DESIGN OUTLAWS

November 5, 2001

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

Re: ENSC 340 Design Specification for the *Ranger* Electric Bicycle

Dear Dr. Rawicz:

Attached you will find *Design Specification for the Ranger Electric Bicycle*, prepared by Design Outlaws. This document lists the design specification for the implementation of our ENSC 340 project.

We are in the process of building an electrically-assisted bicycle that maintains a user-settable speed. Please review our progress to-date and offer any suggestions. We are looking forward to presenting you with a working prototype in the near future.

Sincerely,

Rhiannon Coppin
Project Manager
Design Outlaws

Enclosure: *Design Specification for the Ranger Electric Bicycle*

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DESIGN OUTLAWS

DESIGN SPECIFICATION FOR THE *RANGER* ELECTRIC BICYCLE

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Submitted to
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Revision
2.0

Executive Summary

As city streets become more congested, fuel prices continue to rise, and air pollution increases in severity, people are demanding a more convenient, inexpensive, and healthy transportation alternative. Design Outlaws have determined that one of the most promising alternatives for many lifestyles is the electric bicycle. Therefore, our mission is to make the electric bicycle a more attractive commuting option.

The development of the electric bicycle will be split into two phases. After completion of the first phase, the prototype *Ranger* will support the following features:

1) The user must be able to preset their target speed, and have the motor compensate for pedaling deficiencies.

2) Provide gradual and natural-feeling acceleration.

3) Basic safety features such as motor auto shut-down when the bicycle exceeds the selected speed, and a separate motor kill switch.

4) Battery rechargeable through interface to an AC wall outlet.

5) Speedometer.

6) Compliance with non-motorized vehicle regulations set out by both Canada and USA.

The prototype is being developed as a consumer add-on kit for an existing bicycle. Future developments may include improvements to the user interface, while the first prototype, which will be completed in December 2001, is a proof-of-concept device.

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1. Introduction

The *Ranger* is an electric bicycle, incorporating a rechargeable electric power source, a variable torque and variable speed electric motor, and associated control mechanisms. The *Ranger*'s unique features include a pre-settable speed control, and smooth acceleration to the target speed in the presence or absence of external pedaling. The *Ranger*'s control system will allow the user to pedal as with a regular bicycle, and will determine the level of motorized output necessary to achieve and maintain the desired speed that the user selects through a digital interface. The *Ranger* will function on various terrains and under severe conditions. Finally, the *Ranger* will incorporate all safety features as set out by various state and federal legislation, in addition to the safety features deemed necessary by Design Outlaws.

1.1. Scope

This document describes the design specification for a prototype of the *Ranger* commuter bicycle. This prototype will act as a proof-of-concept device and will allow for further feature developments, which are briefly documented in the final section. The requirements we have set forth for the prototype, along with the consideration of future requirements, both motivate the design of the *Ranger.*

1.2. Acronyms

ADC - Analog to Digital Converter
DAC - Digital to Analog Converter
LCD - Liquid Crystal Display
OSC - Oscillator
PWM - Pulse Width Modulator
UI - User Interface

1.3. Referenced Documents

[1] Proposal for Design and Implementation of Electric Bicycle Technologies. Design Outlaws, Rev 2.0, September 18, 2001.
[2] Functional Specification for the Ranger Electric Bicycle. Design Outlaws, Rev 1.0, September 27, 2001.
[3] *MOTOR VEHICLE SAFETY ACT: Regulations Amending the Motor Vehicle Safety Regulations (Expiry Dates for Sections 108, 131 and 206).* Canada Gazette Part II, Vol. 135, No. 8. 2001-04-11. Registration SOR/2001-116, 29 March, 2001.
[4] Bordonaro (Senator Mountjoy, coauthor), *An act to amend Sections 406 and 12804.9 of, and to add Section 24016 to, the Vehicle Code, relating to vehicles*. TOPIC: Motorized bicycle: electric motor: definition. California Vehicle Code, Measure A.B. No 1501, Chaptered (Chapter 804) 10/13/95.

[5] Thibaudeau, Wood, Haugen, and Prince (Senators), *Senate Bill 5968, Chapter 328, Laws of 1997: Electric-assisted bicycles*. State of Washington Laws. Effective Date, 7/27/97.
[6] PIC Microcontroller: MICROCHIP PIC16F870/871 28/40-Pin 8-Bit CMOS FLASH Microcontrollers, 1999; document #DS30569A.
[7] LCD Panel: NAN YA PLASTICS CORP. 24X2 LCD Module (LM_B3_025_2), Mar 24, 1998; Spec No. LM025-0. (U.S. Marketing: Mark Products Corp., Illinois.)
[8] Power Pack: Electric Transportation Company, *Rack Installation and User's Manual, Revised.*
[9] Linear Technology LT1173 Micropower DC/DC Power Converter, Adjustable and Fixed 5V / 12V.
[10] Pushbuttons: Model JB15F, nkkswitches.com.
[11] Brake Sensors: Cherry Corp. Microswitches (DB1) Catalog: db-sub.pdf
[12] International Rectifier IRLZ44N: HEXFET Power MOSFET. PD - 9.1346B, 8/15/97.
[13] Fairchild Semiconductor, KA239/KA239A, KA339/KA339A, KA3302, KA2901 Quad Comparator, Rev. 1.0.1, 2001.

1.4. Intended Audience

This document is intended for designers, design engineers, and managers to use in the construction and development of the *Ranger.*

2. System Specifications

2.1. System Overview

Figure 1 illustrates the overall system of the *Ranger* bicycle.

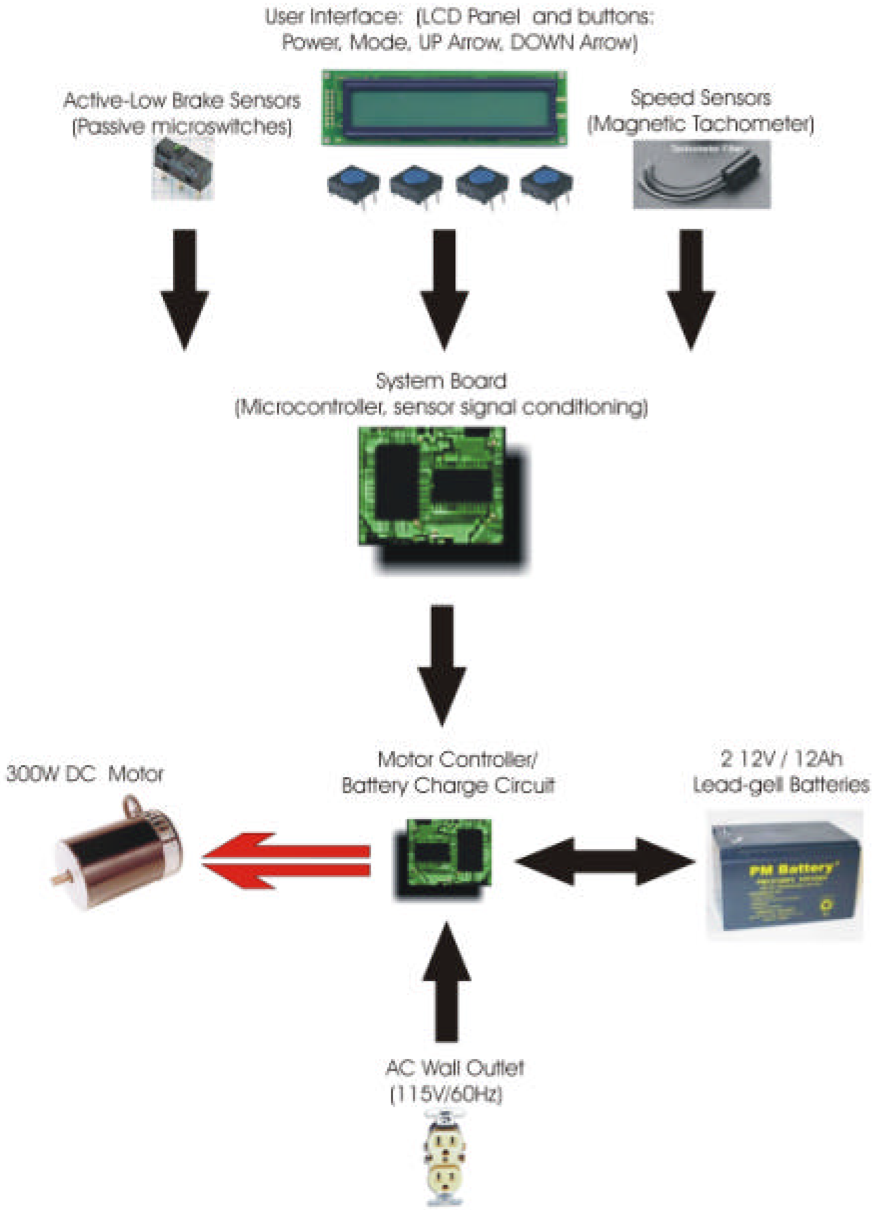


Figure 1: Electric Bicycle System Diagram

We have purchased the *ETC Express Pack* electric motor, rack, battery, and battery charger kit from ETCBikes (www.etcbikes.com). The DC motor mounts on the rack above the rear wheel of a standard adult bicycle, and contacts the rear wheel directly, propelling it via direct friction on the tire. The batteries are two rechargeable 12V/12Amp-hour lead-gel cells.

We are building and integrating the following components:

- A user interface, allowing the user to input a desired bicycle speed and give important system parameters as feedback (current speed, desired speed, battery charge status, motor status)
- An emergency switch, allowing the user to immediately engage or kill the motor operation.
- A System Board, which will use a PIC microcontroller to monitor the bicycle speed, the desired speed, motor status from the Motor Controller Baord, and battery status. The microcontroller will control the LCD display of system parameters, and output a pulse-width-modulated (PWM) signal at 20kHz to the power circuitry for motor control.
- A Controller Board which accepts the 20kHz PWM signal and uses a power amplifier circuit to feedthrough power from the battery to the motor.
- A battery charge circuit.

The user will be able to select a target motor-assisted commuting speed between 0-30km/hr. Then, if the user engages the motor with a separate switch and begins pedaling, the motor will engage to accelerate the bicycle to that target speed. The acceleration will be gradual, smooth, and feel natural and safe to the user. As the user increases the amount of pedaling, the control system will reduce the motor output in order to maintain the target speed.

When travelling at speeds greater that the target speed, (for example, when going downhill), the motor will disengage and the motor will reengage once the speed drops 3km/hr below the target speed, providing hysteresis in the motor control.

The control system will sense the application of either brake, and the motor will turn off when the brakes are applied.

2.2. Motor and Battery Specifications

The *Ranger* utilizes the Electric Transport Company’s (ETC) Express Pack, consisting of a motor and battery packaged together, along with a pack mounting frame that is fixed to rear of the bike, behind the seat and above the rear wheel. The mounting unit is shown in Figure 2.

Figure 2: ETC *Express Pack*

The ETC Express Pack is specified as follows:

Table 1: Motor and Battery Specifications

Type	Fully removable electric power pack with built-in motor, control, charger, and batteries
Weight	12.25 kg
Dimensions	406mm long x 120 mm wide x 200mm high
Drive	Friction on rear tire
Batteries	Dual 12 V, 12A sealed lead acid
Electronic Control	Current response manager to optimize performance and battery life
Minimum Speed	5 km/hr
Maximum Speed	20 km/hr
Charger	120 VAC 60 Hz @ 1 A built-in self-regulating to prevent over-charging
Full Recharge	4-6 hours
Trigger	Handlebar-mounted on/off control operating at speeds above 5 km/hr
Operating Temperature	4.5°C to 38°C

The components of the above system that have been replaced for the *Ranger* include the electronic control and trigger.

2.3. System Mechanics

The motor we were able to afford for the prototype is a 300W model, whereas the legal limit in Canada for motor power is 500W. We calculate that the model we have should be able to propel a 68kg person up a 7% grade at a speed of 10.8km/hr. However, this is assuming an ideal case, and in real-world operation, this figure is reduced. Our calculations are based on the following model:

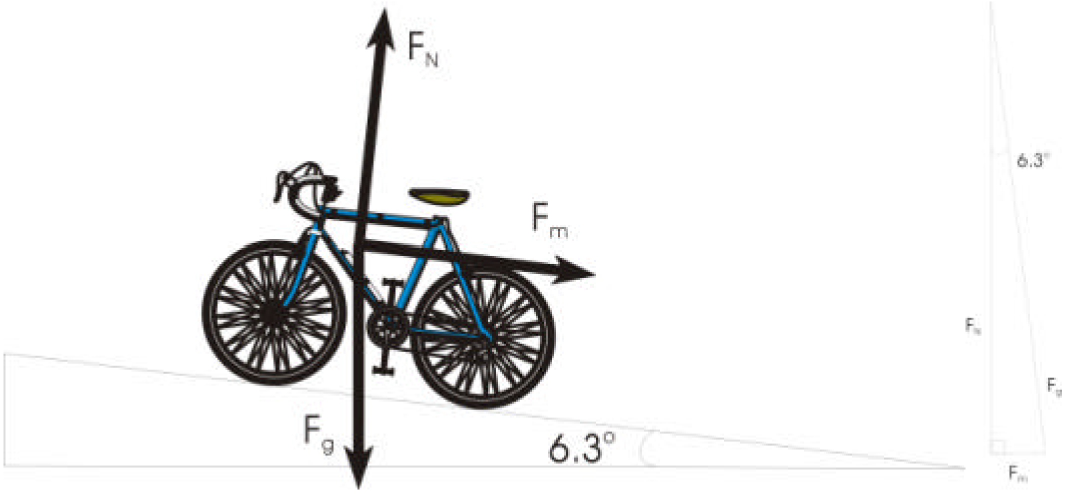


Figure 3: Free-Body Diagram of Bicycle on 6.3° Incline

We estimate that the total system mass, based on a 68kg load (person), a bicycle weight of 12.75kg, and motor/battery weight of 12.25kg is 93kg.

Assuming a grade of 7%, this translates to an angle of 6.3° from horizontal.

Therefore, assuming negligible drag from friction, the component of the force of gravity to be matched by the motor for constant speed is:

$$\begin{aligned} F_m &= mg * \sin(6.3^o) \\ &= 93\text{kg} * 9.81\frac{\text{m}}{\text{s}^2} * \sin(6.3^o) \\ &= 100\text{N} \end{aligned}$$

Therefore, with a motor capable of developing a power of at most 300W, the maximum speed we should be able to attain on this incline is:

Using $\text{Power} = \frac{\text{Work}}{}$ and $\text{Work} = \text{Force} ´ \text{Distance}$

Then:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} = \frac{\text{Work}}{\text{Force} \times \text{Time}} = \frac{\text{Power}}{\text{Force}} = \frac{300\,\text{W}}{100\,\text{N}} = 3\,\text{m/s} = 10.8\,\text{km/hr}$$

During real operation of our prototype, other factors will determine the limits of output performance of our battery-motor combination. First of all, the motor's power rating will be closer to 200W, while 300W is only the largest power developed by motors of this type. Additionally, there is power loss due to the frictional nature of the motor-tire coupling, due to friction between the tire and the pavement, and due to air resistance. In initial tests, the motor is able to propel the user without user aid on very low grades only (1-2%). For higher grades, the addition of the developed motor torque still provides an easier riding experience for the user.

The system we are designing for assumes a 500W motor, and all the speed protections and capabilities for that power. Our lower-power system will be the proof-of-concept device for a 500W system, and will be different from a 500W system only in its speed/torque performance (not in its behaviour).

2.4. System Power

2.4.1. Motor Power

The power source for the DC Motor is the accompanying rechargeable battery pack. For the prototype, no additional power features, such as options to recharge the battery either via solar recharging, pedaling, or regenerative braking, will be implemented.

The purchased kit includes a battery recharging circuit for use with a standard North American AC 115V/60Hz wall outlet.

2.4.2. Board and Sensor Power

For the prototype, we are employing a power converter to step-down the battery voltage from 24V DC to 5V DC to power the board and provide power for the sensors, which are passive entities. The converter we are using is Linear Technology's LT1173. We will limit the current supplied to the converter switch to 1.5A using an external fuse, and the LT1173 internally limits the output current to 300mA. The circuit diagram in Figure 4 is from their data sheet. (The diode shown must be a Schottky diode).

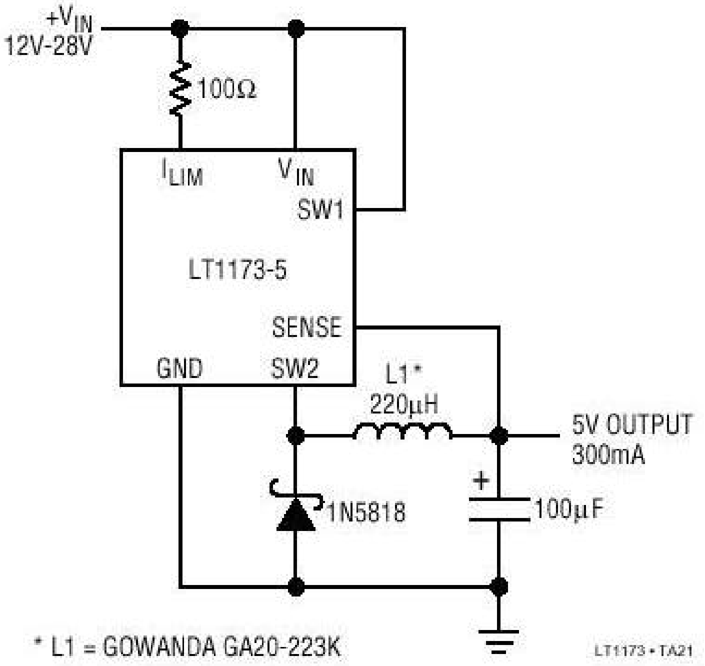


Figure 4: +24-5V Step-Down Converter

3. System Hardware

3.1. Hardware Overview

Figure 5 represents the hardware design for the electric bicycle system.

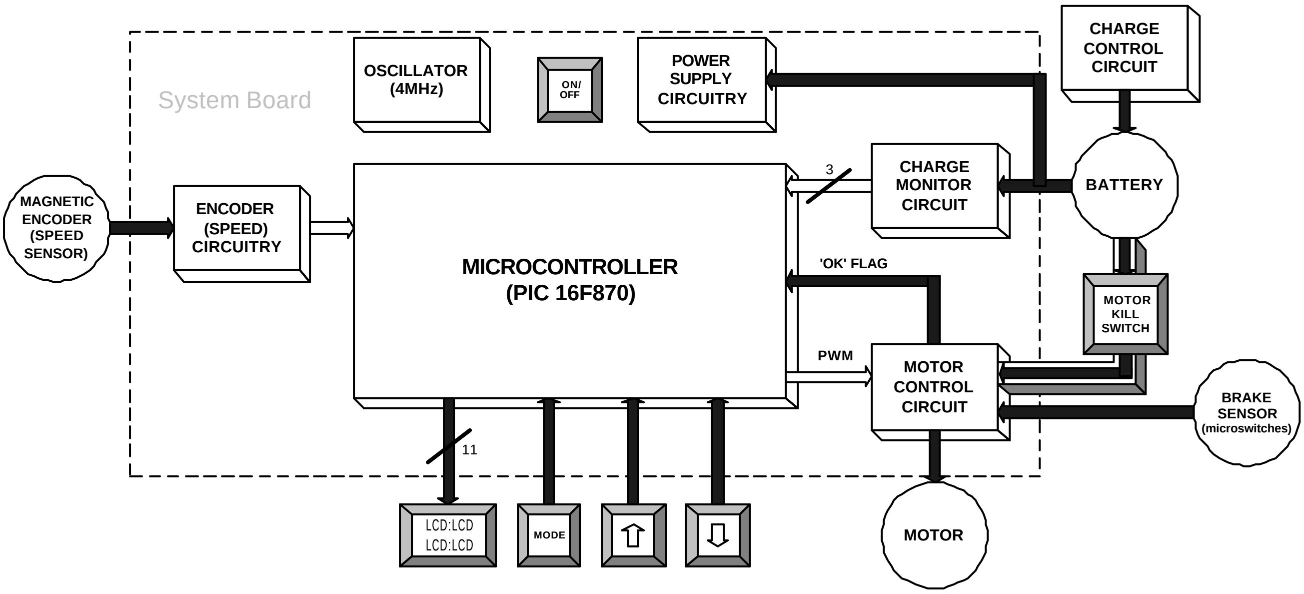


Figure 5: System Block Diagram

The dotted line represents the physical logic board. On-board systems are contained within.

Input to the board is provided by the following components:

- Digital speed encoder
- Battery terminals
- Motor status through feedback circuitry
- Pushbuttons (3) (The fourth pushbutton is power on/off)

Output from the board is:

- Motor drive signal (from power MOSFET)
- LCD display (visual feedback to user)

Additional systems which by-pass the board are:

- On/off motor "kill" switch
- Brake sensors (2)

Note that the brake circuitry bypasses the microcontroller. This is to allow the motor to be stopped via application of the brakes even if the microcontroller malfunctions.

Also note that since the motor controller is on-board, the motor will not be able to function without the board being activated (for obvious safety reasons).

We have chosen to use standard 5V logic.

3.2. Speed Sensor

3.2.1. Summary

The speed sensor provides speed information to the microcontroller for LCD display and use in the control of the motor. The sensor consists of two components, one that moves as the wheel moves and one that is fixed to the bicycle frame. A magnet is attached to one of the spokes of the rear wheel, at such a radius that it passes the second sensor component, which is normally an open electric connection but which becomes closed as the magnet passes closely. Thus by connecting one pin of the microcontroller to one end of the sensor, and a current-limited 5V to the other, every wheel revolution generates an active high signal. This allows the microcontroller program to calculate the speed of travel.

Note that we will not be able to determine direction, for example if the user wheeled the bicycle backwards. These types of situations should not be of consideration in any case.

3.2.2. Detail

The velocity sensor is a fundamental component of our electric bicycle design, and serves two main purposes. This sensor provides speed information to the LCD for display to the user. Most importantly, however, the sensor provides the feedback necessary for the control system to regulate the motor. The motor will be controlled based on the user-specified target speed, the maximum motor-assisted speed, and the threshold motor start speed.

Bicycle velocity information is obtained through use of a rotational velocity sensor. A number of different styles of sensors can provide this information, including an optical encoder, a Hall effect sensor, and electrical conducting sliding contact sensor, and magnetic reluctance sensors. However, optical encoders are negatively affected by varying light conditions, Hall effect sensors are somewhat expensive, contacting sensors have mechanical limitations, and magnetic reluctance sensors require AC carrier signals. We chose a simple and readily available sensor—a form of relay whereby the presence of a magnetic field closes a contact between two wires. A likely design involves the suspension of a ferromagnetic wire inside a conducting shell. A sufficiently strong magnetic field, coming from any direction, pulls the wire towards the shell, closing the contact.

Now we place the relay portion of the sensor on the bicycle frame close to the wheel and affix a magnet to a spoke of the wheel at a distance from the center such that the magnet passes directly along the relay. Thus we have a momentarily closed circuit once for every rotation of the tire. This design is used in most bicycle velocity computers, and so we can obtain the sensor element from a discarded bicycle computer at a local bicycle shop.

If we place 5V on one wire of the sensor, we obtain a 5V pulse on the other wire every time the magnet comes close to the sensor. We send this voltage to the input of our microcontroller, placing a 100S resistor in series with the microcontroller input to limit current flow in the case that an internal short circuit occurs. We also place a filtering capacitor and a 10kS resistor in parallel to ground at the input.

The microcontroller can calculate velocity using the time between two pulses and the diameter of the wheel using the following equation:

$$v = (\pi * \text{diameter}) / (\text{time between pulses})$$

According to the PIC16F870 Data Sheet, the minimum input capture low and high times are, in the worst case, 120ns. Thus our pulse must remain high for at least 120ns. If our pulse did not meet this requirement, this requirement can be met using a monostable ("one-shot") multivibrator, as shown in Figure 6.

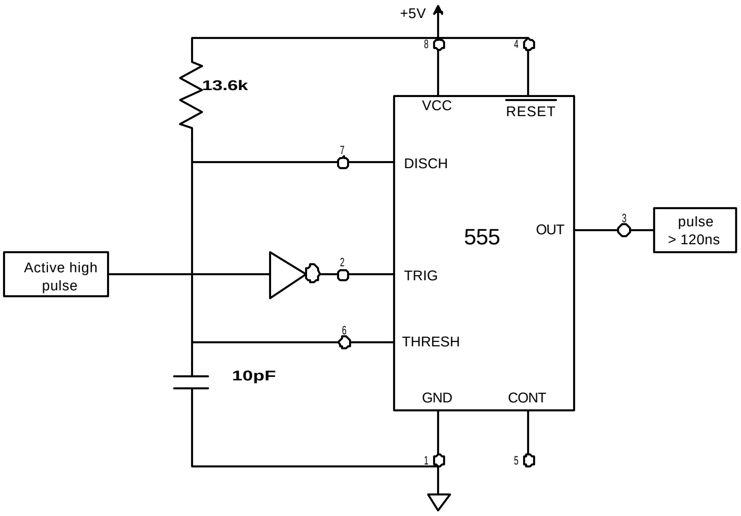


Figure 6: One-shot Pulse Generator

Using this configuration, the 555 timer has a minimum trigger pulse width of 50ns.

However, through experimentation we determined that the minimum duty cycle of the velocity pulse is 4.5%. Equating 120ns to 4.5% of the duty cycle, then one rotation of the wheel would occur every 2.67X10-6, which is 37451 rev/sec (far above our needs).

For these experiments, we mounted the speed sensor close to the hub (approximately 1/4 of the radius form the center) in order to maximize its high time.

3.3. Brake Sensor

The brake sensors are two durable microswitches, mounted at the brake handle interface so that the small button on top (shown green in Figure 7) is depressed, completing the circuit, when the brakes are not applied. This will require modifying the sensors with a flat-mountable metal piece, which will make contact with the button and pivot at one end, using the button's spring as its spring. The other end will fit between the moveable and stationary parts of the brake hinge. An example of a flat-mounted metal lever is shown in Figure 8.

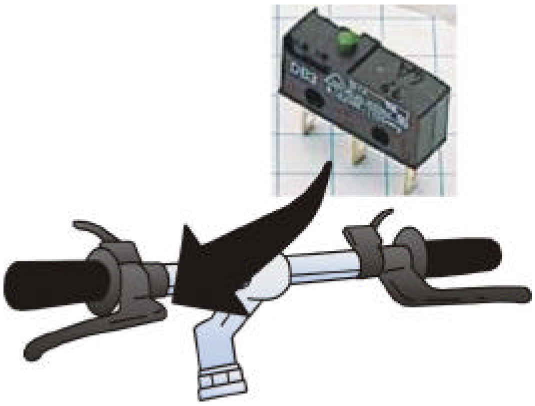


Figure 7: Brake Sensor Mounting

Figure 8: Microswitch with Lever

This type of design provides an active-low brake sensing system. Any fault in the system (and the fault on loose mounting) should generate a low signal by default, indicating that the brakes are applied and that the motor should be stopped.

A simple circuit implementation is shown in Figure 9. Because the switch is normally closed, we wish to draw negligible current, which can be accomplished with a suitably large resistor. During the closed (no brakes) state, V_{out} is grounded. During the open (brakes) state, V_{out} is pulled-up high to +5V.

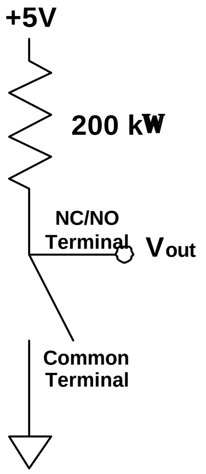


Figure 9: Microswitch Wiring Circuit

The microswitches are manufactured by Cherry corporation. The inner construction is shown in Figure 10.

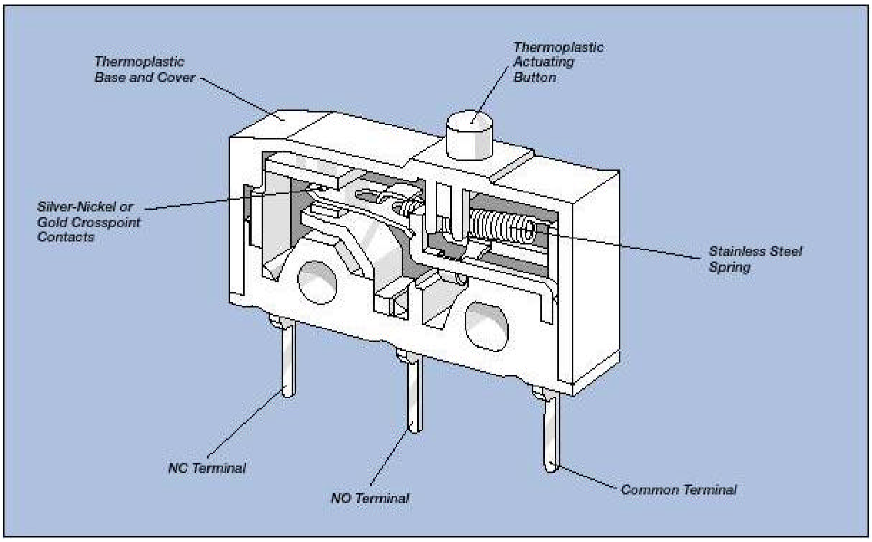


Figure 10: Cherry Corp. MicroSwitch (Active-low Brake Sensor)

3.4. Interface Push Buttons

We are using JB15FP tactile switches. They provide a contact debounce time of 0.1ms, and so we will generate one-shot circuits (as in section 3.2.2) to stretch their pulses to 120ns for the PIC I/O.

The switch is shown in Figure 11.

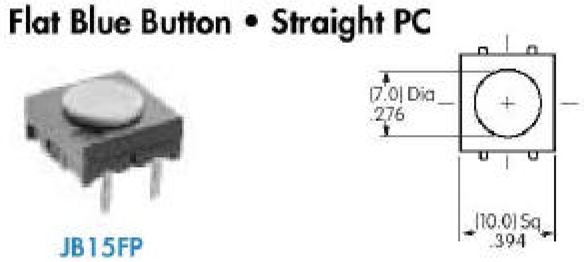


Figure 11: NKK JB15FP Pushbutton Switch

For further information, please refer to the datasheet.

3.5. LCD Unit

The LCD unit for the prototype is a 24X2 dot-matrix LCD screen (each character is 5X8 dots), with 11 I/O for programming the display. The PCB-mounted unit is 118mmX35mm (width <5mm). This unit was chosen for prototype development primarily for convenience and affordability, since it is larger than a desirable LCD for this application, and the characters are smaller than desired. A more suitable LCD will be found for further developments past the proof-of-concept device. The PCB-Mounted LCD is shown in Figure 12.

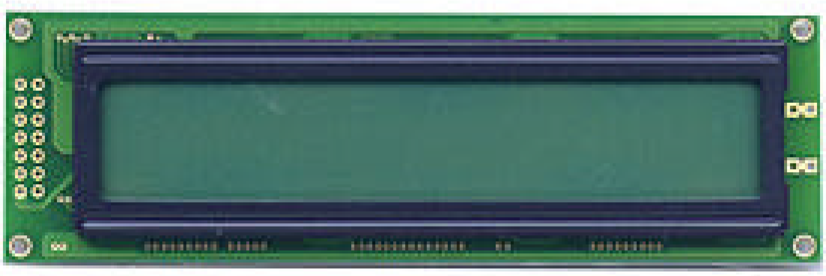


Figure 12: LCD Unit Photograph

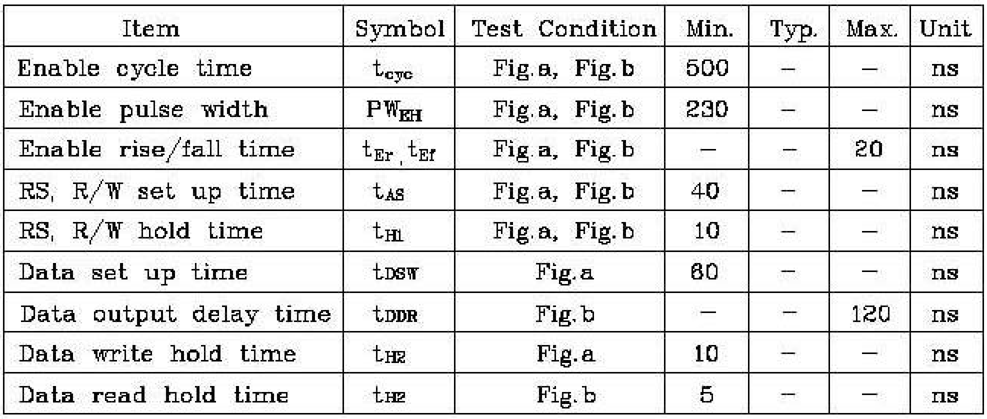
The I/O for this unit is:

Table 2: LCD I/O Pinout

Pin No.	Symbol	Level	Function	
1	V_{SS}	-	0V	Power Supply
2	V_{DD}	-	+5V	
3	V_O	-	-	
4	RS	H/L	H: INSTRUCTION CODE L: DATA INPUT	
5	R/W	H/L	H: DATA READ (FROM LCM TO MPU) L: DATA WRITE (FROM MPU TO LCM)	
6	E	H, H->L	ENABLE SIGNAL	
7	D0	H/L	DATA BUS	
8	D1	H/L		
9	D2	H/L		
10	D3	H/L		
11	D4	H/L		
12	D5	H/L		
13	D6	H/L		
14	D7	H/L		

Timing information is as follows:

Table 3: LCD I/O Timing Parameters



Item	Symbol	Test Condition	Min.	Typ.	Max.	Unit
Enable cycle time	t_{cyc}	Fig.a, Fig.b	500	–	–	ns
Enable pulse width	PW_{EH}	Fig.a, Fig.b	230	–	–	ns
Enable rise/fall time	t_{Er}, t_{Ef}	Fig.a, Fig.b	–	–	20	ns
RS, R/W set up time	t_{AS}	Fig.a, Fig.b	40	–	–	ns
RS, R/W hold time	t_{H1}	Fig.a, Fig.b	10	–	–	ns
Data set up time	t_{DSW}	Fig.a	60	–	–	ns
Data output delay time	t_{DDR}	Fig.b	–	–	120	ns
Data write hold time	t_{H2}	Fig.a	10	–	–	ns
Data read hold time	t_{H2}	Fig.b	5	–	–	ns

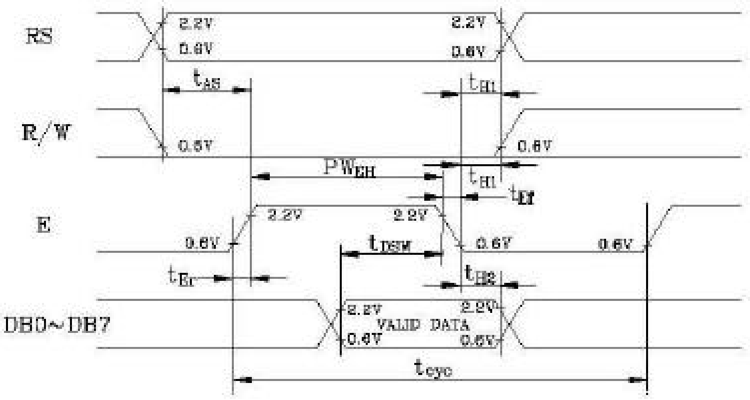


Figure 13: LCD Write Timing Cycle

More detailed information, including character map and instruction code map, can be found in the referenced specifications.

3.6. Microcontroller

The microcontroller for this application is the PIC16F870-I/SP-ND. Please consult the datasheet for specific information.

3.7. Motor Control Circuitry

The motor control circuitry on the *Ranger* bicycle consists of two primary components: System state and system control components. Four observations of the current system state are made through the use of voltage comparators to determine whether it is safe and appropriate to begin motor operation. If the output of each comparator is high, a flag is sent to the micro controller indicating that it is safe to begin motor operation. The microcontroller then determines the appropriate motor output power based on its various inputs and sends a PWM signal back to the motor control circuitry, which delivers the electrical power to the motor power. This continues until the user terminates the motor operation, or one of the comparators goes low, indicating it is no longer safe or appropriate to continue motor operation.

The complete motor control and battery charge circuitry can be found in schematic form in Appendix A. Inputs 1-, 1+ to 4-, 4+ and outputs O1 to O4 refer to the comparators in the quad comparator chip KA339A, and Vchip to the positive supply voltage for the comparator chip.

Prior to motor operation, the HEXFET power MOSFET (IRLZ44N) is non-conducting, leaving Mot- disconnected from the negative terminal of the battery, placing both Mot+ and Mot- at the same voltage and yielding no current flow through the motor and thus no power generated (see Figure 14). The gate of the MOSFET must receive a positive voltage from the microcontroller to begin conducting current, which connects the negative terminal of the motor to the negative terminal of the battery, thus placing the battery voltage across the motor.

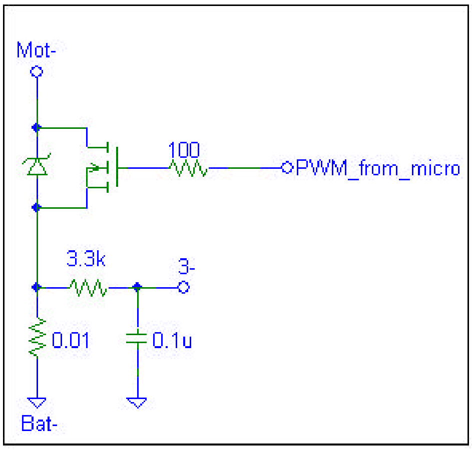


Figure 14: MOSFET Operation and Current Protection

The microcontroller will only send a positive voltage to the MOSFET if it receives a high voltage from O1, which will only be the case if all comparator outputs are also high (otherwise the diodes D10 to D12 conduct and 1+ is pulled to 0V, which forces O1 low). The conditions which must exist for O1 to be high are as follows:

1) The two switches, kill switch and battery switch, must be closed, which connects the positive battery terminal to the transistor emitter (see Figure 15).

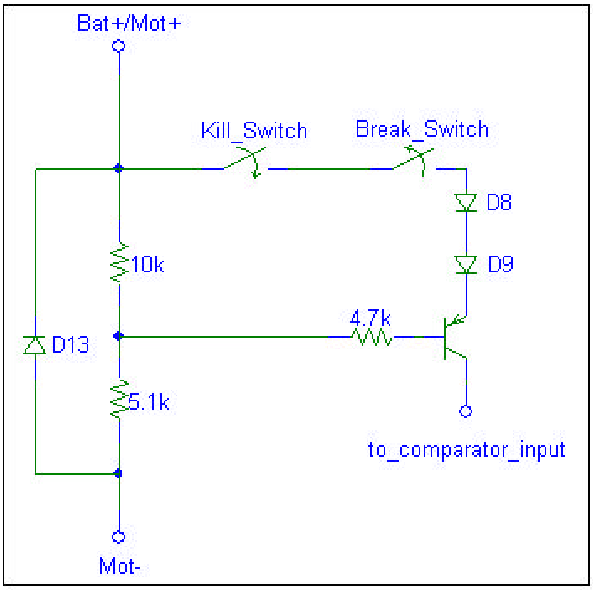


Figure 15: Switch and Back-EMF Operation

2) The bicycle must be moving at the minimum motor turn on speed, which generates a motor back-EMF that supplies the transistor base-emitter turn-on voltage through the 10kohm and 5.1kohm voltage divider shown in the previous figure. This allows current to flow through the transistor and places 2+ at approximately half the battery voltage and 1- and 4+ at approximately one quarter the battery voltage (a PNP transistor with capacitors protects 1- and 4+ from high frequency voltage transients).

3) Transient motor terminal voltages must not be so large as to make 2- exceed 2+ (see Figure 16).

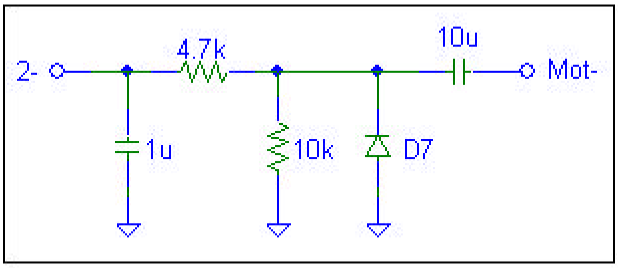


Figure 16: Transient Voltage Protection

4) When the motor is on, 3+ is placed at approximately 0.2V, and the motor current must not be so large as to make 3- exceed 3+ (approximately 20A). The current detector, 3-, is shown above in Figure 14.

5) The battery must not be charging, else 4- is placed at a voltage higher than 4+.

3.8. Battery Charge Monitor

The type of battery we are using is a 12V 12Amp-hour lead-acid gel cell battery (two of them). These batteries each have six 2V cells in series, which should not be discharged below 1.7V each, or approximately 10.2V across the entire battery.

More stringent requirements suggest that 10.5V should indicate a state of "zero-charge" on such a battery, to prevent further use and damage to the cells.[1]

As such, we will map 10.5V - 12V (a 1.5V range) to 0 - 4V, using +5V as an op-amp power source. This 0-4V value will be sampled by the 3-input PIC A/D port, as indicated on the System Overview (Figure 1).

This voltage mapping will be accomplished using a simple subtractor-amplifier circuit as shown in Figure 17.

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[1] http://www.bath.ac.uk/~bspahh/bikelights/node24.html#SECTION00222000000000000000

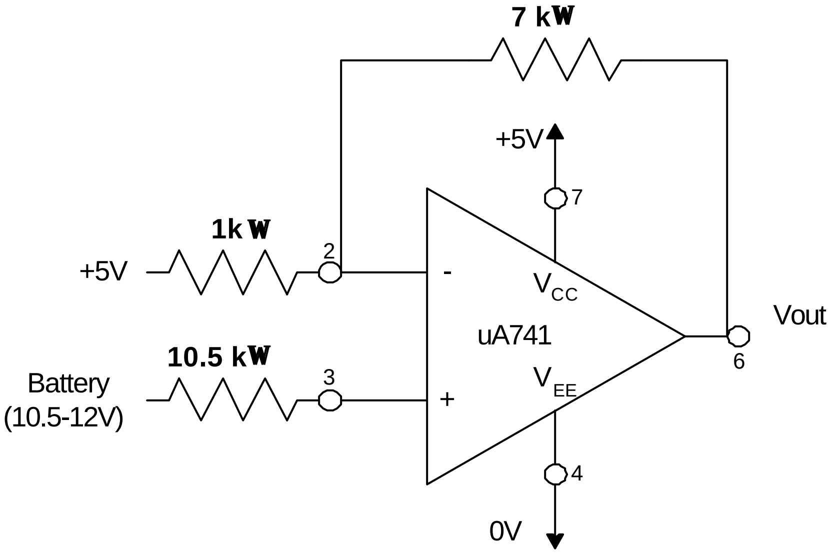


Figure 17: Battery Voltage Mapping Circuit

The PIC should sample this output value (which will be between 0-4V) once a minute. Once the battery charge becomes critically low (below 10%), the PIC will signal the motor to shutoff to prevent permanent damage to the batteries. The LCD will display an appropriate error message.

Note that the battery-charge reading will only be valid when the motor is in use (i.e. the battery is under normal load conditions). This is due to the following behaviour of the gel cells (which are 6 in series per battery):

A typical cell will show the following voltages:

Fully charged, open circuit, at rest with no charge/discharge for at least 12 hours	2.12 V/cell
As soon as load is applied (internal V-drop)	2.00
Fully discharged, under load	1.70
Fully discharged, open circuit	1.99
Beginning of charging	2.10
70% to 80% charge (gassing begins)	2.35
Full charge	2.65

4. Firmware Design

4.1. High Level Design

The firmware to be implemented on the PIC16F870 will be coded in Microchip's assembly language. A full list of the instruction set can be found in the corresponding datasheet.

4.1.1. System Design

An overall block diagram of the software is shown in Figure 18 (on following page).

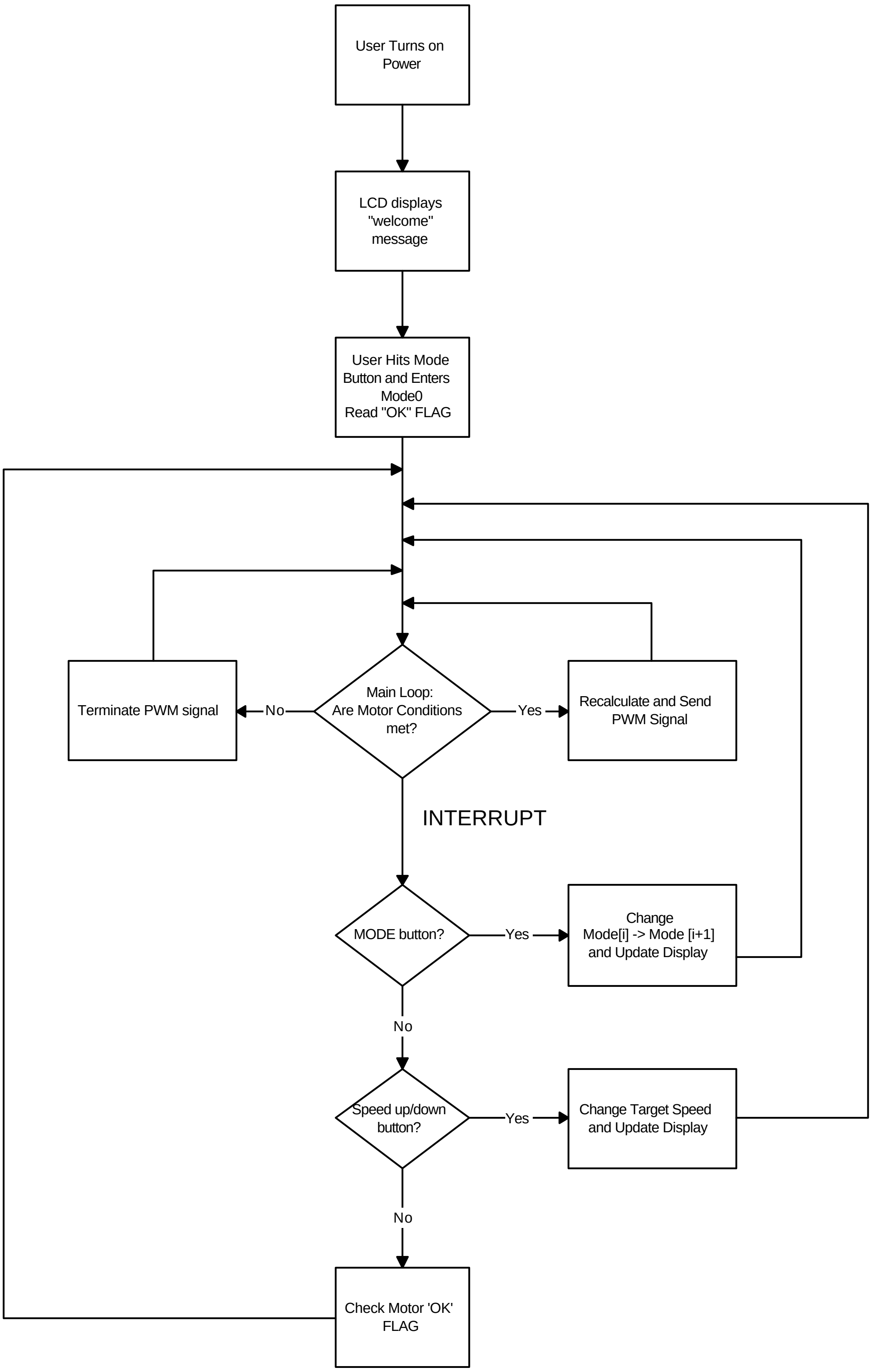


Figure 18: Firmware Block Diagram

4.1.2. UI Design

The user interface output will constitute the main loop of the program. The loop will begin by examining which mode the user is currently in and will display the corresponding information.

Table 4: Program Modes

Mode	Information to Display
0	Current and Target Speed
1	Total distance traveled
2	Battery Information

If the user is Mode 0, the current speed and the target speed will be displayed. The algorithm for calculating the current speed is given in section 4.2.3. Furthermore, anytime the user changes the target speed, the mode is set to 0.

Mode 1 relates to the user the total distance she has traveled since the microcontroller was turned on. Unfortunately, because the on board memory of the microcontroller is volatile, information is not saved after the microcontroller is powered off. This issue may be resolved by using non-volatile off-board memory.

Mode 2 provides the user with information about the state of the battery. As mentioned previously, the voltage range that the battery should experience is between 10.5 and 12 Volts for, respectively, an empty and a full battery. This voltage will be sampled by the on-board analog to digital converter and displayed either as a numerical percentage or as a bar graph. Also, when the battery charge level falls to a preset value, the LCD will display to the user a warning message and prompt the user to recharge the battery.

The other major component of the main body is the comparison of the current speed with the intended speed. The intended resolution of speed tracking is 3 km/hr. Thus, if the current speed is below the target speed by more than 3 km/hr, the microcontroller will cause the generation of a larger DC output to the motor.

In section 4.2 we describe the method for controlling the DC output and for handling the various safety checks required for the motor to become operational.

4.2. Low Level Design

4.2.1. Button Handling

There are three buttons that require attention from the microcontroller: The increase target speed button, the decrease target speed button, and the mode button. All three buttons will be directly connected to an interrupt and the interrupt handler will deal with each interrupt accordingly.

On the 16F870, the interrupts that the buttons will be connected to are PORT B pins 4, 5, and 6. Unfortunately interrupts of this nature all trigger the same interrupt handler. Therefore, each interrupt needs to be decoded via software. The method by which we will decode and handle the three interrupts is as follows:

1. Upon receiving an interrupt, disable all interrupts
2. Save working register
3. Read PORT B to determine which pin caused the interrupt

The interrupt handler that will control the mode will simply toggle the mode between the three possible states. The interrupt handler that responds to the increase/decrease button will increase/decrease the target speed respectively and change the mode to 0 so that the change is displayed to the user.

4.2.2. LCD Interface

As shown above in the description of the LCD, 11 inputs to the LCD are required to generate a character. Fortunately, we will only be writing to the LCD and this allows us to hardwire one of the input lines. For the other inputs, we will be using seven of the PORT C pins as well as PORT B pin 3 to write data to the LCD. (One of the PORT C pins is required for the pulse width modulator) For the enable and the data/instruction input, we will be using PORT A pins 4 and 5 respectively.

Setting up the LCD will occur upon power up and involves turning on the LCD, setting the cursor mode to "increase", and displaying the title screen. To write a character to the LCD, the cursor must first be set to the desired position. (This is accomplished using a separate function.) A character can then be displayed at the given location and the cursor is automatically incremented as per described in the setup.

4.2.3. Sensor Reading Conversion

The speed sensor output will be directly connected to the microcontroller and will act as an interrupt at PORTB pin 0. Upon receiving the interrupt condition, the handler will proceed to timestamp the interrupt. Also, because the distance traveled between two encoder pulses is approximately 82 inches (the circumference a 13-inch radius tire), a simply conversion will generate the current speed of travel where

$$\frac{\mathbf{0.0021km}}{\mathbf{time\_between\_two\_pulses}} = \frac{\mathbf{x\_km}}{\mathbf{3600}} = \frac{\mathbf{x\_km}}{\mathbf{hour}}$$

The total distance traveled can be calculated by multiplying the number of encoder counts * 0.00021 km/count. The total distance traveled will only be reported for the time period between the microcontroller being turned on until the time it is turned off (i.e. powering off the microcontroller will result in a resetting of the odometer.)

4.2.4. PWM Calculation

In order to control the output of the motor, a pulse width modulation scheme is used to control the DC voltage applied to the motor. On the 16F870, the output of the internal PWM is pin 2 of PORT C. We chose the period of the PWM to be 1 milli-second (20kHz frequency), as the MOSFET can support this frequency and it is outside human audible range. Furthermore, the 16F870 supports up to 10-bit resolution for the PWM. However, we don't believe that this degree of resolution is necessary and will therefore divide the PWM period into duty cycles of ten percent increments.

When the comparison is made between the current speed and the desired speed a flag will be set if the current speed is below the target. If this flag is set the PWM will increase its duty cycle by the ten percent step and the main loop will begin. This increase will continue until the current speed matches the target speed (±5 km/hr) Increasing the PWM at ten percent increments serves a dual purpose. Firstly it allows the controller to narrow in on the target speed in a linear manner. Other algorithms such as a binary search could be used, however the complications associated with them do not warrant their use. Secondly, the ten percent increments acts as a ramp function to prevent sudden increases in speed that may disturb the user.

If, during operation, the measured speed is greater than the target speed the PWM is required to turn off. When doing so, the present value of the duty cycle is saved and is reused when the speed falls 3 km/hr below the target speed. The 3 km/hr window acts to provide hysteresis to the system, which is desirable to prevent the motor from turning on and off if the bicycle speed is rapidly oscillating about the target speed.

There are three conditions that must be satisfied before the PWM signal is generated. Firstly, according to government regulations, the motor may not engage unless the speed of the bicycles is 5 km/hr. Secondly, neither brake must be applied. If the brakes are applied, a signal generated by the brake sensor will be passed to the microcontroller indicating to the controller that the motor must not be turned on. Finally, the kill switch that turns the motor on or off must be engaged. Again, having the motor control board send a signal to the microcontroller when the switch is engaged can easily check this condition.

5. Test Procedure

This section outlines the individual test plan for each design block. After the individual blocks pass these tests, we will begin system testing with the procedures outlined in the Functional Specification for the Ranger Electric Bicycle (see referenced documents [2]).

5.1. Hardware Test Plan

5.1.1. Sensors

1. Verify the output of the speed encoder and brake microswitches manually using +5V test voltage inputs and verifying the output with a voltmeter when the circuits are closed.

5.1.2. Board Connections

1. Verify connection of IC pins to socket and board
2. Verify components connections to board
3. Verify all connections match schematics
4. Verify resistor values are within 5% of nominal values

5.1.3. Power Levels

1. Verify individual circuit sections for correct output behaviour by selectively applying test signals.
2. Verify that the batteries used in the system are charged to between 10.5 - 12V, with 12V being ideal. (Recharge batteries if necessary.)
3. Turn on microcontroller, and verify this functionality by observing "welcome" message on LCD.
4. Verify voltage levels (carefully) to motor drive circuitry.

5.2. Firmware Test Plan

5.2.1. Mode Changes

1. Verify the ability to toggle between modes through the "mode" button, observing the result on the LCD

5.2.2. Mode 0

1. Verify the ability to increase and decrease the target speed by 5km/hr per button press, between 0-30km/hr, by pressing the interface arrow buttons and observing the result on the LCD screen while in Mode0.

5.2.3. Mode 1

1. Prop up the bicycle (where the back wheel is free to rotate without contact to any surface) and turn the motor, with the controls set to 10km/hr.
2. After 5 minutes, verify that the reported total distance traveled is approximately 0.83 km +/- 0.05km.

5.2.4. Mode 2

1. Simulate battery voltages between 10.5 - 12V, using an external voltage reference, to be applied to the subtractor-amplifier circuit which interfaces to the microcontroller.
2. Verify correct readings through the LCD output.

5.3. System Test Plan

Following these tests, provided all safety and functional tests pass, road testing may begin with a willing test subject, who is aware of all possible risks with this device, and who complies with Canadian laws with respect to road rules and the wearing of a helmet.

5.3.1. Speed Sensor

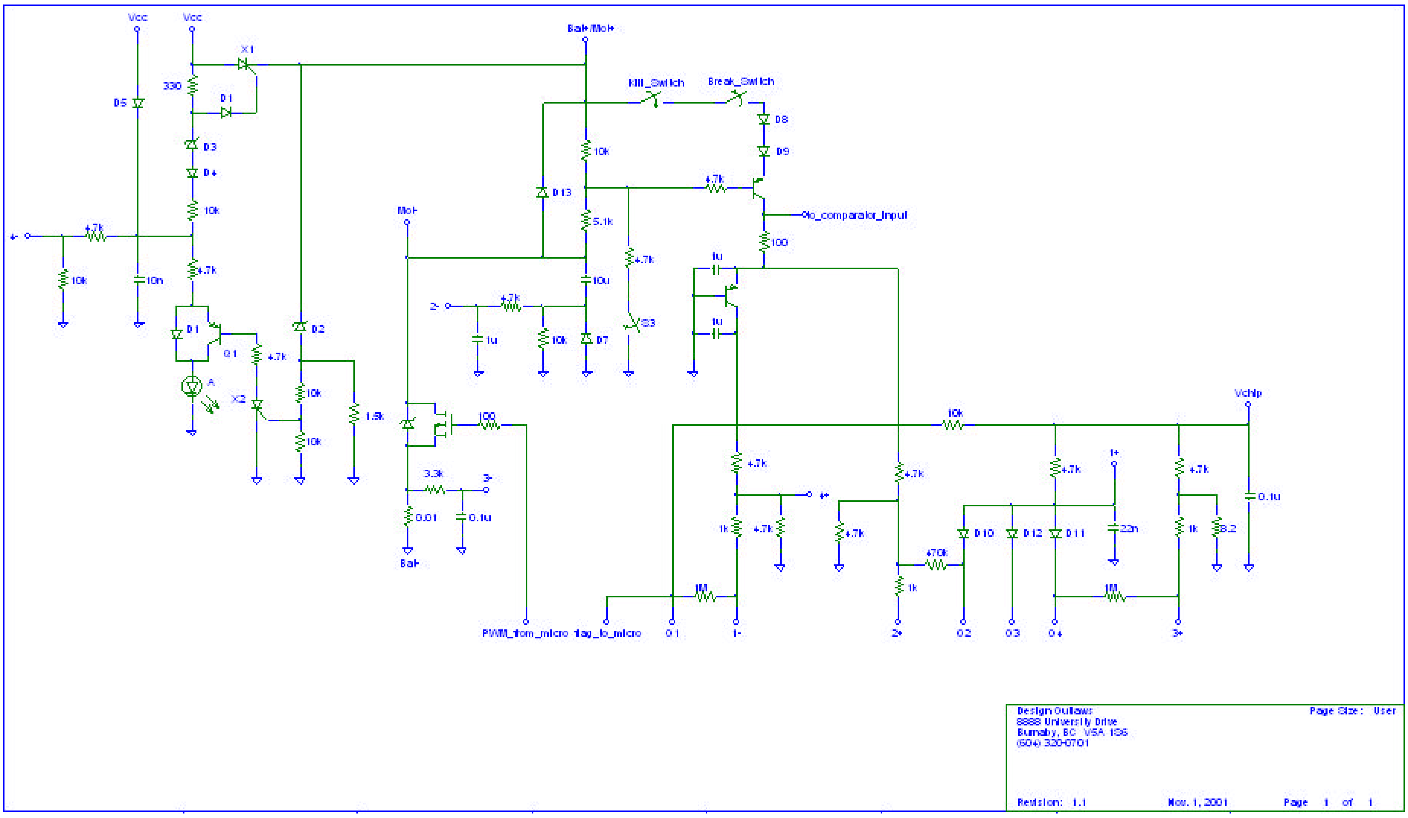
1. Prop up the bicycle.
2. Turn on the microcontroller, but leave the kill switch off.
3. Set the desired speed to 10km/hr.
4. Rotate the tire so that the reported speed is above 5km/hr. The motor should not turn on
5. Toggle the kill switch to 'on'. The motor should now turn on, and the tire should rotate at a rate that translates to 10km/hr, which is approximately 1 rev/sec.
6. Use an external pulse counting circuit to count the number of pulses generated by the speed sensor in 15 seconds and average this to determine the error in the maintained speed.
7. Verify the target speed vs. actual speed relationship for all target speed settings (which are in increments of 5km/hr).

5.3.2. Brakes

1. With the bicycle propped up and the motor in use, apply one of the brakes. The motor should turn off.
2. Repeat with the other brakes.
3. Repeat with both brakes.

Appendix A

Schematics


Vcc
Vcc
X1
330
D1
D5
D3
D4
10k
+-
4.7k
10k
10n
4.7k
D1
Q1
4.7k
D2
A
X2
10k
10k
1.5k
Bat+/Mot+
Kill_Switch
Break_Switch
D8
D9
10k
D13
4.7k
to_comparator_input
Mot+
5.1k
100
4.7k
1u
2-
4.7k
10u
1u
1u
10k
D7
S3
100
3.3k
3-
0.01
0.1u
Bat-
Vchip
10k
4.7k
4.7k
4.7k
4.7k
1+
4+
0.1u
1k
4.7k
4.7k
470k
D10
D12
D11
22n
1k
8.2
1k
1M
1M
PWM_from_micro
flag_to_micro
O1
1-
2+
O2
O3
O4
3+
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