Homework 6

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Group # 12

Brushless DC Scooter: System Test Plan

1.0 Introduction

This document serves to introduce and guide areas in the BLDC Motor Powered Scooter that require testing. The Scooter is comprised of a brushless motor driver connected to a 22.2V LiPo battery as well as a sensored motor, and these are mounted to a custom modified scooter, assembled from aluminum and connected to the motor via a geared belt drive. Elements that will require testing are the motor controller's speed control and feedback systems, ensuring it responds correctly to throttle input and reports correct speed, battery voltage and temperature information. The physical scooter assembly will require testing to see if it can withstand user weight as well as correctly being connected to the drive system. The entire system will need to be tested, ensuring that it meets range specifications given its battery capacity.

2.0 Documentation

2.1 BLDC Scooter System Specification

The scooter must adhere to the following requirements:

- The vehicle must be capable of moving a full sized adult a constant speed of at least 6 miles per hour
- The motor controller should work efficiently enough so that you can travel more than 2 miles with 133 watt/hours of battery
- The vehicle should be able to transmit relevant driving information to the rider such as speed and battery voltage.
- The final vehicle including the motor, motor controller, scooter base and battery must be less than $300.

2.2 BLDC Scooter Block Diagram

The motor controller acts as the brain and the muscle for the system, energizing the motor's power coils based on its position given by the hall effect sensors, with a speed determined using PID control and the scooter's throttle. The motor controller using pwm will fire the power mosfets to move the motor. The controller is capable of giving debug information such as speed, battery voltage and board temperature.

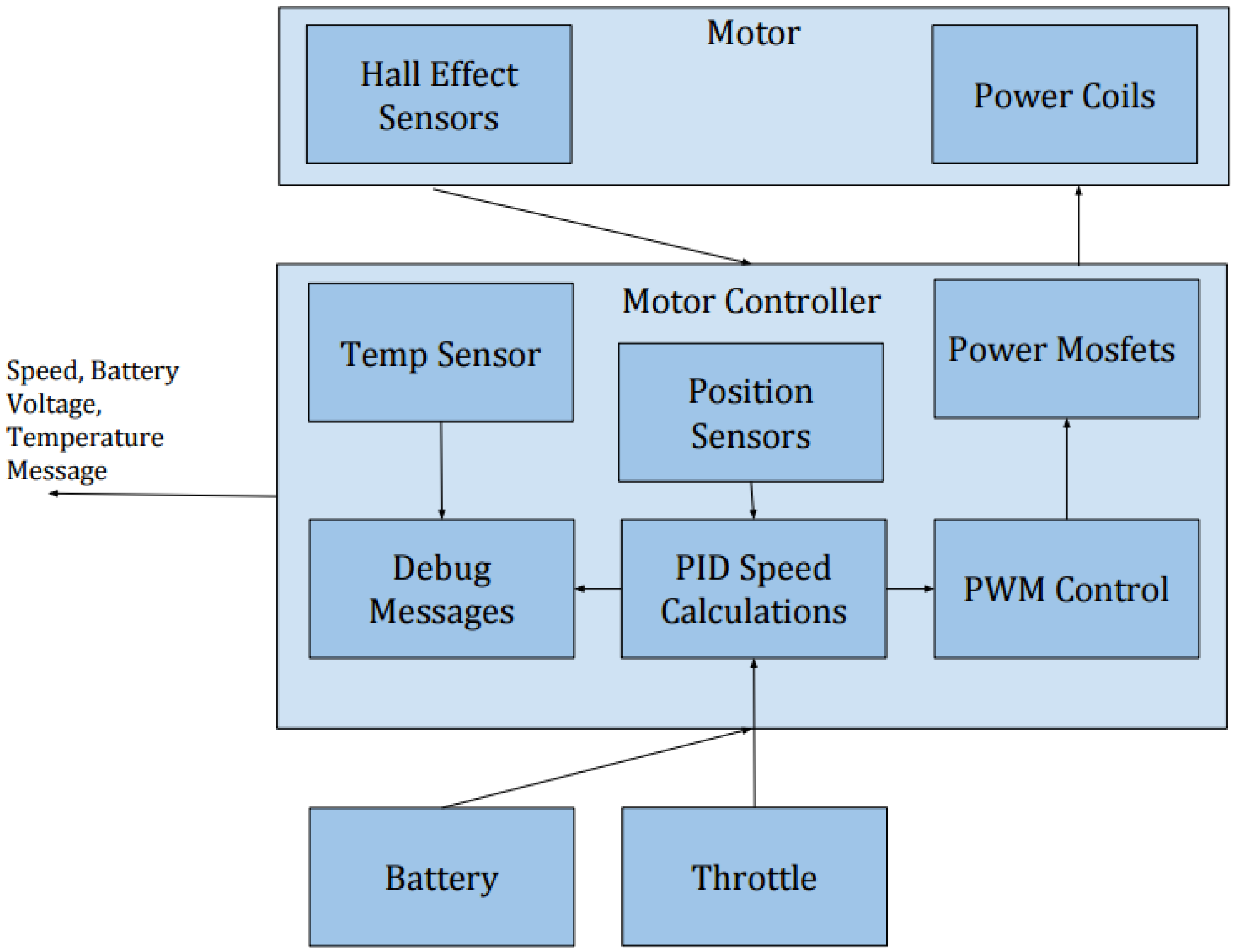

Fig. 1: System Block Diagram

2.3 BLDC Scooter Motor Controller Schematic

- *BLDC Motor Controller Schematic.pdf*

2.4 BLDC Scooter Control Algorithm

- *Brushless DC Motor Scooter.pdf, Concept detail, Microprocessor Control Code*

2.5 Applicable Oregon Electric Bicycle Regulations

In Oregon, there are regulations for any “power assist pedal bicycle”, which while technically does not apply to us, has potentially relevant regulations should other forms of power assisted vehicles come to market. We should be aware of the regulations in place pertaining to motor power as well as vehicle speed in particular. Oregon states under ORS 801.258 that the vehicle does not exceed a power output of 1000W, and that the vehicle does not exceed 20 mph on level ground. Both of these can be regulated in software, as the motor controller calculates speed. The speed can be regulated to less than 20 mph if needed, and similarly our power output can be regulated by reducing our average current to the motor using pulse width modulation.

3.0 BLDC Scooter Overview

3.1 Operational Description

Attach an electric motor to either an existing or manufactured kick board scooter for use as a personal electric vehicle. The vehicle must be capable of moving a full sized adult a constant speed of at least 6 miles per hour. The motor controller should work efficiently enough so that you can travel more than 2 miles with 133 watt/hours of battery
The vehicle should be able to transmit relevant driving information to the rider such as speed and battery voltage. The final vehicle including the motor, motor controller, scooter base and battery must be less than $300.

3.2 Motor Speed Control

The electric BLDC motor is attached to a small PCB equipped with a microprocessor, which functions as the speed controller. There are two segments on this board. The right half of the board contains the BLDC circuit arrangements of mosfets and resistors, and the left half contains an Atmega328P 8 bit microprocessor which functions as a controller. It takes input from the throttle and converts that into a value which corresponds to correct sequence of MOSFETS that must be fired in correct order to move the motor. The power for this circuit is delivered by a 22.2V LiPo battery pack mounted nearby, in the motor assembly.

3.3 Motor Speed Calculation

The motor speed is classified in our case as rotations per minute (RPM), and is calculated by monitoring the motor's changes in state. The motor will change its phase a total of 45 times in a full rotation, so the changes in phase are counted to 45 and then the rpm is taken by measuring the time taken to make the full rotation. For conversion to miles per hour, the rpm will be multiplied by the gearing ratio (15: 50) and then multiplied by the circumference of our wheel.

4.0 Pretest Preparation

4.1 Test Equipment

- Tachometer
- Measured 2 mile long distance
- Computer with a type A USB port and some form of tty terminal.
- 6 cell LiPo capable battery charger.
- Thermometer capable of measuring PCB temperature.
- Oscilloscope Tektronix
- True RMS Multimeter
- Atmel Studio IDE
- AVR Dragon Programmer

4.2 Test Setup and Calibration

For measurements involving distance the scooter will need to have level terrain and a pre measured 2 mile distance. The distance does not have to follow a straight path if need be.

For measurements involving verifying board readouts, such as temperature or speed, the on board sensors will require a calibrated thermometer and tachometer to check against the board tachometer and temperature sensor.

5.0 Unit Tests

5.1 Temperature Report

Monitor and record the operating temperature of controller circuit board. Using the included on board temperature sensor, confirm that the temperature is accurate to the RPM readings. The purpose of this report is to confirm the accuracy of the temperature sensor, and verify it functions properly.

5.2 RPM Report

Monitor the RPM status message output from the motor controller and verify that it is accurate to +/- 5%. The speed will be provided in the form of RPM, and should be compared with a calibrated tachometer to verify that the speed report is correct and functions properly.

5.3 Correct Logic Level

Test correct logic level outputs from microprocessor and verify all possible logical sequences are producible and are valid. This logic level is critical to our system because they will control the mosfets which will send power to the motor through various cycles and speed. Without correct logic levels our controller will not work. Logical levels will be 5 volts +/- .3V.

5.4 Software Control

Test that the uploaded program code is working correctly. The easiest way to do this is to connect to the output port and verify you are receiving accurate debug rpm, temperature and battery voltage measurements. This can be done by checking the battery voltage readout with the battery voltage using a multimeter. To check that the software is correctly working at controlling the mosfets, check the voltage of the test pins provided on the board to ensure that the processor is outputting the correct pulse width values on the correct pins by applying throttle while the motor is unplugged.

5.5 Logic level switching MOSFET Check

Test correct voltage output on mosfets. This test is to make sure each mosfet outputs the correct voltage value for each of the six possible combinations inputs. This will make sure our mosfets are working correctly and corresponds to the logic inputs. All measurements will be measured via multimeter and looked up on our table of inputs/outputs.

5.6 Power MOSFET Check

Test correct voltage output on mosfets. This test is to make sure each mosfet outputs the correct voltage value for each of the six possible combinations inputs. This will make sure our mosfets are working correctly and corresponds to the logic inputs. All measurements will be measured via multimeter and looked up on our table of inputs/outputs.

5.7 Voltage Regulator

This test will check if the voltage regulators will output the correct stepped down voltages. Main power will be from a 24 volt battery and the voltage regulator will step the voltage down to 15 volts and the second voltage regulator will step the 15 volts future down to 5 volts. This will give us two rails different voltages to use. The 15 volts to drive the power MOSFET's and the 5 volts to power our processor and logic level mosfets. This test will look at the voltage outputted from each regulator.

5.8 Reset Button

Test the reset function of the processor. This test is to make sure the rest button is function correctly. To test this we will press the button and confirm that the program that is currently running on the microprocessor will be reseted.

5.9 Hall Effect Sensors

Test the hall effect sensors on the motor. This test will connect the hall effect sensors from the motor to our board, from there we will check if all possible 6 positions are detected and read properly to our processor. This test is key to our system, without the current position of the motor there would be no way to move the motor correctly.

5.10 Potentiometer for Throttle

Test the throttle handle on our scooter. This test makes sure the throttle outputs a mapped value of 0-255. This is key to controlling how fast the motor will spin. The 0-255 values will be used to control the PWM of the circuit thus changing the power. Make sure in rest position of throttle it outputs a 0 and as we turn it to maximum it will linearly increase to 255 where the handle will max out.

5.11 PWM Outputs on Logic Levels

This test will check the PWM logic outputs onto our logic level mosfets. Use oscilloscope to confirm the duty cycle and frequencies of each pulse width output. This test will make sure our power control on the motor will work correctly because the system uses PWM logic levels to control the amount of power to the motor.

5.12 ISP Programmer Port

This test will confirm if the ISP programming port is working properly. The ISP programming port is very important. If the port does not work the microprocessor cannot be programmed. Will be using AVR Dragon Programmer to test this port. If chip is programmable and detected, unit test success.

5.13 USB Port Pins

Test will confirm if USB port pins are working. Will be tested using serial cable, if serial data is sendable and receivable, this verifies serial port works. This is significant to our program debugging software.

5.14 External Clock

Use Oscilloscope probe to verify correct 16 MHz frequency. This will be important for serial communication.

5.15 Brushless Motor

The Brushless DC motor used is a 2 HP motor around two inches in diameter and 3 inches in height. The three hall effect sensors attached provide info on the positioning of the motor while undergoing a full revolution. There are six stages in a revolution. Test each stage and map them by using arduino programmer. Mapping each stage by comparing to BLDC control graph will also allow mapping of the correct MOSFET output.

5.16 Li-Po Battery

Test Voltage and current on LiPo battery via multimeter. Make sure battery is in good health and chargeable. Will be using Li-Po charger to check battery status.

5.17 Power Status LED

For programming and also to verify system state, This LED should receive power through 5V input. When this LED is on, the system is on.

5.18 Atmega 328p

This tests will confirm if the microprocessor chip is working or dead. Will connect microprocessor chip to AVR Dragon Programmer, if chip is detected then it will pass the test. Will also check each solder joint on the chip to confirm no bridging of any solder joints.

5.19 Gears of Drive Train

Test efficiency of drivetrain. Motor Assembly requires two gears, one driven by motor and another directly attached to rear wheel. Belt should be tight with no slack over the gears. Belt must withstand operational conditions of friction, heat, longevity. Belt must not fracture / break at full motor operational speed.

5.20 Motor Mount

Test placement and strength of motor mount within motor assembly. Motor mount should have proper spacing for mounting, and the thickness of metal shall be sufficient to withstand any vibrations/operational conditions that may occur.

6.0 Integration Test

6.1 On board controller to BLDC circuit

After verification of BLDC circuit functioning with Arduino code, and after programming on board controller component, connect output pins of board controller to the input pins of BLDC. The controller should function identically to the arduino run code, powering the BLDC motor efficiently but without the complex arduino connections.

6.2 Battery to motor controller

After successful test of motor controller with Bench power supply, test successful operation of Motor controller and the corresponding BLDC motor while connected and powered by 11.2 V and 22.2V battery. The differences in current require that the circuit not short or overload, damaging components.

6.3 Throttle to motor controller

Having mapped our hall effect states, with arduino code the motor can only be run at one set speed with the firmware. This test will take the potentiometer / throttle and connect the power, ground, and input to the arduino. Map the inputs in firmware to test speed control. Motor should speed up and slow down proportional to the position of the throttle.

6.4 Motor Assembly On Scooter

After verifying motor assembly functions, and construction of scooter chassis capable of receiving motor assembly, confirm fit and finish and that the assembly functions identically on scooter compared to outside of scooter.

7.0 System Test

7.1 Motor Speed Control

Confirm that the scooter's motor speed responds proportionally to the throttle on the scooter. This should be done by attempting to speed the scooter quickly along the motor's power curve, and similarly it should be done slowly, by following the motor's efficiency curve.

7.2 Scooter Assembly test

Confirms that the scooter assembly is structurally capable of supporting the weight of a human plus some cargo such as a backpack. For this test, the tester should place about 220 pounds of force on the board spread over the area of a typical adult human foot. The custom wheel assembly must remain tight with no issue.

The motor should be coupled with a belt to the scooter. When the motor wheel spins, the belt should drive the motor with no slipping and visa versa.

8.0 Operational Acceptance Test

8.1 Motor Speed Test

Test Case Name: Verify Motor Speed			
Description: Checks that the on board motor speed calculator is accurate, giving accurate results that can be used to calculate vehicle speed. This is not a vehicle speed test.			
Setup: Motor assembly detached from scooter, no belt required. Test should be run on a workbench with tachometer.			
Step:	**Actions:**	**Expected Result:**	**Comments**:
1:	Connect to the processor over the provided USB connection and open the corresponding ttyUSB or COM port.	The reported rpm by the processor should be 0 rpm until the motor is spun.	
2:	Spin the motor using the throttle through a range of speeds , beginning at stopped (0 rpm) to it's maximum speed (650 rpm) and measure the rpm of the motor using a tachometer, comparing against the rpm readout over USB.	The rpm readout over usb should now be equivalent or within 5% of the tachometer reading.	
3:	Bring the motor to a stop, get a final rpm reading and disconnect the usb port and unplug the battery.	The motor should return to 0 rpm and the board should now be powered down.	
Overall test result:			

8.2 Motor Startup Torque Test

Test Case Name: Motor Startup Torque Test			
Description: Measure that the torque is sufficient to move the weight of a full sized adult. plus the entire weight of the vehicle. Purpose is to determine whether torque is suitable, not finding discrete torque values in lb-ft. The scooter is allowed to fail this test, as it was not a part of the original design requirements.			
Setup: Place a full sized adult with known weight close to 180 lbs on scooter, start scooter at rest.			
Step:	**Actions:**	**Expected Result:**	**Comments**:
1:	Place test load on vehicle, 180 pounds on vehicle, To simulate human passenger.	The motor should move full weight from starting velocity of 0 m/s	
Overall test result:			

9.0 Parametric Test

9.1 Overall Scooter Range / Battery Charge

Test Case Name: Battery Range Test			
Description: Measure the range and overall power consumption of the included 22.2V battery. The aim is to set several fixed distances and determine whether the battery can power the scooter for the entire distance.			
Setup: Charge battery fully, for a 22.2V 133 watt/hour LiPo battery, fully charged will be 25V. Scooter should be ridden with a full sized adult for duration of test.			
Step:	**Actions:**	**Expected Result:**	**Comments**:
1:	Startup and mount vehicles, start accelerating to 20 mph and maintain speed.	Scooter should be able to accelerate passenger to top speed of 20 mph.	
2:	Maintain speed of 20 mph for 2 miles with less than 50 feet	The scooter should maintain the top speed of 20mph for the entire	

	of elevation gain or decline while allowing the motor controller to handle cut off voltage (if applicable).	duration of the 2 mile ride. The scooter will cut off power once the battery reaches 18V, our depleted charge voltage.	
Overall test result:			

10.0 Stress Testing

10.1 Motor Stress Test

Test Case Name: Motor Stress Test			
Description: Measure the durability of the motor. In comparison to range test, this case is testing the durability and performance of the BLDC motor in running continuously. The circuit components should maintain normal operating temperature and the motor should be able to run.			
Setup: Charge battery fully, fully charged will be 25V. Use device with rolling resistance, either a treadmill or proper dynamometer. Position scooter so it remains upright without human assistance.			
Step:	**Actions:**	**Expected Result:**	**Comments**:
1:	Place load on Scooter, on device that provides rolling resistance, like treadmill or Dynamometer. Set and hold throttle to max speed, run this scooter for 20 minutes.	Motor should run continuously for the duration without failure or overheating of any component.	
2:	Suspend scooter so that wheels do not touch ground, ie no resistance, no load on scooter. Set and hold throttle to max speed, run for 30 minutes	Motor Should run continuously for the duration without failure or overheating of any component.	
Overall test result:			

11.0 Alpha Testing

11.1 Alpha test for scooter

Test Case Name: Scooter Alpha Test			
Description: Have each team member to test scooter by riding around campus			
Setup: Completely build scooter, get rider to test			
Step:	**Actions:**	**Expected Result:**	**Comments**:
1:	Get on scooter and ride around at various speeds.	Scooter moving at 5 - 10mph. Change speed via throttle on handle	
Overall test result:			

12.0 Environmental Testing

12.1 Scooter environmental conditions

Test Case Name: Scooter Environment Test			
Description: Run scooter is hot, cold and wet environments			
Setup: Build final version of scooter thats ready to be ridden			
Step:	**Actions:**	**Expected Result:**	**Comments**:
1:	Use scooter in the Rain	Runs like normal, should not stall or fall apart. Should not short circuit.	
2:	Use scooter in freezing temperatures	Runs like normal, should not freeze up.	
3:	Use scooter in hot temperatures	Runes like normal, should not overheat and shut off.	
Overall test result:			