Design, development, and performance assessment of a high speed, low cost electric skateboard

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This project involved the development of an electric skateboard using off-the-shelf components. Advancements in battery technology and the use of brushless DC (BLDC) motors provide the foundation for this project. BLDC motors offer higher efficiency and performance compared to traditional brushed motors, making them ideal for electric skateboards. The design incorporated a Controller Area Network (CAN) bus for communication with the electronic speed controller (ESC), enhancing software debugging and integration with a Raspberry Pi for expanded functionality. The project involved four primary objectives: developing the initial prototype, transitioning to a functional skateboard, maximizing efficiency, and implementing a wireless remote control. Each stage included detailed component assembly, software integration, and rigorous testing to ensure functionality, safety, and performance. Currently, the skateboard is able to reach a maximum speed of 30 miles per hour and a maximum range of 25 miles.

Keywords: *skateboard, motor, battery, brushless DC, transportation*

Skateboards have increasingly gained popularity as a viable method of transportation. Both skateboards and longboards have transcended their traditional skater-style image, becoming recognized for their practicality and active lifestyle benefits. Recently, electric skateboards have experienced a resurgence, particularly among urban residents and college students. However, the high cost and barriers to entry remain significant challenges to their widespread adoption. This project addresses these issues by focusing on the development of affordable, customizable, and environmentally sustainable electric skateboards.

The feasibility of electric skateboards as urban transportation has been significantly enhanced by advancements in battery technology, particularly the creation of lightweight and reliable lithium-ion batteries in the early 2000s. Essential components for building an electric skateboard include the motor, electronic speed controller (ESC), wheel trucks, and battery pack. This project not only aims to build an electric skateboard suitable for urban transportation but also emphasizes the construction of its components with a focus on performance, safety, and sustainability.

Electric skateboards predominantly utilize brushless DC (BLDC) motors due to their significant advantages over brushed DC motors. BLDC motors, which use magnets to control rotor position (See *Fig. 1*), achieve higher efficiency (approximately 85%) compared to the lower efficiency (approximately 75%) of brushed motors, which suffer from power loss due to friction generated by brushes (Derammelaere, 2016). Additionally, BLDC motors operate at cooler temperatures, offer higher top speeds, and have increased power density.

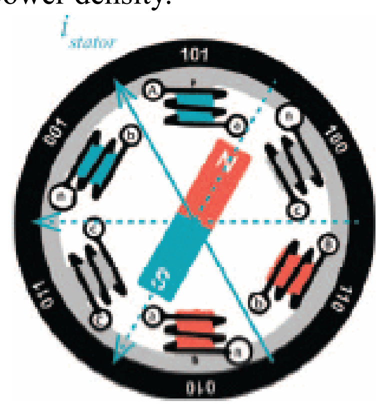

Figure 1: Diagram of a Brushless DC (BLDC) electric motor.

The operation of BLDC motors requires an electronic speed controller (ESC) to activate the magnetic field for rotor movement. While some motors include a built-in ESC, this project opts for a Controller Area Network (CAN) bus for communication with the ESC, diverging from the more commonly used VESC format. The CAN bus offers broader industry support, simplifies software debugging, and facilitates integration with a Raspberry Pi. This setup reduces software overhead and introduces expanded features, such as a PID controller for maintaining constant speed, akin to the cruise control function in automobiles.

Project Purpose

The purpose of this project is to design and build an affordable, efficient, and environmentally sustainable electric skateboard tailored for urban and intra-campus transportation. This project addresses the growing demand for convenient and active transportation options among young adults in urban and college environments. By leveraging advancements in battery technology and the superior performance of brushless DC motors, the project aims to overcome the high cost and accessibility barriers associated with commercially available electric skateboards. Through rigorous testing and development of key components, including a custom PID controller and a wireless remote control smartphone app, this project seeks to deliver a high-performance electric skateboard that meets critical criteria such as functionality, portability, speed, safety, and ease of use, ultimately promoting a more sustainable mode of transportation.

Objectives

1. Implementation of a mobile computer.
2. Integration of a brushless DC (BLDC) motor.
3. Accomplishment of a minimum 10 mile riding range.
4. Achievement of a maximum 3 hour battery charge time.
5. Achievement of a maximum $900 cost to build.
6. Addition of a CAN (Controller Area Network) bus.
7. Development of a mobile application to serve as a wireless remote control for the skateboard.

System Overview

The electric skateboard is designed with a focus on maximizing efficiency, safety, and user convenience. Central to its operation is the CTRE Falcon 500 brushless electric motor, chosen for its high efficiency and power density. The motor is controlled via a Raspberry Pi using the Controller Area Network (CAN) bus protocol, ensuring reliable and responsive communication. Due to the Raspberry Pi's limitation of not being able to natively support the CAN protocol, this skateboard utilizes the HERO Development Board from Cross The Road Electronics (CTRE), flashed with firmware that allows the board to act as a USB to CAN adapter when plugged into the Raspberry Pi. This setup enables the integration of advanced control features, including a custom PID controller that maintains constant speed and provides a smooth riding experience. The skateboard's power system includes two DeWalt 6.0Ah 20 volt drill batteries, which supply the necessary voltage while maintaining a lightweight and compact design. These batteries are managed by dual DC step-down converters to regulate power distribution, ensuring optimal performance and a minimum riding range of 10 miles on a single charge.

The physical design of the skateboard incorporates high-quality components to ensure durability and ride comfort. The board features 97mm wheels, wheel bearings and a motion transfer system consisting of gears and pulleys, enabling effective power transmission from the motor to the wheels (See *Fig. 2*). Due to the heft of the board's components, rubber riser pads are placed under the wheel trucks to reduce the risk of board flex when a rider is using the skateboard. Developed alongside the skateboard is a mobile application that serves as the skateboard's remote control, providing intuitive and precise control over speed and braking. The mobile app pairs seamlessly with the motor controller over the skateboard's built-in WiFi connection. Throughout the development stages, various software tools, including Visual Studio Code and Onshape's 3D CAD Design Software, are employed to model, test, and refine the system's components.

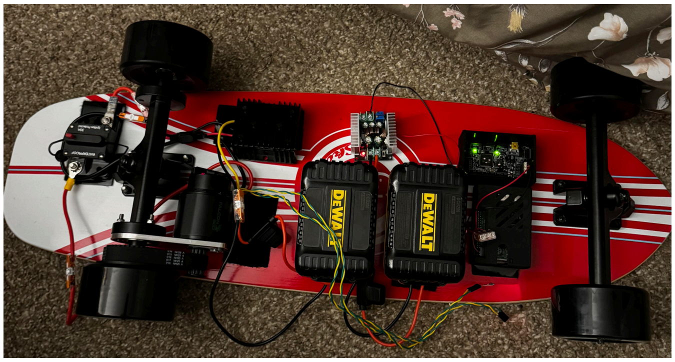

Figure 2: The underside of the skateboard, showcasing the power supplies, motor and computers.

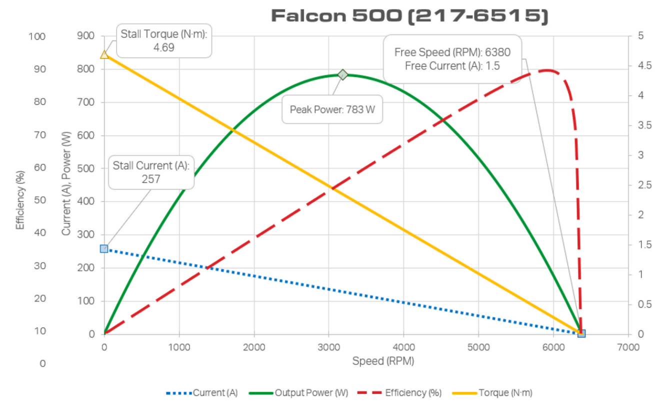

Figure 3: Graph displaying the Falcon 500's peak power, stall current, maximum free speed, and peak stall torque.

Motor

The Falcon 500 motor was chosen for the electric skateboard due to its superior performance characteristics and integrated functionalities, which align perfectly with the demands outlined in urban and intra-campus transportation. Key among these is the motor's brushless design, which offers significant advantages over traditional brushed motors. Brushless motors like the Falcon 500 have higher efficiency and reliability, primarily because they eliminate the friction and wear associated with brushes. This results in less heat generation, greater power output, and a longer operational lifespan, all of which are critical for maintaining consistent performance in a compact and portable electric skateboard.

Furthermore, the Falcon 500 motor provides exceptional power density. According to Cross The Road Electronics (2023), the Falcon 500 delivers just under 400 watts of continuous power at 40 amps and 12 volts, with peak power capabilities exceeding 780 watts (See *Fig. 3*). This high power output enables the electric skateboard to achieve impressive speeds and acceleration, enhancing its utility for quick urban commutes. The motor's high efficiency, reaching up to 89% in optimal conditions, ensures that the energy from the battery is utilized effectively, thereby extending the skateboard's range and reducing the need for frequent recharges.

Another significant factor in the selection of the Falcon 500 is its integrated Talon FX motor controller and 2048 CPR (cycles per resolution) encoder. These built-in components streamline the design and implementation process by providing precise motion control and eliminating the need for additional external controllers. This integration not only reduces the overall complexity and potential points of failure but also enhances the responsiveness and smoothness of the ride. Additionally, the motor's compact size and robust thermal protection mechanisms make it well-suited for the compact form factor and operational stresses of an electric skateboard.

Batteries

The DeWalt 20V 6.0Ah battery offers robust performance and reliability, making it an excellent choice for powering the electric skateboard. According to DeWalt (2017), this battery has a nominal voltage of 20 volts and a capacity of 6.0Ah (amp hours), allowing this lithium-ion battery to provide a consistent and long-lasting power supply. The high capacity ensures that the skateboard can operate for extended periods without frequent recharging, which is crucial for maintaining long-range travel and continuous use. Additionally, lithium-ion technology is known for its efficiency and high energy density, which translates to more power in a lighter and more compact form.

Ride Computers

The Raspberry Pi was chosen for this project due to its versatile and powerful computing capabilities, compact size, and extensive community support. As a small, single-board computer, the Raspberry Pi can handle complex tasks such as real-time data processing, communication with peripheral devices, and running custom software applications, all crucial for the advanced control systems of an electric skateboard. According to Jolles (2021), it offers multiple GPIO pins for interfacing with sensors and other hardware components, which is essential for integrating various features like speed control, battery management, and safety mechanisms. Jolles (2021) also states that the Raspberry Pi is equipped with various communication protocols (I2C, SPI, UART). This allows seamless integration with other electronic modules, ensuring a cohesive system design. Additionally, its cost-effectiveness and widespread use in educational and hobbyist projects make it an accessible and reliable choice for developing and iterating the skateboard's control system.

The HERO Development Board, based on the STM32F4 microcontroller, was selected for this project due to its robust capabilities and compatibility with CTRE CAN Bus devices. According to Cross The Road Electronics (2023), the HERO provides a 168 MHz Cortex-M4 processor, 256 KB of RAM, and 2 MB of flash memory. The board supports CAN2.0B communication (Cross The Road Electronics, 2023), making it an ideal platform for integrating motor controllers and other peripherals via the CAN Bus, which is known for its reliability and efficiency in automotive and industrial applications.

One of the standout features of the HERO board is its extensive Input and Output (I/O) capabilities. Cross The Road Electronics (2023) states the HERO board supports multiple UART, SPI, I2C ports, and GPIOs (See *Fig. 4*), which facilitate flexible hardware integration. These interfaces are crucial for connecting the various sensors, actuators, and communication modules required for the skateboard project. The board also features USB ports for easy programming and debugging, which simplifies the development process. Additionally, the HERO board's compatibility with the C++ programming language allows for rapid development and testing of control software.

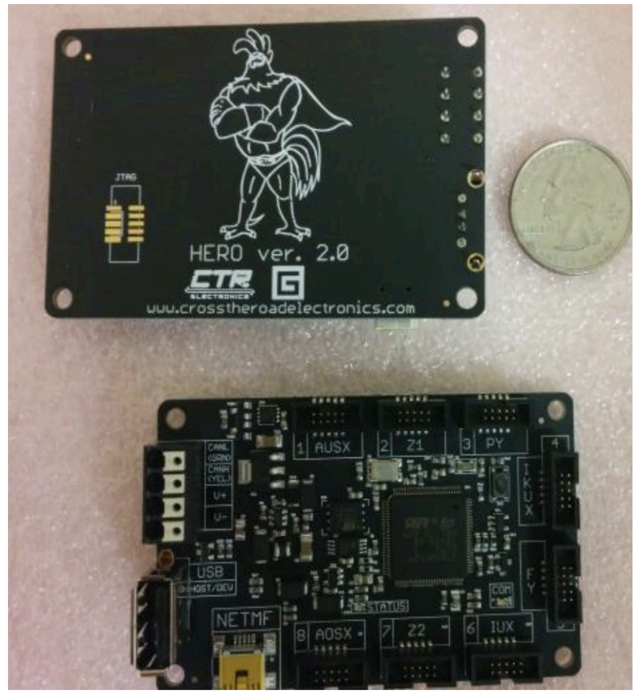

Figure 4: Front and back photo of Cross The Road Electronics' HERO Development Board showcasing various inputs.

Safety Features

The electric skateboard integrates several advanced safety features designed to enhance the rider's security and ensure reliable operation under various conditions. One of the critical safety components is the main circuit breaker switch. This multifunctional switch serves three essential roles: it acts as the primary on/off button, breaks the circuit if the power draw exceeds 40 amps, and functions as an inertia switch. The on/off functionality provides a simple and effective way to power the skateboard, allowing the rider to easily start and stop the device. By automatically breaking the circuit when the power draw exceeds 40 amps, the switch protects the electrical components from potential damage due to overcurrent, which could result from a short circuit or other electrical faults.

The inertia switch capability adds an extra layer of safety by cutting off power if the skateboard experiences sudden and unexpected movements, such as being kicked up or hitting a significant obstacle. This feature is crucial in preventing the motor from continuing to run in potentially hazardous situations, therefore reducing the risk of injury to the rider and damage to the skateboard. By immediately halting the motor, the inertia switch helps maintain control and stability, especially in emergency scenarios.

In addition to the hardware-based safety mechanisms, the electric skateboard also incorporates a software-controlled deadman's switch within the remote controller smartphone app. The forward button on the app is configured such that the rider must hold it down to keep the motor running. This design ensures that the rider maintains constant attention and physical interaction with the control system, preventing the skateboard from moving if the rider becomes distracted or loses grip on the remote. This feature significantly enhances safety by ensuring that the skateboard only operates when the rider is actively engaged and attentive, reducing the likelihood of accidents caused by inattention or loss of control.

Software Stack

The software stack of the electric skateboard is designed to provide robust and efficient control of the skateboard, ensuring smooth operation and real-time responsiveness. At the core of this stack is the main control software, written in C++, which runs on a Raspberry Pi. The choice of C++ leverages its performance efficiency and low-level hardware control capabilities, crucial for managing real-time operations and processing the data required for the skateboard's functionality. The Raspberry Pi acts as the central processing unit, interfacing with various components and executing the control algorithms necessary for the skateboard's operation.

Communication between the Raspberry Pi and the motor controller is facilitated by the HERO Development Board, which functions as a USB-to-CAN adapter. The Raspberry Pi sends motor instructions via USB to the HERO board, which then translates these commands into CAN messages. This approach ensures reliable and high-speed communication with the Falcon 500 motor, a critical factor for maintaining precise motor control and achieving the desired performance characteristics. The use of CAN (Controller Area Network) is particularly advantageous due to its robustness and noise-resistant properties, making it well-suited for the dynamic and potentially noisy environment of an electric skateboard.

User input for the skateboard's speed is managed through a mobile app, which serves as the skateboard's remote control. The skateboard is equipped with an ESP8266 chip, enabling it to create its own WiFi network. This network allows the mobile app to communicate directly with the Raspberry Pi. The app sends the desired speed in the form of a JSON request to an API backend server hosted on the Raspberry Pi. This server processes the input and integrates it into the control logic that determines the motor speed. By using WiFi for communication, the system ensures a responsive and flexible user interface, allowing for real-time adjustments and control.

Results

The results obtained from the testing of the electric skateboard demonstrate its potential to significantly impact the commercial electric skateboard market. The skateboard achieved a remarkable top speed of 30 MPH, which surpasses the rated top speed of the Evolve GTR at 23.6 MPH (Evolve, 2022) by 27%. This substantial increase in top speed highlights the advanced performance capabilities of the designed skateboard, making it a compelling option for users seeking high-speed urban transportation. The improved speed is a testament to the effective integration of the Falcon 500 motor and the sophisticated control systems implemented in the design.

However, this enhanced top speed does come with trade-offs in terms of driving range. At the maximum speed of 30 MPH, the skateboard recorded a driving range of 13.45 miles, which is less than the Evolve GTR's 18.6 miles (Evolve, 2022) at a speed of 23.6 MPH. This reduction in range can be attributed to the higher power consumption required to sustain the increased speed. Despite this trade-off, the skateboard still offers a respectable range that is suitable for many urban and campus environments. The balance between speed and range reflects a common challenge in electric vehicle design, where performance gains often come at the expense of energy efficiency.

The charging performance of the skateboard is another area where it shows considerable promise. The battery charging test results indicate that the skateboard can be fully recharged from zero to 100% in one and a half hours. This rapid charging time is a significant advantage over the Evolve GTR, which requires between four to five hours for a full recharge (Evolve, 2022). Faster charging times enhance the usability of the skateboard, reducing downtime and making it more convenient for users who rely on it for daily transportation.

This improvement in charging efficiency can be particularly beneficial in urban settings where quick turnarounds are essential. The battery used in the Evolve GTR is not easily swappable, whereas the DeWalt drill batteries used in this project are swappable. This is an effective selling point as the rider has the ability to carry extra batteries on their trip with the skateboard so they are able to keep riding for longer.

The bill of materials for the skateboard amounts to $890, which is significantly lower than the Evolve GTR's starting price of $1199 (Evolve, 2022). This cost advantage, combined with the superior top speed and competitive range, positions the skateboard as a highly attractive option in the market. The lower cost of production, without compromising on key performance metrics, suggests that this skateboard could disrupt the market by offering a high-performance, cost-effective alternative to existing products.

Discussion

The skateboard's ability to achieve a top speed of 30 miles per hour demonstrates the successful implementation of the high-performance Falcon 500 motor and the efficient communication between the Raspberry Pi and the HERO development board. This speed exceeds the Evolve GTR's top speed by 27%, a clear indication that the skateboard can cater to users seeking higher velocity for urban commuting. The increased speed aligns with the growing demand for quicker and more efficient urban transportation solutions, making this skateboard a viable contender in the market.

While the enhanced speed is a notable achievement, the resultant trade-off in driving range is also evident. At 30 miles per hour, the skateboard offers a range of 13.45 miles, which, although shorter than the Evolve GTR's 18.6 miles at 23.6 miles per hour, still provides a practical distance for many urban and intra-campus journeys. This finding is consistent with the generally accepted principle that higher speeds typically result in increased energy consumption, thereby reducing range. The 13.45 mile range at top speed is sufficient for most short to medium commutes, especially considering the rapid recharge time, which enhances the skateboard's practicality.

The charging efficiency of the skateboard stands out as a significant improvement over existing models. The ability to recharge from zero to 100% in just one and a half hours, compared to the four to five hours required by the Evolve GTR, highlights the effectiveness of the chosen battery and charging system. This rapid charging capability not only reduces downtime but also aligns with the fast-paced lifestyle of urban commuters who require quick turnaround times. The efficient use of DeWalt 20V 6.0Ah batteries underscores the importance of selecting high-quality components to enhance overall performance and user convenience.

Economically, the skateboard's lower production cost, with a bill of materials totaling $890, presents a substantial advantage over the Evolve GTR's $1199 starting price. This cost efficiency, achieved without compromising on key performance metrics, makes the skateboard an attractive option for cost-conscious consumers. The combination of lower price, higher top speed, competitive range, and fast charging positions this skateboard as a disruptive force in the market. It provides an accessible, high-performance alternative that could potentially expand the user base for electric skateboards.

References

Cross The Road Electronics (2023, February 15). 217-6515 Falcon 500 User Guide. CTR Electronics. https://store.ctr-electronics.com/content/user-manual/Falcon 500 v3 User's Guide.pdf

Cross The Road Electronics (2023, February 15). 16-728279 HERO User Guide. CTR Electronics. https://store.ctr-electronics.com/content/user-manual/HERO User's Guide.pdf

Derammelaere, S., Haemers, M., Jasper, D. V., Verbelen, F., & Stockman, K. (2016). A quantitative comparison between BLDC, PMSM, brushed DC and stepping motor technologies. http://hdl.handle.net/1854/LU-8544760

DeWalt (2017). DeWalt 20V MAX XR Premium Lithium-Ion 6.0AH battery Pack. https://www.dewalt.com/product/dcb206/20v-max-xr-6ah-battery

Evolve Skateboards (2022). Evolve GTR Carbon all terrain. https://www.rideevolve.com/products/gtr-carbon-all-terrain

Jolles, J. W. (2021). Broad‐scale applications of the Raspberry Pi: A review and guide for biologists. Methods in Ecology and Evolution, 12(9), 1562–1579. https://doi.org/10.1111/2041-210x.13652

Appendix 1: Skateboard Bill of Materials

No.	***Vendor Name***	**Item SKU**	**Item**	**Item Price**	**Qty.**
1	Amazon.com	B01M751WC3	DeWalt 20V 6.0Ah Cordless Batteries	169.00	1
2	Amazon.com	B01BQM1A2W	DeWalt Battery Charger	30.95	2
3	Amazon.com	B0BRV88HHC	30A Circuit Breaker	15.99	1
4	Amazon.com	B09GW6TC43	DeWalt 20V Battery Adapter	13.98	2
5	mboards.co	N/A	Super Blacks Bearings	14.99	1
6	mboards.co	N/A	Rubber Pads	4.99	2
7	mboards.co	N/A	265mm Notched Drive Belt	10.00	2
8	mboards.co	N/A	38T Push in Wheel Bearing	17.50	2
9	mboards.co	N/A	97mm Wheels	39.99	1
10	mboards.co	N/A	Front and Rear Fixed-Mount Motor Trucks	119.99	1
11	West Coast Products	WCP-0319	12T 15mm wide Aluminium Pulley for Falcon 500	11.99	2
12	Amazon.com	B0BL9V4RJ1	20V to 12V-30A Step Down DC Converter	26.99	2
13	Cross The Road Electronics	16-728279	HERO Development Board	59.99	1
14	Cross The Road Electronics	19-708850	Falcon 500 Brushless DC Electric Motor	219.99	1
15	Amazon.com	B0CJ5QF3VX	Assorted WAGO in-line Splicing Connectors	18.99	1
			Total	**890.75**	