate under a specific set of conditions. A single input to the microcontroller (an OK flag) indicates whether the motor is ready to operate or not. When the flag is high, the microcontroller calculates the power required from the motor and sets the PWM output as necessary. The OK flag is high (indicating the motor can turn on) under the following conditions (as described in detail in our Design Specification):

1. The kill switch must be in the "ON" position
2. Both brake switches must be closed
3. The tilt switch must be in the conducting mode (indicating no tilt)
4. The bicycle must be moving at the minimum turn-on speed
5. Motor terminal voltages must not be fluctuating too rapidly
6. The motor current cannot be too high
7. The battery must not be charging

All of our switches are wired in series in an electrical path that lowers the OK flag when the path is broken. Figure 9 is a diagram of the OK flag path that we added on to the kit circuit. The original criteria for the OK flag is implemented in the kit circuit, and consists of items 4-7 in the list above.

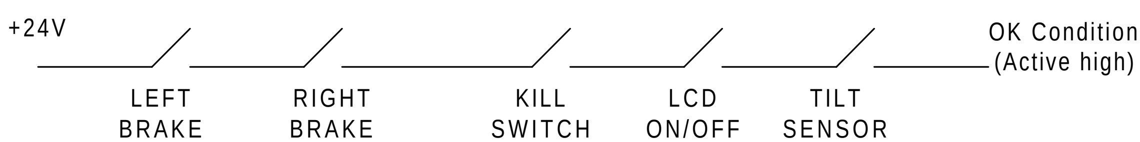


Figure 9: Added OK Flag Path

5 Firmware

The firmware was developed by Sam Hu using the Microchip MPLAB environment, with some debugging help added by various group members. We can provide a printout of the PIC assembly code written by Mr. Hu upon request. The code is available for inspection during and after the demonstration.

6 Improvement Strategy

6.1 Motor and Battery

We chose the motor/battery/housing package that we did for ease of interfacing to our bicycle, and because we were price limited. Our package is sufficient to demonstrate the new electric bicycle technologies that we developed, but if we were assembling a complete electric bicycle for sale, we would make some significant design modifications. First, we would move the batteries from their position at each side of the rear wheel to the center of the bicycle frame, in between the pedals. This would lower the bicycle center of gravity, and make it less prone to tipping when not in motion. Furthermore, we would devise a motor system whereby we use a secondary chain to couple to the rear wheel. Chain coupling is more efficient than friction contact, causes less wear, and doesn't degrade in the rain. Last, judging the market demand, we could increase the power of our motor by an additional 200 watts.

6.2 Battery Regeneration

Regenerative braking and solar power charging are two potential features of the *Ranger* that, had we had more time or a larger group, we might have pursued for this design release. These are both technologies implemented in many homemade electric bicycles, and would have not been novel technologies for us to consider in our product, but are features that would enhance the attractiveness of the *Ranger*. Regenerative braking consists of implementing an H-bridge (for example) for powering the motor in order to recover power from the event of motor being forced to a stop when the bicycle comes to a stop. Solar charging consists of finding an appropriately-sized panel (price, physical size, and power sizing) and interfacing its voltage-current characteristics to those required by the battery. A solar panel could be permanently affixed to a convenient location (as we will show in the demo), or be a home-installed item with proper power cords, plugs, and power interfacing to the batteries. Ideally, the user could lock up their bike outside their home or workplace (perhaps on a balcony), and plug in a solar-powered charging kit to refresh the battery.

7 Budgetary and Time Issues

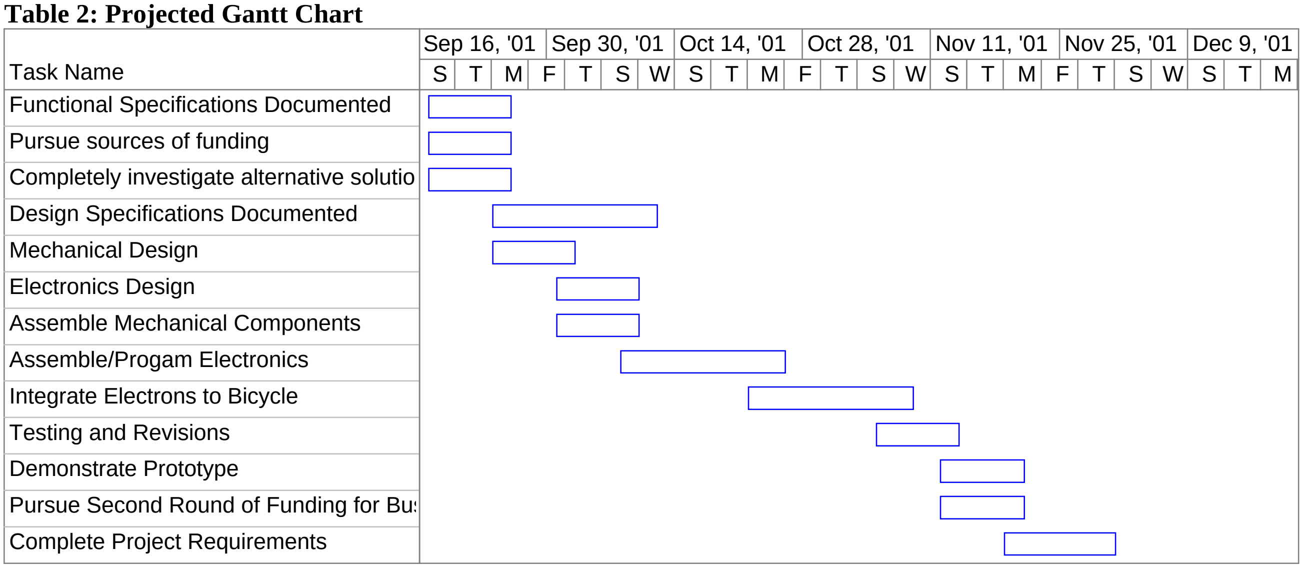
Our final development schedule deviated from our projected time frame. This is not a surprising outcome, given that many 340/370 groups in the past have fallen into the same scheduling traps that we have. We feel that despite this, we are at no tangible loss, for, after all, this is a learning experience.

The final development stages began later and stretched out longer than we anticipated, mainly because the further along the project we were, the more lucid the complexity of certain tasks became. In terms of budgeting, we were fortunate to find avenues allowing us to cut costs. Through various generous sources of funding, were able to completely cover our costs.

7.1 Time Frame

The chart, labeled Table 2 outlines the expected tasks and their associated projected time blocks, whose schedule we intended to follow during the budgeted twelve weeks available for research and development.

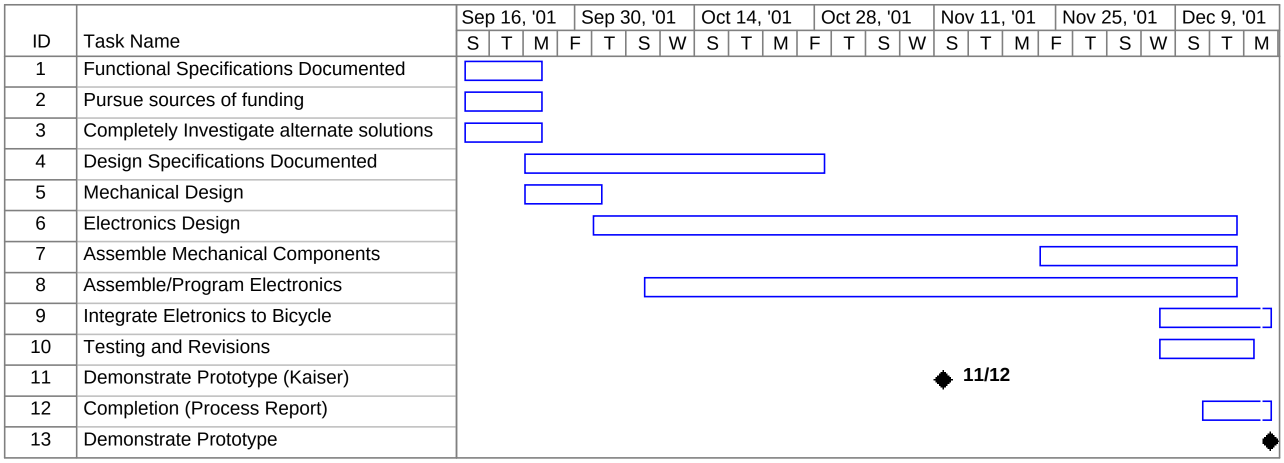
Table 2: Projected Gantt Chart



Our realized timeline deviated significantly, as shown below in Table 3.

8888 UNIVERSITY DRIVE ● BURNABY ● B.C. V5A 1S6 ● TEL: (604)320-0701 ● FAX: (604)291-4251

Table 3: Realized Gantt Chart



Scheduling is an iterative process, and the vast discrepancy between the first and final Gantt charts could have been reduced by a timeline planning revision every two weeks. No member was specifically engaged in keeping the development on track, nor in comparing progress to the original plan: The Gantt chart was put into the proposal and never looked at again. Ideally, a project leader would be effective in enforcing the timeline and inter-group deadlines, and open to suggestions and amendments to the timeline during the product development.

The portion of time allotted to electronics design and assembly/programming of the electronics clearly occupied the bulk of our efforts. It extended so far due to the trying class and personal schedules of the individual group members, and to unforeseen design problem.

We did not anticipate several technical issues that were encountered towards the end of the project. We suspect that the DC converter we originally built (to convert our 24V battery voltage to a 5V logic reference and power source) blew out 2 of our 3 PIC microcontrollers over the final weekend. We did not keep one isolated to our development board (i.e. we inserted all of them in the proto-board), but luckily managed to save one. To get more of this part (in small quantities) at this stage, we would have to order them again from Digikey, which has none in stock until 01.01.2002. Instead, we ordered a large quantity (15) from Future, out of desperation.

Throughout, we have been wiring the proto-board with sockets, in order to make part replacement painless, which was a useful activity. After some fumbling with hasty integration, we took the extra time to create a fully-functional breadboarded system. We then duplicated it on the proto-board, ran it off the safe lab power supplies, and finally began using our fully-tested on-board power supplies. We could have saved time by following this process from the very beginning.

We should have predicted component failure and power problems early on: days before the Kaiser Foundation visit, we blew out the motor control MOSFET. We had enough lead time to order an overnight shipment of more MOSFETs.

One stage of development that was completed later than it should have was the motor control DAC. Despite weeks of work on it, it was not completed until the final days. This section was halting full system testing, as it was the link between the PIC and the motor controller. In retrospect, it being as important as it is, the DAC and output stages should have been the first sections to be developed. This, of course, was difficult to predict as a necessary implementation, since we assumed the PIC would be able to handle the PWM output directly.

Another stage of development that should have been completed earlier was the interface mounting and creation, which wasn't started until after exams (due to time constraints). Once it was in place on the bicycle, it created a sense of things "coming together", and as a symbol, could have helped by being in place earlier.

Our final timeline includes the addition of one week of integration, debugging, and testing, which took place over January 3 to January 9 (2002). During this week we replaced broken components and re-tested their integration.

For time management, Design Outlaws suggests that ENSC340 could benefit from a more formal mode of babysitting, as lame as that may seem, similar to the babysitting of group projects that take place in ENSC100. With regularly scheduled tutorials (for a single group, or split between two), group members will benefit from enforced weekly group meeting/discussion sessions. The TAs can offer input or suggestions, but are there to act as mediators, keeping the team on track in discussion. They could also potentially help encourage members who are late in their deadlines to contribute, benefiting the group by acting as an impartial, trustworthy, outside opinion.

7.2 Budgeting

Table 4 lists the expected costs during the research and development of the Ranger bicycle, whereas our actual costs are shown in Table 5.

Table 4: Expected Cost for Research and Development

Components	Expected Costs
Bicycle	250
Motor	300
Battery	200
Wiring, Fixtures, and Housing	100
Electronic Hardware	150
Microcontroller board	300
Sensors	100
Literature	50
Total	**$1450**

Table 5: Actual Cost For Research and Development

Components	Actual Costs
Bicycle	Borrowed from Eric
Motor/Battery/Housing	716.90
Wiring, Fixtures	45
Electronics	171.00+
Sensors	25
Literature	0
Miscellaneous (failed circuits0, shrink tubing, etc…)	20
Total	**$977.90**

As the above two tables show, we were able to save some money through borrowing a bicycle, finding some clever and inexpensive sensors (magnetic switch velocity sensor and mercury tilt switch), buying the motor and battery housings together with the motor and battery as a package, and borrowing literature. The motor, battery, and housing kit was a little more expensive than we expected, and we realize, looking back, that we budgeted an initially unreasonable amount of money for the sensors and the electronics. However, the difficulty we ran into with frying parts and debugging problems resulted in the purchase of additionally parts beyond our expected costs. Having gone through the whole design process, we now have a more realistic idea as to the cost of assembling a prototype circuit.

It would have been useful to have a list of willing sample sources, such as Maxim (Sunnyvale, CA), and OnSemi.com. Other 340 groups made use of samples quite readily. This was not an area we investigated, since none of our members were familiar with companies that provide sensors.

7.3 Sources of Funding

We obtained funding from the following sources:

Source	Amount ($)
Engineering Undergraduate Student Society Endowment Fund	200.00
Wighton Development Fund; Managed by Dr. Andrew Rawicz	788.82
Cap's Bicycle Stores, New Westminster (450 East Columbia St.)	Bicycle Equipment

We sought funding from many other sources, including:

- APEGBC student project funding program
- BC Hydro Corporate and Regional Donation Outreach Program
- DynaMotive Technologies
- Solar Energy Limited
- Northwest Public Power Association
- Blak Dog Bikes, Coquitlam, BC
- Cambie Cycles, Vancouver, BC
- Simon's Bike Shop, Vancouver, BC
- Cycle BC Rentals
- Burnaby North MP and MLA
- Urban Cycle

Some of these individuals and businesses were very interested, and keen to help, but in the end were unable, for one reason or another, to provide anything concrete. It was a worthwhile search, however, and ultimately we were able to cover our costs through SFU funds, and obtain a few bicycle components from Cap's Bicycle Stores.

7.4 Team Dynamics

We believe our team worked very well together, and were able to complete our project in a high-quality manner with few strains. Team cohesion seemed much easier to maintain in the early days of the project when time pressures were virtually nonexistent. Still, documentation, design, coding, and hardware implementation were spread always among several group members, so that no member felt slotted into a narrow role. Personal views on team functioning remain positive, and are expressed in *Section 8: Member Experiences*.

8 Member Experiences

This project was challenging in technical, organizational, and time management arenas. The group members have diverse educational backgrounds and differing areas of expertise, and these were reflected in their primary contributions to the project. Each member leaves this project with specific 'lessons-learned' and outlooks on their strengths and weaknesses, which is reflected in the personal statements contained herein.

8.1 Rhiannon Coppin – Project Manager

A fellow 340 participant said something quite poignant to me a few weeks short of the end of the term: "In group work, there are 'group' people, and there are 'me' people". As the end of this most laborious and frustrating course approaches, I would propose that the greatest frustrations that arise in team dynamics are not issues of differences of opinion, overall enthusiasm or lack thereof, nor of any gaps in knowledge of another member's work, but instead issues of how available one makes oneself for the group, and what one expects from the other members. Any severe imbalance in group participation, such as a member under a heavy courseload (or under a courseload whose schedule is queer with respect to the group's) who is restricted in time, a member who is generally unavailable certain days of the week, or a member who participates under great duress, stresses the entire project and relations within a project. It is crucial, if one is a very holistic-oriented group participant, to find groups that value the same level of participation.

For Design Outlaws, it became difficult early on to schedule weekly group meetings, due to the opposing and dynamic schedules of the group members. All members, I believe, underestimated the amount of time they would be able to contribute, but the fact that the time they could contribute did not fall together made parallel development important. However, much of this project would have benefited from earlier integration.

I learned more technical skills, such as familiarity with microcontroller programming, switch interfacing, and motor control theory. What was more important though, was the use I was able to make of skills I gained between attempting to take ensc370, at which time I had virtually zero real electronics experience, no machine shop know-how, and few mental resources to draw upon in order to solve parts problems or system design. I definitely found ensc340 challenging, but not insanely overwhelming, because there were very apparent real solutions for some of our design problems. For my personal development as an engineer, this project course definitely should have been scheduled in my fourth year or beyond. (This type of scheduling would also make a 340-to-thesis transition more palpable.)

Having had group dynamics problems previously with this course, I felt it necessary to attempt to have control over the project in order to prevent being 'phased-out' of development. I believe in the existence of natural leaders, and have long held myself to not be a member of their club: this experience reinforces that I am not yet a capable leader, (perhaps I will be one day with enough training), and that I am definitely not someone who automatically commands authority. At some point during the term, everyone, including me, began reporting to Eric Hennessey, who evolved as the natural leader, though we all maintained a level of independence, and formed a dynamic leadership in development: area experts maintained authority over their implemented progeny.

8.2 Eric Hennessey – Technical Lead and Marketing Manager

When discussing what one learned from a group project, most people probably say something along the lines of “the need for good communication” or “good team management”. However, in our particular group I believe we all had a good sense of these things right from the start—both from common sense and from past job and school group experiences.

At the very start of this project, as soon as our group formed, each of the four members discussed his or her past technical and project experience, as well as his or her significant strengths and weaknesses. This discussion allowed us to assign each member to head a particular part of the project, and as new tasks came up we were all able to see which member was most appropriate to take responsibility for that task. However, in assuming particular tasks, we all had the implicit understanding that it was important to keep all of the other members aware of how the task was progressing and what problems and successes were encountered. Each member did not hesitate to seek the assistance from the other members, and we were often able to provide each other with significant help because we were all up to date on each stage and section of the project. Sam, for example, has more experience coding in a project environment than any of us, and so assumed the position of Software Lead. Rhiannon is good at keeping things together, so became Project Manager. Eric Keung has good hardware experience, but is not as strong in English so focused his energies on hardware. I personally have a wide range of experience in hardware, software, and public relations, so became the Marketing Manager and Technical Lead. These loosely-held roles worked very well in task distribution. If one of the things that I have through this project, or rather that I had reinforced, was the utility and effectiveness of our project management, and I will eagerly follow our example in future projects.

On the more technical side, I found it very valuable to pursue a project from concept to creation—something that we almost never do in school and often don't experience in industry as projects are on such a large scale. We came up with an idea that we all found very interesting, and were able to go through the brainstorming process, trying many different designs and settling on one. It was enjoyable working with the other members in exploring different avenues of design, and gaining experience selecting a design that best met our functional requirements. It was very good experience working on individual electronic components and then interfacing them. We did such a thorough testing of each component before trying to put it all together that it was quite easy to do so when the time came, with few surprises. This experience reinforced the concept of using thorough planning and careful testing at each step to mitigate many potential catastrophes.

In the future, I would like to see the prototype electronic board put together at least a few weeks before the project completion date. Assembling a through-hole prototype board is a time-consuming process, and makes it very easy to introduce errors into the design. It would be good to have a large chunk of time to carefully plan the layout of the prototype board, and have more time to assemble it while performing continuous and diligent testing. Everything taken into account, however, I consider our project a complete success and a very positive experience.

8.3 Eric Keung – Head of R&D

Most people comment on the fact that all the things we learn in school will be not directly related with future work (since what we learn is supposedly completely out-of-date) and is therefore one thing and one thing only: useless. Contrarily, during the course of ENSC340 development, I found that most of my solutions were almost right out of my ENSC425 (Electronic System Design) textbook. But this presents an interesting dilemma to the average student: If one actually follows the curriculum, one wouldn't take ENSC425 until two semesters later. Are students properly prepared in knowledge and experience to handle 340? I am no expert, having only one view of this experience, but I can say that I am glad that I took that course last year.

As ENSC305 emphasizes, one of the age-old problems in a project course such as this is communication. I believe that our group probably makes a good counter-example to that belief. Every issue that arose was talked-out, becoming clear and well-defined to all members. This could be due to the fact that three out of four of us are from a "more senior" year. Firstly, we knew what to expect (having heard the tales), and secondly, experience in working on other labs made us realize how important communication is during group work processes. Additionally, I feel that having great leaders like Rhiannon and Eric H. helped keep us on track.

Since my expertise lies within the hardware department, I was designated to work on the interface between the micro-controller and motor control: my course on analog design really paid off here.

There are two major technical-oriented lessons I've learned in this class. One is to never design any mixed-signal system with only a single ended supply, i.e. running analog components with 0V ~ 5V logic levels. This problem arose in the later stages of the design phase after we had definitely decided to implement a DAC for converting digital signals to analog signals (to run the PWM). We failed to recall at first that op-amp saturation voltage is always lower than the supply voltage, and hence, we could never drive our PWM properly. Once the problem was identified, it was a matter of finding a higher potential on the circuit and use that to power the op-amp. The other lesson I've learned is to never, ever, underestimate the power of static electricity… Which makes me wonder: why do we have a carpeted laboratory that was 'designed' and built as an electronics laboratory?

8.4 Sam Hu – Lead Software Engineer

I love a challenge; I always have and will,
But coding assembly is an almost impossible skill!
  The code fits all snug,
  Until we debug,
And spend the night re-writing my swill!

9 Future Prospects of the Ranger

Over the next five months, we expect to demonstrate our enhanced *Ranger* electric bicycle in a number of different venues in order to satisfy our primary goal, which was to create a prototype for demonstration in order to create public awareness of emerging electric vehicle options and to publicize the field of engineering along with the work that is being accomplished at SFU.

Specifically, we are in planning stages for providing demonstrations at the following events:

- Western Engineering Conference 2002
- Canadian Engineering Conference 2002
- Simon Fraser University during National Engineering Week (Feb. 2002)
- Local High Schools
- ASI (Advanced Systems Institute) Exchange, March 2002
- Other functions as requested

We are very pleased with our deliverables, and hold as true that our implementation is simple, effective, and inherently safe. We believe that we have succeeded in providing a groundbreaking technology to the field of electric vehicle design — an electric bicycle with speed control, including required and appropriate safety features. Design Outlaws identified the need for increased public knowledge of and acceptance and adoption of alternative transportation, and is contributing towards the fulfillment of this purpose.

The *Ranger* human-electric-hybrid bicycle, as we planned, can provide the safe, healthy, and enjoyable journey everyone desires.

10 Acknowledgements

We would like to credit our sponsor, Cap's Bicycle Stores, New Westminster (450 East Columbia St.), and our financial contributors, the Wighton Development Fund (Managed by Dr. Andrew Rawicz) and the Engineering Undergraduate Student Society Endowment Fund (ESSEF).

Technical consultants for this project include Ben Lake, George Austin, and Fred Heep. We would also like to thank Eric Haberger for rescuing us with voltage regulator components, and the other 340 groups for being respectful and cooperative in the sometimes-tight lab space.

Ichiban™ noodles and Nescafé™ deserve honourable mentions as contributors.

11 Appendix

A – Transport Canada Motor Vehicles Safety Act

The Motor Vehicle Safety Regulations (Subsection 2(1)) define the following requirements:

"power-assisted bicycle" means a vehicle that:

a) has steering handlebars and is equipped with pedals,
b) is designed to travel on not more than three wheels in contact with the ground,
c) is capable of being propelled by muscular power,
d) has an electric motor only, which has the following characteristics, namely:
    i. it has a continuous power output rating, measured at the shaft of the motor, of 500W or less,
    ii. if it is engaged by the use of muscular power, power assistance immediately ceases when the muscular power ceases,
    iii. if it is engaged by the use of an accelerator controller, power assistance immediately ceases when the brakes are applied, and
    iv. it is incapable of providing further assistance when the bicycle attains a speed of 32 km/hr on level ground.
e) bear a label that is permanently affixed by the manufacturer and appears in a conspicuous location stating, in both official languages, that the vehicle is a power-assisted bicycle as defined in this subsection, and
f) has one of the following safety features,
    i. an enabling mechanism to turn the electric motor on and off that is separate from the accelerator controller and fitted in such a manner that it is operable by the driver, or
    ii. a mechanism that prevents the motor from being engaged before the bicycle attains a speed 3km/hr.

Further requirements, from California and Washington State laws are:

- The device will operate in such a manner so that the electric motor is disengaged or ceases to function when the brakes are applied, or operate in a manner such that the motor is engaged through a switch or mechanism that, when released, will cause the electric motor to disengage or cease to function.
- The device will comply with the equipment and manufacturing requirements for bicycles adopted by the Consumer Product Safety Commission (16 C.F.R. 1512.1, et seq.)