Electric Longboard Safety Suite

ECE 445 Project Proposal - Spring 2021

Project # 17

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I. Introduction

1. Objective

Electric Skateboards and Longboards have skyrocketed in popularity for personal transportation in urban cities and towns. Their nimble and speedy characteristics allow users to easily navigate long distances of congested vehicle or foot traffic, yet are small and lightweight enough to be carried around indoors. Despite their value as a useful transportation and recreational tool, it is clear from the relatively simple motor and user interface designs that nearly all consumer electric longboards lack seemingly paramount safety features.

To begin, no consumer electric longboard attempts to discern whether the user is physically on the longboard or has jumped/fallen off. This allows for highly dangerous scenarios where a user falls off the electric longboard while inadvertently maintaining the throttle; having lost the weight and control of the user, an electric longboard may rapidly accelerate out of control, possibly towards pedestrians. Next, no consumer electric longboard includes mechanisms that attempt to mitigate wheel-slip, which commonly arises due to the wheels having imprecise contact with the ground or the user inputting too much acceleration or braking throttle. Wheel-slip is a significant safety risk as it dissolves the user's control of the board. In severe cases, wheel-slip may entirely upset the balance of the user, causing him or her to fall off - risking an injury. To remedy these safety concerns, we wish to implement a two-fold plan. First, we will integrate weight sensors within the deck and/or trucks of the longboard. Second, we will develop and utilize wheel-revolution sensors across each of the four wheels. From there, we will then use that sensor data to identify whenever wheel-slip or user-ejection has occurred; when it is identified, we will interface with the motor controllers to reduce motor power to the responsible wheel(s) appropriately.

2. Background

In the electric skateboard industry today, very few safety features are used, if at all. The most important among those features is a "dead man switch", or a button on the remote control that the user must press at all times in order to engage the motors. This button is intended to cut off motor power if the user drops the remote or falls off of the board. However, if the user happens to hold the dead man switch while falling off - which is entirely possible in the shock of the moment -

this feature will not prevent the board from accelerating out of control. We believe a more robust solution is one that automatically senses when the user has ejected himself from the longboard, regardless of any other user input. That way, the board will not be allowed to accelerate without a user actively riding the longboard.

Furthermore, the motor control design of consumer electric skateboards is arguably too simple. Nearly all electric skateboards power the rear wheels with individual motors, but the throttle control given to the user via the remote applies power to both wheels identically. While suitable for most straight-line, even-terrain travel, this design does not properly account for uncertain conditions - such as uneven terrain, harder turning, or extreme acceleration/deceleration. As aforementioned, this wheel-slip can easily cause users to lose control of the electric board and can result in injury to both the user or to passerbys. While the statistics of electric longboards have not been formally studied, in the similar case of electric bicycles (another, more popular form of personal electric vehicle), 31% of accidents were a result of wheel-slip [1] - the most common among accident types by far as seen in Figure 1. Instead, we want to actively monitor the rotational speed of every wheel to calculate whenever wheel-slip is occurring. If wheel-slip does transpire, we will reduce the torque applied to the failing wheel.

Categories predefined in the questionnaire	n	%
Skidding (e.g. on wet leaves, ice, gravel), excluding skidding on tram line	200	31%
Crossing a threshold (e.g. pavement, kerbstone, bump, change of surface)	114	18%
Getting into or skidding on a tram/railway track	81	13%
Evasive actions (e.g. other road users, pothole, object on the lane)	73	12%
Collision with an obstacle on the lane (e.g. object, pothole)	36	6%
Slipping off pedals or getting caught in the e-bike	32	5%
Not aware about the reason of falling	25	4%
Running off lane (for other reasons than due to evasive actions)	17	3%
Don't know/not specified	4	1%

Figure 1: E-bike Accident Mechanisms

3. Visual Aid

All commercially available electric longboards utilize remote controllers as their user interface design. For our project, we will not deviate from this, as seen on label A in Figure 2. Our board

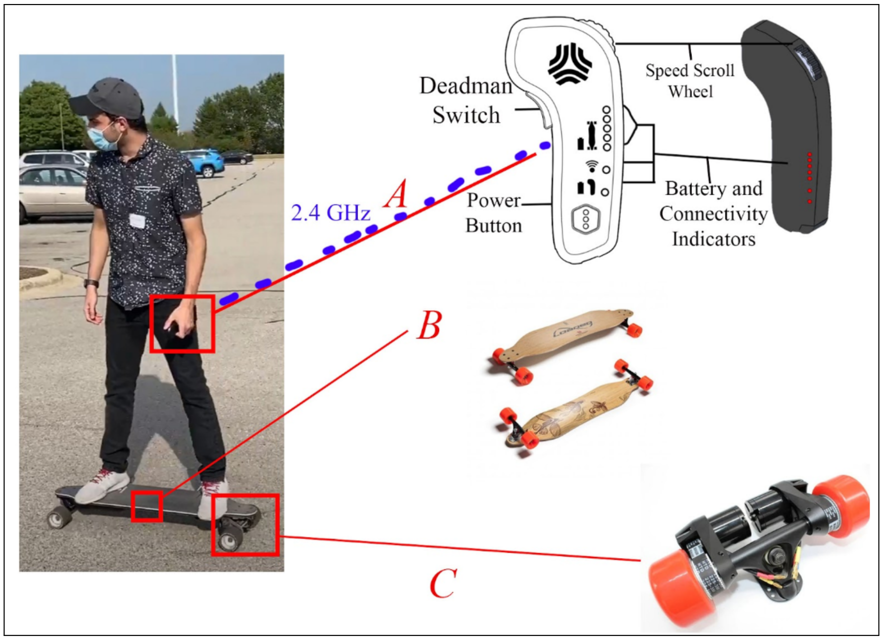

Figure 2: Visual aid of assembly of an electric longboard

microcontroller will receive user throttle input from the remote via 2.4GHz RF signal, in addition to a input from a dead man switch as described above, such that if the button is released, motor power is disengaged.

On a fundamental level, our longboard starts as a basic, non-electric longboard, including a wooden deck, skateboard trucks, and urethane wheels. This is seen as label B on Figure 2. This establishes the fundamental control for the user, as he or she will stand upon the longboard and turn by leaning in the corresponding direction.

Then, to begin the conversion of our basic longboard into an electrically powered one, we will then attach the following specifically to the rear trucks and rear wheels: motor mounts, brushless outrunner motors, and a belt & pulley system. This is seen as label C on Figure 2.

After all the important physical components are installed, we will complete the installation of the electronic components to the longboard, which include the batteries, electric speed controllers, safety microcontrollers, wheel/rotational speed sensors, and weight sensors.

4. High Level Requirements

In order for our project to be successful, our safety suite must fulfill the following:

1. Our electric longboard is able to sense when the weight atop the board is significantly less

than that of a normal user (a threshold value of 70 pounds). If the weight sensed is below the threshold for a second or more, motor power is reduced to a maximum speed of a typical walking pace.

2. Our electric longboard is able to measure the rotational speed of each wheel on the longboard, whether they are powered or unpowered.

3. Our electric longboard is able to calculate whether one or both powered rear wheels are exhibiting wheel-spin based on their rotational speed measurements. When detected, our electric longboard will reduce motor power to the failing wheels until the wheel-spin is mitigated.

II. Design

1. Physical Design

For the front wheel RPM sensing, we will attach a magnet to the inside of the wheel and secure a Hall Effect sensor to the truck, pointing at the wheel. As seen in Figure 3 on the left, when the magnet passes by the Hall Effect sensor, the Hall Effect sensor detects the magnetic field and outputs “HIGH”. In Figure 3 on the right, when the magnet not by the Hall Effect sensor then the output will be “LOW”.

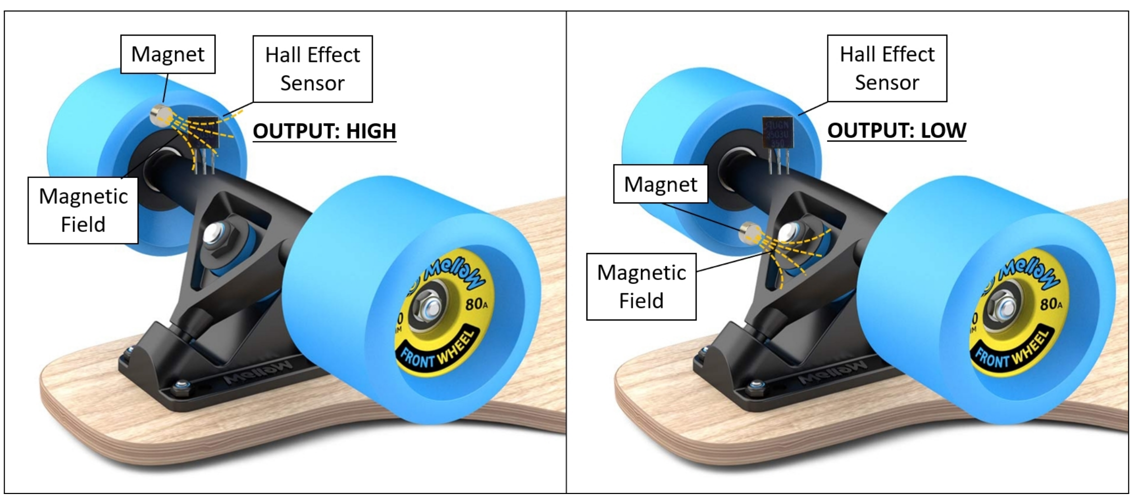

Figure 3: Assembly for front wheel RPM measurements with a Hall Effect Sensor

For weight detection, we will put a pressure sensor in-between the front/back trucks and the bottom of the deck. When there is someone on the board as seen in Figure 4 on the left, the user's weight will be distributed to the front/back trucks, strongly compressing the sensor in between the deck and the board. When there no one is on the board as seen in Figure 4 on the right, only the weight of the deck (negligible to a person) will distributed to the front/back trucks, minimally compressing the sensor in between the deck and the board. If necessary we will use risers in between the trucks and the deck to adjust the pressure threshold.

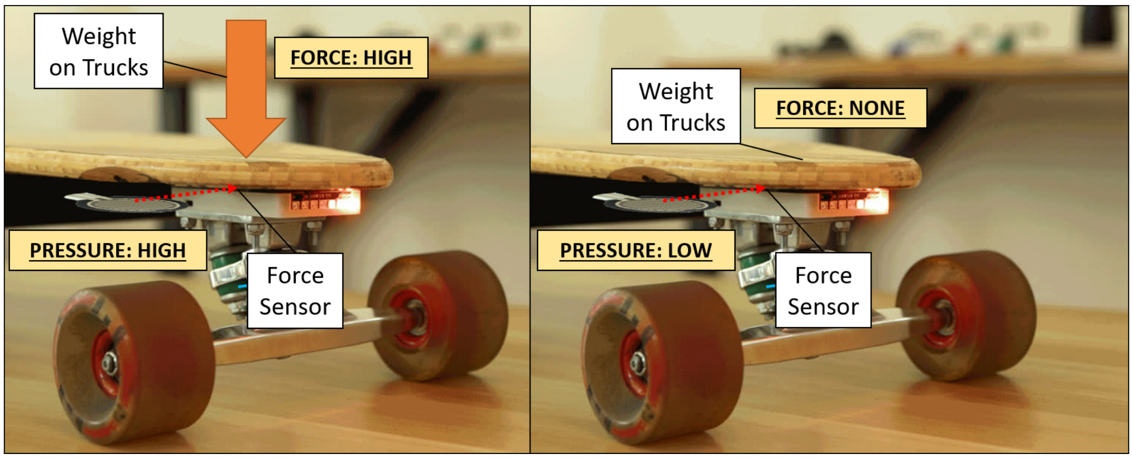

Figure 4: Assembly for weight detection on board using pressure sensor

2. Block Diagram

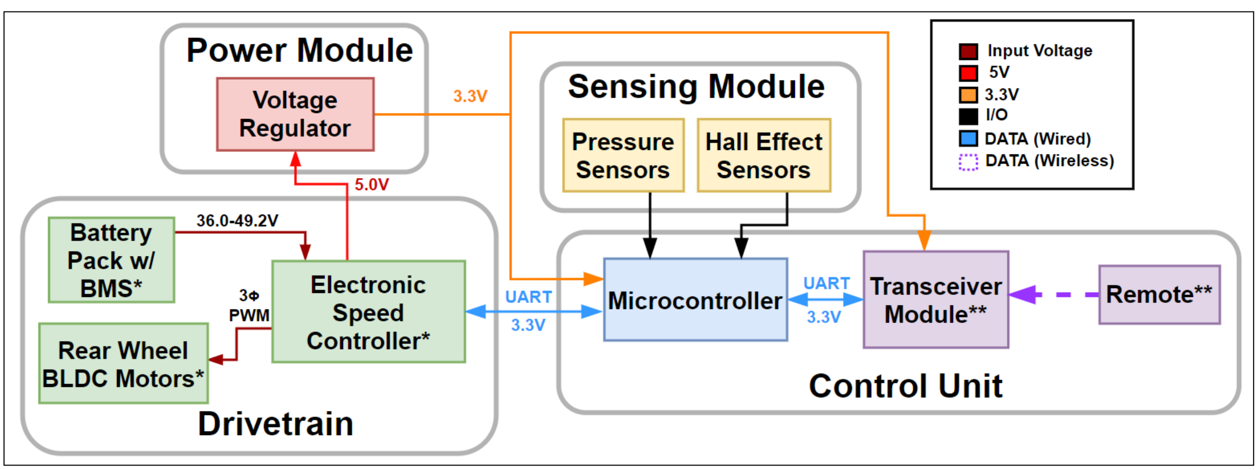

Figure 5: Electric Longboard Safety Suite block diagram. (*) Denotes commercial Electric Longboard Parts. (**) Denotes part necessary for board control but not specific to Safety Suite.

3. Functional Overview & Block Diagram Requirements

i. Sensing Module

The sensing unit will be responsible for gathering information regarding the amount of weight on the board and the angular position of the front wheels. The pressure sensors are essentially force-sensitive resistors – when the pressure on them increases, their resistance decreases [2]. We will put this variable resistor in series with a pull-up resistor to form a voltage divider circuit between VCC and GND. We can calculate the resistance of the pressure sensor based on the voltage drop across it. The type of Hall Effect sensors we will be using are Hall Effect Switches, as these indicate "the presence or absence of a magnetic flux density compared to a defined threshold" [3]. When the Hall Effect sensor is close to the magnet on the wheel, there will be a presence of a magnetic flux density above the defined threshold, outputting logical "HIGH". When the Hall Effect sensor is away from the magnet on the wheel, there is an absence of a magnetic flux density which is below the defined threshold, outputting logical "LOW".

Table 1: Pressure Sensors – Requirements

Requirements
• The pressure sensors will decrease in resistance as the force applied to them increases, and based on assembly the resistance curve must not saturate before the equivalent of the weight threshold of a person, 70lb, is applied.

Table 2: Hall Effect Sensor – Requirements

Requirements
• The Hall Effect sensors must send a digital HIGH or LOW signal that will determine whether the magnet-covered portion of the front wheel is adjacent to the hall effect sensor. • The Hall Effect sensors must exhibit hysteris behavior: Once the magnetic field strength crosses the "High" threshold, the sensor will output HIGH, and it will hold this value until the magnetic field strength threshold crosses the "Low" threshold, where the sensor will switch the output to LOW. • The Hall Effect sensor output must go from LOW to HIGH exactly once per revolution of wheel.

ii. Control Unit

The Control Unit is the central system of the whole Longboard Safety Suite. Firstmost, the microcontroller must retrieve the sensor values which include the two front wheel Hall Effect sensors, and the two board pressure sensors. It must also retrieve the two real wheel motor RPM measurements from the Electronic Speed Control and the remote inputs (throttle wheel, dead man switch, etc.) from the transceiver. Second of all, it must convert all sensor voltage readings into usable values such as front wheel RPM and board pressure in pounds. Third, it must determine algorithmically whether wheel slip has occurred and detect when the user has not been on the board for a threshold of time. Fourth, whenever there is a wheel slip or user ejection event, the microcontroller must determine the course of action for adjusting motor speed to regain traction or slow down the board respectively. Lastly, the control unit must send motor speed information to the Electronic Speed Controller.

Table 3: Microcontroller – Requirements

Requirements
• The microcontroller must be able to convert pressure sensor voltage readings to equivalent force in pounds and based off this value detect whether the the threshold of the user being on the board has been met, 70lb ±10%. • The microcontroller must be able to detect any change in state of the front wheel Hall Effect sensors outputs via interrupts or polling. • The microcontroller must be able to calculate front wheel RPM based off of Hall Effect sensor readings with a margin of error of less than 10%. • The microcontroller must recalculate board pressure and wheel RPM readings every <250 ms. • The microcontroller must be able to detect whether wheel spin has occurred based on an algorithm using front and rear wheel RPM data. • The microcontroller must be able to calculate what reduction to motor speed needs to me made in order to recover from wheel slip to regain traction (within 3 seconds) or to slow down the board quickly when the user has not been detected on the board (for over 1 second). • The microcontroller must be able to communicate serially with the Electronic Speed Controller to send and receive data. • The microcontroller must be able to communicate serially with the transceiver to receive remote input data.

iii. Power Module

The Electronic Speed Controller provides regulated 5V output, but for our purposes we will to a 3.3V supply. First of all, the Electronic Speed Controller communicates via UART with 3.3V logic levels. Additionally, even though the nRF24L01 is 5V input signal tolerant, it still requires a 3.3V supply [4]. To avoid extra complexity of using 5V to 3.3V level shifters, we will operate all logic levels at 3.3V. This will require us to operate the ATmega328p at 3.3V, which still falls between the required supply voltage range of 2.7V to 5.5V [5]. We will be using a switch-mode power supply as opposed to a linear regulator as we can achieve efficiencies of over 90%, as opposed to a linear regulator efficiency of 66% calculated in Equation 1 [6]. Since we are only stepping down the voltage, we will be using the Buck Converter topology.

$$\eta_{LR} = \frac{V_{out}}{V_{in}} = \frac{3.3V}{5V} = 66\% \tag{1}$$

Table 4: Board Voltage Regulator – Requirements

Requirements
• Must be able to take an input voltage of 5V ±5 % and regulate it to regulate it to 3.3V ±5%
• Must be able to supply output current of at least 100mA.

iv. Drive-train

The Drivetrain is responsible for controlling power delivery to the to the motors, and consists of commercial parts used in DIY electric longboard builds. This includes the battery pack which is responsible for providing power to the Electronic Speed Controller, with charging monitoring and cell balancing from the Battery Management System. The Electronic Speed Controller delivers 3-phase PWM output to the brushless DC motors, in which the motor power is set based on control signals from the board microcontroller.

4. Commercial Component Selection

i. Rear Wheel Motors

For our electric skateboard build, we will be using 6354 brushless DC outrunner motors with integrated Hall Sensors. We chose this specific motor as it had the shortest width, while maintaining the motor power/capability that we felt was necessary for powering our electric longboard. The integrated Hall Sensors will be used to determine RPM of motor.

ii. Electronic Speed Controller

For our Electronic Speed Controller, we will be using dual ESC's based on Benjamin Vedder's open-source electronic speed controller project. The designs for both the hardware and MCU firmware are open to the public. We chose this for our project, as they are the most common for personal electric skateboard builds, and they offer us the flexibility to modify the firmware to our needs, if necessary.

iii. Board Battery & BMS

For our battery, we chose to custom build our battery using 18560 Samsung 30Q cells in a 12 x 2 format. We chose this as was the most economic blend of capacity, nominal voltage, discharge rate, and size. Additionally, we chose an LLT Smart BMS to protect our battery, as it comes integrated with a bluetooth module, allowing us to monitor the parallel group voltages and configure its charging/balancing behavior.

5. Risk Analysis

The nature of riding electric skateboards is inherently dangerous, and requires a skilled, attentive operator at high speeds. Nearly every subsystem of the electric longboard is integral to upholding the safety of the user; focusing specifically on those components which we aim to build ourselves, the most important is the main microcontroller. It is ultimately responsible for directing the throttle of the electronic speed controllers, which in turn direct the powerful motors. If our microcontroller fails to perform this duty properly, control of the longboard is lost, potentially leading to serious bodily harm to users or pedestrians. To reduce this risk of injury, we will incorporate the following safety principles into our design. Should the wireless connection to the remote control fail, our microcontroller must disengage the motors entirely - not braking, as this can upset the balance of the user. Because we are using belt-driven motors, our longboard will coast with high resistance, slowing down gradually over a short period of time. Furthermore, should our pressure sensors fail, a similar situation as the one just described will occur. The user will maintain his or her momentum with constant resistance, and can use a small amount of motor power if the need arises. Finally, should our wheel revolution sensors fail, our main microcontroller will apply the wheel-slip mitigation protocol that reduces motor power over time. In turn, the user will be put again in the aforementioned scenario of coasting with resistance. In short, we will attempt to mitigate any component failures to the best of our ability by utilizing the inherent resistance of our belt-driven motors.

III. Ethics and Safety

Our project aims to improve safety features on consumer electric longboards by targeting two dangerous situations that are possible with general electric longboard designs. With this project we are trying to increase the effectiveness of safety standards, which correlates to IEEE's Code of Ethics Section I.1, which is to "to hold paramount the safety, health, and welfare of the public" [7]. Skateboards and longboards are known to be dangerous, as users are not secured to the vehicle. Should a user lose his or her balance, they automatically risk injury to themselves or others. Our project aims to mitigate some of the hazards present in current electric longboard designs; however, we will not completely eliminate the risks involved. To do so would be to eliminate the longboarding part of the experience entirely. With regarding the effectiveness of the mitigation we will not falsely claim that our that our system cannot prevent all accidents, which falls under IEEE's Code of Ethics Section I.5 by being "honest and realistic in stating claims or estimates based on available data" [7].

Additionally, there are concerns present with the use of Li-Ion batteries. Lithium-Ion batteries pose a fire hazard, especially if the battery is poorly maintained or is in bad health. Fortunately, with our smart BMS, we will be able to precisely monitor our battery packâs health. We aim to follow guidelines to regulate charging and discharging of the battery to ensure the battery's health and users safety. This can prevent the fault of overcharging, which "can lead to more severe faults, such as accelerated degradation and thermal runaway" [8].

By undertaking this project, we hope to bring awareness to the discoveries we have made in regards to improving the safety of longboarding "to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems" as in IEEE's Code of Ethics Section I.2 [7].

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