PERFORMANCE ANALYSIS OF THREE WHEEL VEHICLE USING EXPERIMENTAL TESTING METHOD

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DECLARATION

I declare that this thesis entitled "PERFORMANCE ANALYSIS OF THREE WHEEL VEHICLE USING EXPERIMENTAL TESTING METHOD is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled " PERFORMANCE ANALYSIS OF THREE WHEEL VEHICLE USING EXPERIMENTAL TESTING METHOD", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Mechatronics Engineering with Honours

Signature	:	
Supervisor Name	:	En. Bazli Bin Bahar
Date	:	17/6/24

DEDICATIONS

To my beloved mother and father

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ABSTRACT

This study examines the functionality and performance analysis of an electric trishaw that has been designed and developed by “Beca Team” from UTeM, with a specific focus on an efficient, dependable, and environmentally friendly urban transportation alternative. The project entailed conducting tests on the functionality of its electrical components and evaluating its performance in terms of speed and power consumption. The study emphasizes the influence of fluctuating load situations and the ability of the trishaw to adapt to different terrains on its speed and acceleration. The study employs rigorous testing in real-world situations to identify potential stress spots and electrical component difficulties, thereby guaranteeing the vehicle's durability and long-term functionality. The key findings indicate that trishaws experience a decrease in performance when faced with higher inclines due to the increased power requirement. The voltage analysis forecasts that the device will operate for approximately 34.3 minutes under a constant load before it reaches the cut-off voltage. Guidelines for improving motor efficiency and establishing efficient load distribution methods are given to predic the trishaw's performance and its dependability in various urban settings. This study provides useful information that can be used to enhance the design and operation of electric trishaws, hence advancing sustainable options for urban mobility.

ABSTRAK

Kajian ini mengkaji kefungsian dan analisis prestasi beca elektrik yang telah direka dan dibangunkan oleh "Beca Team" daripada UTeM, dengan tumpuan khusus pada alternatif pengangkutan bandar yang cekap, boleh dipercayai dan mesra alam. Projek itu memerlukan menjalankan ujian ke atas kefungsian komponen elektriknya dan menilai prestasinya dari segi kelajuan dan penggunaan kuasa. Kajian itu menekankan pengaruh situasi beban yang turun naik dan keupayaan beca untuk menyesuaikan diri dengan rupa bumi yang berbeza pada kelajuan dan pecutannya. Kajian ini menggunakan ujian yang ketat dalam situasi dunia sebenar untuk mengenal pasti titik tekanan yang berpotensi dan kesukaran komponen elektrik, dengan itu menjamin ketahanan kenderaan dan kefungsian jangka panjang. Penemuan utama menunjukkan bahawa beca mengalami penurunan dalam prestasi apabila berhadapan dengan kecondongan yang lebih tinggi disebabkan oleh keperluan kuasa yang meningkat. Analisis voltan meramalkan bahawa peranti akan beroperasi selama kira-kira 34.3 minit di bawah beban tetap sebelum ia mencapai voltan potong. Garis panduan untuk meningkatkan kecekapan motor dan mewujudkan kaedah pengagihan beban yang cekap diberikan untuk meramalkan prestasi beca dan kebergantungannya dalam pelbagai persekitaran bandar. Kajian ini menyediakan maklumat berguna yang boleh digunakan untuk meningkatkan reka bentuk dan pengendalian beca elektrik, dengan itu memajukan pilihan yang mampan untuk mobiliti bandar.

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CHAPTER 1

INTRODUCTION

1.1 Background

Three-wheelers, known as trikes or tricycles, create a unique vehicle category with their trio of wheels. Their evolution spread on different cultures while advancing from human-powered models to motorized versions with multi-purposes. Initially, human-powered three-wheelers were pedal-propelled, used commonly for travel or leisure. But as human move forward to the era of technology, they changed to motorized equipment with internal combustion engines or electric motors that be use as transportation and commercial needs.

In urban areas, three-wheelers are often employed as nimble utility vehicles for transporting goods due to their maneuverability and compact size, allowing them to navigate crowded streets effectively. Some also serve as passenger transport like taxis or affordable public transport in certain regions like India and Thailand.

These vehicles vary in design, impacting their speed, handling, and load capacity. Some have a single front wheel and two at the rear, while others reverse this configuration. They range from open-air models like auto-rickshaws to enclosed structures resembling small cars.

Advancements in electric vehicle tech led to electric three-wheelers, especially for urban travel, contributing to eco-friendly mobility by reducing emissions and operating more quietly than traditional combustion engine models. Even though they are flexible, this type of vehicle faced several safety hurdles due to their unique build and characteristic resulting in differing rules globally.

1.2 Motivation

Particulate matter (PM) and carbon dioxide (CO2) are two examples of the pollutants that can be released into the atmosphere by traditional auto rickshaws that are driven by gasoline or diesel engines. These vehicles contribute to the problem of air pollution and noise subconciously. According to The Energy and Resources Institute (TERI), Bangalore's traditional auto fleet generates 4 tonnes of NOx, 1200 tonnes of carbon dioxide, and 0.5 tonnes of PM10 each day, totaling 0.44 million tonnes of carbon dioxide yearly [1]. Auto-rickshaws running on Liquefied Petroleum Gas (LPG) or diesel are stated to be less efficient compared to other vehicles such as electrical-powered vehicle [2]. Figure 1-1 shows the emission of CO2 for each vehicles.

Sl. No.	Vehicles	Specific CO_2 emission (gm/passenger-km)
1.	Auto-rickshaw (LPG)	23.556
2.	Auto-rickshaw (Diesel)	21.51
3.	Mechanized Van-rickshaw (Diesel)	4.46 – 11.38
4.	E-rickshaw	19.129

Figure 1-1: Emission of motorized three-wheeled vehicles [2]

The tremendous of delevelopment of three-wheel vehicle has a significant impact on reducing road efficiency and increasing traffic congestion [3]. In the metropolitan area of Dhaka, one of the factors contributing to traffic congestion is the improper design of signal timing at signalized crossings [4]. The different in speed of auto-trickshaw with other vehicles also contribute to the traffic jam based on survey conducted [5]. Figure shows the response from 299 respondents on several factors by selecting the decided mark depending on their agreement with the questionaire.

Factors	Question	Mean	Overall mean	Cronbach Alpha
Accessibility and comfortability	Can travel area that cannot be reachable by other transportation	3.3	3.60	0.811
	Provide door to door service	3.7		
	Easy to get by the road	3.4		
	Short waiting time	3.3		
	Provide timely service	3.3		
	Flexible service	3.5		
	Easily exposed to bad weather such as hot and rainy day	4.0		
	Limited legroom for long-distance journey	4.0		
	Limited to two-person per trip	4.0		
Cost	Low budget transportation	3.9	3.9	0.867
	Provide cheap fares than other transportation	3.8		
	Worth for short-distance travel	4.1		
Economy	Provide employment opportunities	4.0	3.9	0.925
	Multiple choice of transportation	4.0		
	Generating income that commensurate with the services	3.7		
	Extra side income	4.0		
Safety	A high risk involving in road accidents	3.9	3.7	0.821
	Become victims of crime (robbery)	3.8		
	Become victims of sexual harassment	3.5		
Traffic flow	Contribute to traffic congestion	3.5	3.6	0.901
	Differences in speed contribute to traffic congestion	3.7		
Health and environment	Exposed to vehicle emissions	4.1	3.7	0.885
	Exposed to contagious disease	3.7		
	Increase environmental pollution	3.5		
	Increase sound pollution	3.5		

Figure 1-2: Mean score of responses to perception factors [5]

1.3 Problem Statement

The performance of the electrical trishaw is greatly impacted by variable load conditions and terrain adaptability, especially when it comes to speed and acceleration. The trishaw can carry weight up to its maximum capacity in a variety of load scenarios, which varies the motor's power requirement and causes uneven speed and acceleration. The trishaw must also manoeuvre over a variety of terrains, such as flat areas, inclining hills, and descending valleys, all of which place unique demands on the engine. For example, moving uphill requires more energy, which results in slower acceleration and lower speed; conversely, moving downhill might result in variations in speed because of gravity's help. For the trishaw to continue operating consistently and to maximize its overall efficiency and dependability, it must be able to adjust to these different loads and terrains.

Additional testing is necessary to verify that the design is both efficient and dependable, while also considering potential changes in the environment and the surrounding area, whether they are controlled or uncontrolled, to minimize any potential risks. This section evaluates the vehicle's velocity, and energy usage across various distances and road conditions. To evaluate the needs and effectiveness of a motorized electrical vehicle, it is necessary to take a comprehensive approach that considers the complexities of the electrical components as well as the practical functioning of the vehicle in real-world conditions. To effectively address issues regarding efficiency and meet the demands of the current transport system, a viable approach is to subject electronic vehicles to comprehensive testing in various environments.

1.4 Objective

- To test the functionality of each electrical components of the designed three-wheel vehicle.

- To examine the performance of three-wheel vehicle based on variety of speed against loads.

- To analyze the performance of three-wheel vehicle based on power consumption.

1.5 Scope and Limitations

- The parameters analyzed are the speed and power consumption of three-wheel vehicle only.

- The three-wheel vehicle is analyze to be use for tourism sector only.

- The experiments are conducted near FTKE's building in UteM only.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The aim of this chapter is to summarize and present a comprehensive review of the studies regarding the title, as well as to provide the work from an open literature review that is useful from previous researchers. Related research about the methods and designs of three-wheel vehicle used for performance analysis has also been written.

2.2 Performance Analysis

Performance analysis is a structured process that involves assessing the current level of performance in a specific task or system and comparing it to the desired or optimal performance. This evaluation encompasses gathering data or observations, defining performance criteria, identifying gaps between existing and desired performance, suggesting interventions for improvement, and continuously monitoring and refining strategies to bridge those performance gaps. Ultimately, it aims to understand how well a process or entity is performing and determine what changes or enhancements are needed to achieve the desired level of performanc.

2.3 Method of Performance Analysis

Several methods were used by researchers to obtain the interested parameters and data that were being discussed to achieve its intention of the paper.

2.3.1 Data Logging Method

Data logging is a method of gathering and keeping track of various occurrences over an extended period of time in various systems or contexts [6]. It involves the use of electronic devices known as data loggers, which capture measurements such as temperature, humidity, pressure, or other variables at set intervals or when triggered by predefined conditions. This method eliminates the need for manual data collection, high probability of error as well as the consumption of man-hours for a very simple operation [7]. This method commonly use a sensor to collect data from environment.

Data logging involves a four-step process: First, sensors collect and record data from various sources. Next, a microprocessor within the data logger performs basic measurement and logic functions, such as calculations and comparisons. Then, the data stored in the logger's memory unit is transferred to a computer or electronic device for analysis. Finally, the analyzed data is presented visually through knowledge graphs or charts, making it easier to interpret and derive insights from the recorded information [8].

Researcher implement this method to gather essential data such as error yaw rates and turning angles by using the sensor, particularly Inertial Measurement Unit (IMU) sensor [9]. This data is then processed using the fuzzy logic method to control the vehicle's turning conditions, improving the vehicle's stability and security during turns. In the design of a vehicle controller, various sensors are employed to measure key inputs such as throttle position, engine RPM, and vehicle speed. The engine speed sensor, and Throttle Position Sensor (TPS) are used to provide real-time engine speed data and the engine power output respectively, which vital for the controller to optimize vehicle performance and efficiency [10].

Data loggers are widely employed across industries for applications ranging from environmental monitoring and industrial processes to research, ensuring the accurate and continuous recording of crucial data for analysis, quality control, and compliance purposes.

2.3.2 Finite Element Analysis (FEA) Method

Finite Element Analysis (FEA) is a sophisticated computational technique used to simulate and predict complex structural behaviors under various physical conditions such as fluid flow, mechanical stress, fatigue and etc. [11]. In Finite Element Method (FEM), the nodes and elements are used to make a grid, which is known as a "mesh". The grid then programmed to contain a structural parameters that will respond to loading scenarios [12]. By solving this system using numerical methods, FEA provides detailed insights into parameters like stress, strain, and displacement within the structure. Finite element analysis may optimize every component during the design stage while lowering the number of physical prototypes made and trials carried [13]. There are a number of eight researchers that use this technique to retrieve the parameters needed for evaluation. Four of them are mainly analyze on vehicle controllability while others investigate on frame or structural of the design.

2.3.2.1 FEA on Controllability

Author [14] use this method to enhance its newly-proposed concept steering fault disturbance and Model Predictive Control (MPC) algorithm, by regulate the input values of steering angle and yaw moment to maintain driving performance [14]. Futhermore, study held by author [15] carried a MATLAB/Simulink simulation to analyze the performance of a BLDC motor drive with both PI and SMC controllers [15]. Additionally, the paper presents a comparative analysis of SMC against the traditional Proportional-Integral (PI) controller, demonstrating the superiority and robustness of the SMC in ensuring stable motor operation. Meanwhile, Author [16] proposed a research on performance of Switched Reluctance Motor (SRM) with a different of rotor pole configuration [16]. The experiment was execute via FEA software. It helps in evaluating aspects like average torque, torque ripple, and motor efficiency for various SRM topologies, aiding in determining the most suitable configuration for electric vehicles via software simulation. Last but not least, author [17] addressed the use of PSAT software to examine the performance of hybrid vehicle in order to build a hybrid controller for power management [17]. The author suggests that the design, with its focus on hybrid technology, presents a viable option for future general vehicles, potentially reducing reliance on fossil fuels and contributing to sustainability in the automotive sector.

2.3.2.2 FEA on Frame/Structural Design

The static analysis is conducted using Implicit LS-DYNA software, simulating real-world conditions to acquire a variation of spring stiffness that can be used to observe how the vehicle behaves under different stiffness levels [18]. It is found that the design can effectively handles loading and distributes stress evenly, minimizing vehicle deflection when loaded. Apart from that, author [19] execute a static and dynamic crash testing using CarSim software to identifies an optimal roof structure shape for TWVs [19]. This finding is important as it contributes to improve the overall safety of three-wheel vehicles, particularly in the context of rollover accidents. Author [20] also impement this method by evaluating multiple swingarm designs through FEA using Computer Aided Engineering (CAE) software. The simulation outcomes under extreme loading conditions strongly suggest that the proposed swingarm structure is both efficient and viable for real-world prototype development. Beside that, author [21] applied this approach by simulating a TWVs during side pole collision, using LS-DYNA software for vehicle design analysis and collision behaviour prediction. The results of these simulations shows that the modified model demonstrated a notable improvement in safety and crashworthiness.

2.3.3 Experimental Testing Method

Experimental testing in performance analysis involves setting up real-world experiments under controlled conditions to collect empirical data about the performance of a system, device, or component. This method typically includes defining specific test parameters, using instruments and sensors to gather relevant data such as speed, fuel consumption and temperature, and then analyzing this data to assess performance. The process is vital for verifying real-world functionality, identifying potential issues, and informing decisions about design optimization and improvements. It is a critical approach in fields such as automotive engineering, aerospace, and manufacturing, where understanding the physical behavior of products or systems under various conditions is essential.

Author in journal [22] used this method to operates an Anti-lock Breaking System in different modes such as boost mode, holding mode, release mode, step boost mode, and step release mode [22]. The results from these tests were promising, demonstrating that the proposed ABS can adaptly adjust wheel braking pressures, making braking maneuvers safer and more efficient. Moreover, author [23] validate their models and identify key parameters that influence stability, particularly focusing on the damping effect within the steering system by running a field tests [23]. The study concludes that in this specific case, the compliance of the frame does not significantly affect the weave and wobble modes which contributing to the development of safer and more stable designs for urban mobility solutions. Author [24] exhibit similar method used for performance analysis in author [23] research. But the significant difference between both study is the parameters that want to analyze. Author [24] performed road testing of three-wheeler vehicle powered by a 5 kW Proton Exchange Membrane Fuel Cell (PEMFC), both with and without the inclusion of lead acid batteries [24]. This study showcases the potential of PEMFC technology in powering three-wheeled vehicles, offering insights into its efficiency and performance dynamics, particularly when combined with lead acid batteries.

2.3.4 Summary

Table 2-1: Comparison of Method

Paper	Method	Advantages	Disadvantages
[11] [12]	Data Logging Method	- Data loggers typically offer high accuracy and can record data at precise intervals, ensuring detailed and reliable data collection.	- There is a risk of data loss due to power failures, equipment malfunctions, or data corruption.
[16] [17] [18] [19] [20] [21] [22] [23]	Finite Element Analysis (FEA) Method	- accurately predicts stress, strain, and deformation in materials and structures under different conditions, aiding in assessing structural integrity and material performance.	- often relies on assumptions and simplifications to model complex structures, which can introduce errors or inaccuracies, especially in nonlinear or dynamic analyses.
[24] [25] [26]	Experimental Testing Method	- provides direct, real-world validation of the behavior and performance of a system or component, offering tangible data for analysis.	- Replicating exact conditions across different tests can be challenging, leading to variability in results and potential inconsistencies.

2.4 Conclusion

In conclusion, thirteen papers were selected from the past five years as they are more relevant to this project. Two of them are using Data Logging Method, eight of them are using FEA Method, and another three are using Experimental Testing Method. Based on the reviewed methods, the experimental testing method seems better than the other two method since it involves with real enviroment conditions making the results that will be obtain in performance analysis more reliable as reference for other projects.

2.5 Gap of Literature Review

From the literature review, a gap can be concluded. From the reviews, there are many journals proposed research on performance analysis on controllability and design of three-wheel vehicle and most of them using the same position of designated wheel vehicle which are two wheels at the back and one wheel at the front center. There is no analysis on the design that consist of two wheels on the back, and one wheels on the front right such as trishaw that are widely used in Malaysia for economy purposes. From this gap, a performance analysis on a different design approach of the three-wheel EVs which will be proposed. In addition, the techniques used to perform an analysis must be suitable and capable of achieving the goals in the most efficient manner possible. Therefore, the experimental testing method will be chosen in this project.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the method and techniques used in achieving the objective for this final year project will be described. Firstly, the flowchart of the project overview will be shown. Then, the brief explanation and the specification of each electrical components that will be use will be described in this chapter.

3.1.1 Methodology Flowchart Overview

Overview of project implimentation flowchart as below.

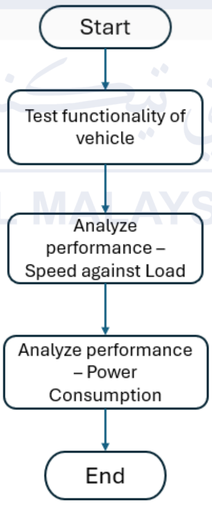

Figure 3-1: Flowchart of Overview Project Implementation

3.2 Electrical Design

Electrical design consist of two parts; electrical components and electrical connection diagram. The overview of electrical components including its technical data or specifications were represented. The connection of the overall electrical components will be presented as well. Note that, some of the components will not be introduce since they are not significant on this performance analysis.

3.2.1 Electrical Components

Electrical components includes the battery, motor and LED controller, regulator as well other devices.

3.2.1.1 Rechargeable Battery 48V Lithium Ion

Lithium is an active material in lithium batteries, which are a type of reusable battery. Because they have a higher energy density than other rechargeable batteries like nickel-cadmium or lead-acid batteries, they can store more energy per unit weight and volume, which has led to their widespread popularity. Lithium batteries come in different varieties, such as Li-ion (Li-ion), Li-polymer (LiPo), Lithium iron phosphate (LiFePO4), and others. Due to their large energy capacity and lightweight design, they are utilized in a wide range of gadgets, including laptops, electric cars, and renewable energy storage systems. However, it can have some drawbacks and safety issues such as the possibility of overheating and fires if they are damaged or handled incorrectly, despite their many benefits. Thus, using lithium batteries requires careful handling and attention.

Table 3-1: Technical Data of Rechargeable Battery

Battery Model	ES-48100
Battery Technology	LiFePO4
Nominal Voltage	48V
Nominal Capacity	100Ah
Nominal Energy	4.8KWh
Dimension (WxDxH)	483x500x177mm
Weight	50.8Kg
Boost Charge Voltage	54V
Discharge Cut-off Voltage	38-40.5V

Max Charge Current	100A
Recom. Charge Current	50A
Max Discharge Current	100A
Working Temperature Range	Discharge: -20°C to +60°C Charge: 0°C to +60°C Storage: -20°C to +60°C
Cycle Life	≥3000 Cycles @ 100% DOD @ 25°C
Communication	None
Safety Standard	CE, UN38.3
Design life	15+ years @25°C
Protection	Short circuit, over charge, over discharge, under charge, under discharge, over/under temperature etc.

3.2.1.2 Miniature Circuit Breaker (MCB)

The purpose of miniature circuit breakers (MCBs) is to safeguard electrical circuits against short circuits and overcurrents. Their amperage ratings, shown by the numerals 63A and 12A, indicate the maximum current that they can safely take. The term "63A MCB" describes a small circuit breaker that has a rated current of sixty-three amperes. It indicates that, in order to guard against overcurrents, this specific MCB is made to withstand currents of up to 63 amps before tripping and cutting the circuit. For bigger appliances or circuits that need more power, these higher-rated MCBs are frequently utilized. Similarly, the term "20A MCB" indicate that it has a rated current of 12 amps. It is intended for lesser current-drawing circuits or devices. Smaller appliances, lighting circuits, or circuits with reduced power requirements might make use of these compared to those that would require a "63A MCB".

Table 3-2: Technical Data of MCB

Type	**DC MCB**
Rated working voltage	DC12-240V
Rated current [In]	6A/10 A / 16 A / 20 A / 25 A / 32 A / 40 A / 50 A / 63 A (optional)
Two levels	2 P
Release technology	Thermomagnetic
Curve code	C
Breaking capacity	4 kA Ics=Icu

Uimp	4 kV
Mechanical durability	10000 cycles
Electrical life	2000 cycles
Operating temperature	-13°F(-25°C) ~ 140°F(60°C)
Mounting bracket	35 mm DIN rail
Tightening torque	2.5 N.m
Standard	**IEC60898-2**
Dimensions LxWxH	1.42 x 2.95 x 3.15 inches
Tightening torque	2.5 N.m
Standard	IEC60898-2
Dimensions LxWxH	1.42 x 2.95 x 3.15 inches

3.2.1.3 DC-DC Converter 36 - 96V to 12V 20A

An electronic circuit or device known as a DC-to-DC converter is used to change a direct current (DC) source from one voltage level to another. It can do this by bucking, bucking down, or changing the level using different topologies like buck, boost, buck-boost, or isolated converters. In many situations, where the input voltage has to be adjusted to meet the specifications of certain systems or devices, these converters are essential. By converting DC power from one voltage level to another, they are widely used in industrial equipment, renewable energy systems, portable electronics, and automobile electronics to effectively manage and regulate power delivery and ensure that different devices or system components operate as intended. The parameters of a DC-to-DC converter, including its input voltage range, output voltage, and current capacity, are described in the description "DC-DC Converter 36V - 96V to 12V 20A". The converter can produce a consistent 12V/20A output while accepting a broad range of input voltages, especially between 36V and 96V.

Table 3-3: Technical Data of DC-DC Converter

Input voltage	**36-96V**
Output voltage	12V
Output current	10A
Features	With short circuit, overcurrent, overvoltage protection and many other functions, to prevent damage during use.
Wiring	Red --input - Battery + 12V (output --LED +) Black - ground (sharing a common thread - Battery -)

3.2.1.4 RGB Control Box 12V

An RGB (Red, Green, and Blue) LED lighting arrangement that runs at a voltage of 12 volts is controlled by an RGB Control Box 12V. Users may usually adjust RGB LED strips or lights' colour, brightness, and occasionally their patterns or effects with this control box. It frequently has a number of features including the ability to be controlled by a remote, a variety of colour possibilities, several modes (such strobe, fade, or static hues), and perhaps even the ability to sync with sound or music. The control box’s operating voltage is indicated by the 12V specification. It may be used with 12 volts RGB LED lighting systems, which are widely utilized in accent lighting for automobiles, gaming settings, home decoration, and other applications where multi-coloured lighting that can be customized is needed.

Table 3-4: Technical Data of RGB Control Box

Working temperature	**-20 °C to 60 °C**
Power supply voltage	DC 12V
Output	3*2A
Function mode	20 mode
Dimensions LxWxH	62 x 35 x 23 mm
Static power consumption	<1W
Maximum load current	2A per way
Output power	12V <72W

3.2.1.5 Wheel Electric Bike Kit

E-Bike LCD Display Screen SW900

An LCD display panel that is put on electric bicycles provides users with a complete interface to control and observe the electric motor, battery capacity, and riding stats of the bike. These handlebar-mounted panels give important information including the amount of battery life left, the motor aid levels that have been set (eco, regular, or sport modes), the current speed as shown by the speedometer, trip data such as distance traveled, duration as well as average speed. They also allow user to control lighting, customize the e-bike's behavior, and get warnings on maintenance requirements or system issues. The LCD display of an e-bike works as a control panel, allowing users to customize their riding experience by changing the degree of assistance, monitoring the battery's condition, and controlling other functions of the e-bike.

Table 3-5: Technical Data of LCD Display

Part Type	E-bike LCD Display
Material	Plastic
Voltage compatible level	24V, 36V, 48V
Port	Waterproof port

DC Motor Controller by Lithium Battery

An electrical device called a DC motor controller controls the direction, speed, and power sent to a direct current motor. By controlling voltage and current, it works as a bridge between the power source and the motor, adjusting the motor's speed, torque, and direction of rotation. The complexity of these controllers ranges from simple resistors that change speed to more complicated systems like microcontroller-based setups or pulse-width modulation (PWM) controllers. Their capabilities include accurate speed control, reversal of direction, and torque management, which are useful for a variety of robots, industrial machinery, electric vehicle, and automation system applications. In addition to controlling speed and direction, these controllers frequently include protections against overcurrent and overvoltage to avoid damage to the motor and controller itself. This ensures reliable and secure motor operation under a wide range of conditions.

Table 3-6: Technical Data of Motor Controller

Controller	48V 1500W
Voltage	DC 36/48V
Rated Current	35±1A
Max Current	60±1A
Speed Set	1.1-4.2V Dual Model
Brake Input	Low Level
Booster	1 : 1

RIM with DC Motor 48V 1500W

Rear In-Wheel Motor (RIM) with a DC motor rated at 48V and 1500W generally refers to an electric propulsion system where the motor is incorporated directly into the wheel hub, usually in the rear wheel of a vehicle. By integrating the engine into the wheel, this arrangement streamlines the drivetrain and provides benefits including better traction, more even weight distribution, and more efficient power delivery. RIM systems are frequently seen in electric scooters, bicycles, and some cars. With a 1500 watts power capacity and 48 volts operation, these motors offer dependable and efficient propulsion, reducing the need for intricate transmission systems found in conventional internal combustion engine vehicles and facilitating the development of more straightforward electric drive solutions.

Table 3-7: Technical Data of RIM with DC Motor

Rim Size	28” (MTX33)
Voltage Input	48V
Outside Diameter	635±0.5mm
ETRTO	622mm
Inner Rim Width	26mm
Max Speed	50-60km/h
RPM	540rpm
Torque	35-45N.m

Break Lever

The brake lever on an e-bike activates the brakes similar on a regular bicycle or car. Squeezing the brake lever presses the braking system, whether disc brakes, rim brakes, or another type, slowing or stopping the bicycle.E-bike brake levers operate both disc and rim brakes and are commonly connected to the electric motor system. Some e-bikes have regenerative braking. The regenerative braking technology turns kinetic energy from braking into electrical energy to recharge the e-bike's battery when the rider pulls the brake lever.Thus, some e-bikes' brake levers can manage speed and stop the bike safely while also recharging the battery through regenerative braking.

Twist Throttle

Twist throttle devices are seen on several electric motorcycles. By twisting the handlebar grip, riders can control the electric motor's speed and power. The electric bike motor receives a signal when the throttle is twisted. The engine powers up without pedaling using this signal. This function allows users to operate the motor and accelerate the electric bicycle without pedaling. Twist throttles help the riders start from a stop or climb steep parts without pedalling. This applies especially when the cyclist has to accelerate quickly. However, not all electric bikes have twist throttles. Some of these bikes use throttle and pedal-assist systems, while others use only pedal boost.

Pedal Assistant Sensor (PAS)

A PAS sensor is an e-bike's "Pedal Assist Sensor." The electric motor assists the rider based on pedaling motion. The sensor delivers signals to the e-bike's motor controller, which modifies motor assistance based on the rider's pedaling speed, cadence, or torque. This method makes electric bike riding more natural. The PAS sensor activates the motor to assist the rider, at different power levels depending on the e-bike's assistance mode. Combining human effort with electric help makes e-bikes efficient and user-friendly, improving the riding experience.

3.2.1.6 Speaker Fidelity FT-204

The speaker which transforms electrical impulses into audible sound waves is a crucial part of audio systems. Speakers are used in many different settings and devices, such as public address systems, professional sound installations, home entertainment systems, and personal electronics like laptops and smartphones. They come in a variety of sizes and designs that are perfect for different audio needs and settings. It works by converting electrical information into mechanical vibrations that produce sound. It is made up of components like a voice coil, a magnet, and a diaphragm. Sound waves are produced when the diaphragm vibrates due to an electrical current flowing through the voice coil and interacting with the magnetic field created by the magnet. Because enclosures and cabinets can affect how sound waves are dispersed, they can improve the quality of sound produced by some speakers.

Table 3-8: Technical Data of Speaker

Model	FT-204
Rated Power	20W
Voltage Input	110V
Impedance	8Ω
Sensitivity	92dB
Frequency Response	60-18kHz
Dimensions L x W x H	250 x 140 x 130mm

3.2.1.7 Amplifier Wiring Kit

An amplifier wiring kit is needed to install an aftermarket amplifier in a vehicle's audio system. This is necessary to manage the amplifier’s increased power safely and efficiently. The bigger power line is necessary since the kit can withstand the increased electrical load without overheating or electrical issues. The grounding wire ensures a stable, interference-free electrical connection for better amplifier performance. Safety is improved by the fuse and holder in the package, which prevents spikes in electricity. The high-quality signal wires deliver audio signals from the head unit to the amplifier with consistency. Overall, the wiring kit protects the vehicle's electrical components and gives the amplifier power, signal, and grounding connections for reliable and amazing sound.

3.2.2 Electrical Connection Block Diagram

Figure below shows the overall connection of the devices as one unit.

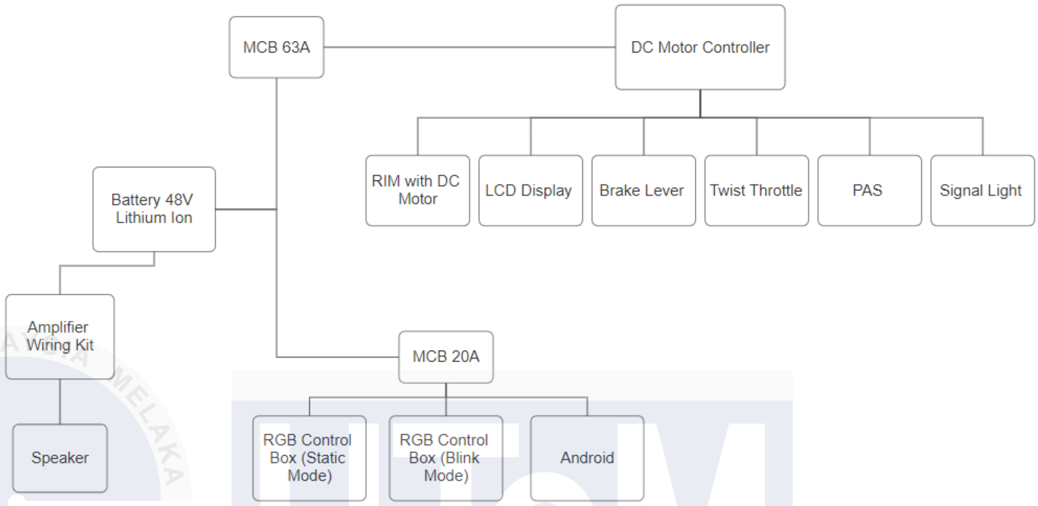

Figure 3-2: Overview of Connection Block Diagram

3.3 Experimental Design

The details for the methodology of experiments that will be conducted are described briefly in the experimental design. These experiments were designed to fabricate, to test the functionalities of components and to analyze the performance of three-wheel vehicle.

3.3.1 Experiment 1: Functionality of Electrical Components

For this experiment, the purpose is to test the functionality of the component parts whether it can be use or not.

Instrument Tools:

1. Multimeter

Procedure:

1. The mutltimeter and clamp meter were calibrated before using it.

2. The type of unit measurement of "DC Voltage" was selected on the multimeter and clamp meter.

3. The probe of red and black wire were connected accordingly and carefully to the component that need to be measure as listed below.
    - Battery
    - Speaker
    - Android Player
    - LCD display
    - RGB Control Box
    - DC Motor

4. The voltage of each of the components were measured and recorded.

3.3.2 Experiment 2: Performance Analysis of Trishaw - Speed Test

In this test, the purpose is to obtain the correlation between the speed and the mass of load. The result that is being priotized is such as Average Speed($Speed_{Avg}$) with the constant distance traveled of 100 meter. The speed of the vehicle are set to 10 km/h, 20 km/h and 35 km/h which labeled as SPEED 1, SPEED 2 and SPEED 3 respectively. In addition to the reliability of the data, the speeds are set by adjusting the speed control on control panel. Since the vehicle's system is embedded with the regulation system particularly on speed control, the speed of the trishaw will not exceed the setting value even when the throttle is fully twist. Each of the speeds are conducted with three additional load mass which are 0 kg, 50 kg and 100 kg, not include the mass of rider.

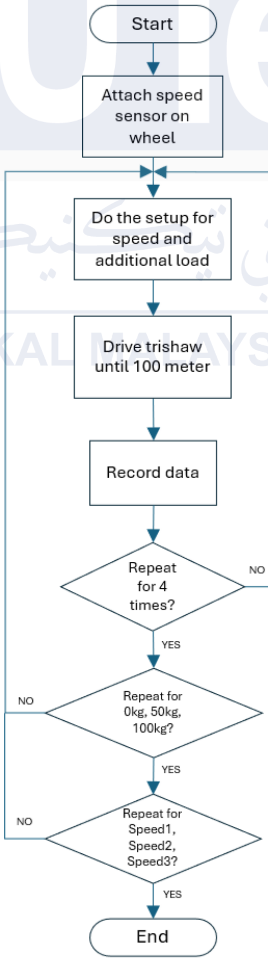

Figure 3-3: Flowchart Overview of Experiment 2

Instrument Tools :

1. Speedometers
2. Application of Starva
3. GPS trackers
4. Measure Tape (50 meter)

Procedure:

1. The starting point is decided and marked.
2. The distance of 100 meter of the horizontal road is measured from the starting point by using the measure tape and the ending point of the measurement is marked.
3. The digital speedometer and GPS trackers are connected to the Strava App.
4. The digital speedometer is attached to the one of the wheels of trishaw while the GPS Trackers is attached to the handle.
5. The vehicle is set to such conditions such as 10 km/h for speed, and no additional load.

Figure 3-4: Setting Speed to 10 km/h

6. Both digital speedometer and GPS Trackers are started the recording as soon the vehicle start to move from the starting point.
7. Both of the devices are stopped the recording when the vehicle reach the distance of 100 meter.
8. The parameters such as average speed and time taken for the vehicle move from starting to ending point are calculated by Strava server. Both of the data are recorded.

9. Step 6 until Step 8 are repeated for four times with the same conditions of vehicle.
10. Step 9 is repeated for different speeds which are 20 km/h and 35 km/h.

Figure 3-5: Setting Speed to 20 km/h

Figure 3-6: Setting Speed to 35 km/h

11. Step 10 also is repeated for different mass of load of 50 kg and 100 kg.
12. All of the recorded data are discussed.

3.3.3 Experiment 3: Performance Analysis of Trishaw – Power Consumption Test

In this test, there are three parts; three different angle of inclination, three different cases of terrain and travel around the FTKE's building. Each of the parts are deduced different set of results and conclusions. The locations for Part 1 and Part 2 are taking place such at:

3.3.3.1 Part 1: Three different angle of Inclination

In this part 1, the trishaw is tested with three different angle of inclination during driving on uphill. The purpose of it is to observed the behavior of the currents during driving uphill with the variable of angle of slope.

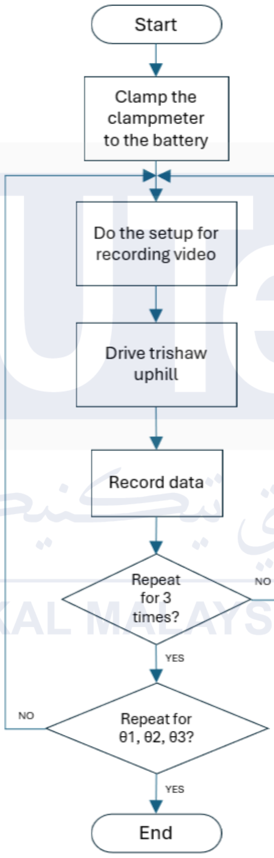

Figure 3-7: Flowchart Overview of Experiment 3 Part 1

Figure 3-8: The locations of the Experiment 3 Part 1

Instrument Tools :

1. Digital Protactor
2. Clampmeter
3. Measure Tape (50 meter)

Procedure:

1. The digital protactor is calibrated before use for taking measurement.
2. The starting point of the inclination is marked.
3. Distance of 30 meter is measured using measure tape from the beginning inclination and the ending point of measurement is marked.

Figure 3-9: Measuring 30 meter using measure tape

4. The angle of the inclination are measured with the interval of 5 meter each.

Figure 3-10: Measuring angle of Inclination using Digital Protactor

5. The average of the angle is determined such as below.

Angle 1, θ1 (º)	Angle 2, θ2 (º)	Angle 3, θ3 (º)
Hill 1	Hill 2	Hill 3
1.8	2.5	4.4
2.2	2.4	3.1
3.3	1.5	2.6
3	2	3.2
2.9	2.9	2.5
1.2	3	2.7
0.7	2.4	2.6

Avgθ1 (º)	Avgθ2 (º)	Avgθ3 (º)
2.16	2.39	3.01

Figure 3-11: Average angle of Hill 1, Hill 2 and Hill 3

6. The clampmeter is set to DC current measurement, and the wire that connected to positive terminal of battery is clamped.
7. The setup to record the video of changing currents is set as below.

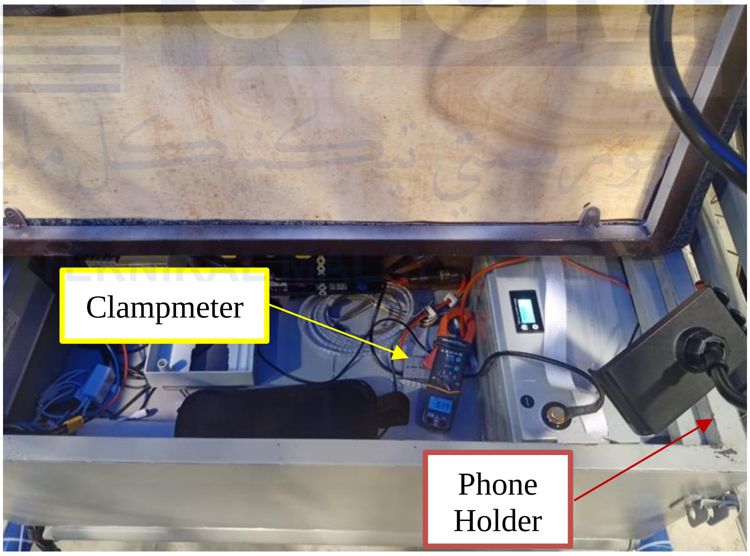

Figure 3-12: The setup before starting Experiment 3 Part 1

8. The video recorder is started to record as soon the vehicle started to move (fully twist throttle) and stopped to record when reach the ending point.
9. The data of the currents is documented from the recording video with 1 second of intervals for 10 seconds.
10. Step 8 until Step 9 are repeated for three times.
11. The experiment also is repeated for all the angle of inclination of the hills.
12. All of the recorded data are discussed.

3.3.3.2 Part 2: Three different cases of Terrain

In this part 2, the trishaw is tested with three different cases of terrains; horizontal or flat terrain, uphill and downhill. The difference of purpose between part 2 and part 1 is that, this part is to monitor how current will behave when driving on different type of terrains. Noted that the angle of inclination for uphill and downhill are the same.

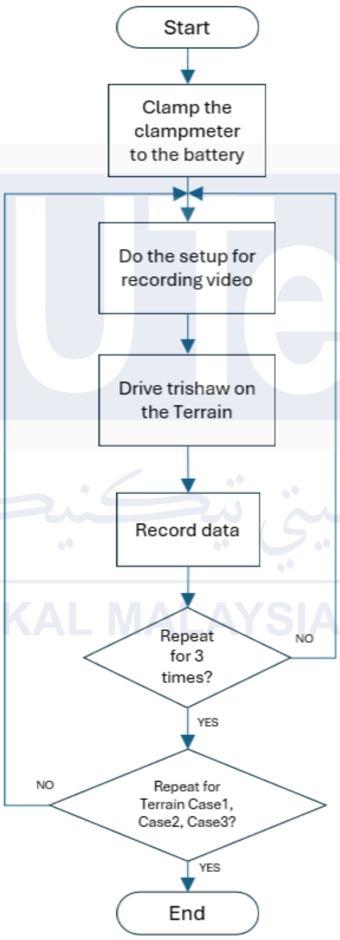

Figure 3-13: Flowchart Overview of Experiment 3 Part 2

Figure 3-14: The locations of the Experiment 3 Part 2

Instrument Tools :

1. Digital Protactor
2. Clampmeter
3. Measure Tape (50 meter)

Procedure:

1. The digital protactor is calibrated before use for taking measurement.
2. The starting point of the inclination is marked.
3. Distance of 30 meter is measured using measure tape from the beginning inclination and the ending point of measurement is marked.
4. The angle of the inclination for Uphill and Downhill cases are measured with the interval of 5 meter each and average of the angle is determined.
5. The clampmeter is set to DC current measurement, and the wire that connected to positive terminal of battery is clamped.

6. The setup to record the video of changing currents is set as below.

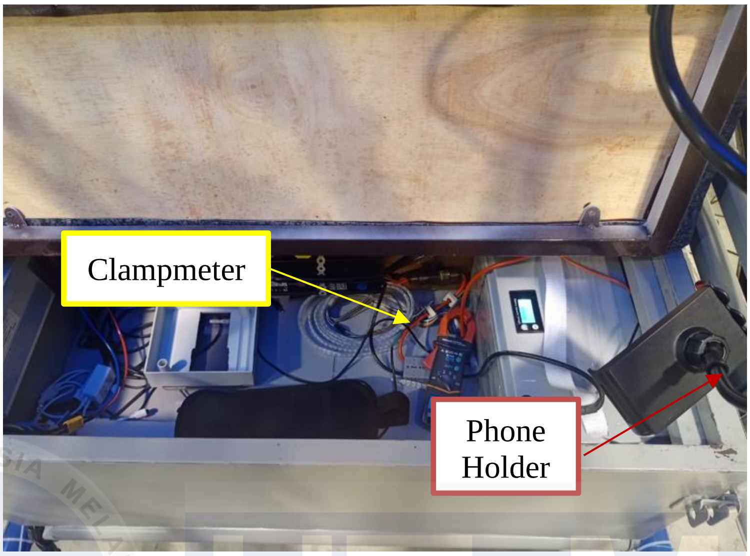

Figure 3-15: The setup before starting Experiment 3 Part 2

7. The video recorder is started to record as soon the vehicle started to move (fully twist throttle) and stopped to record when reach the ending point.
8. The data of the currents is documented from the recording video with 1 second of intervals for 6 seconds.
9. Step 7 until Step 8 are repeated for three times.
10. Step 9 also is repeated until all of the different type of terrains such as horizontal terrain, uphill and downhill cases are done.
11. All of the recorded data are re-organized and discussed.

3.3.3.3 Part 3: Travel around the FTKE's building

In this part 3, the trishaw is drove around FTKE's building for about 3 count of laps to ensure the realibility of the data. The intention of this part is to see the decrement changes of the voltage measured in respect to the time travelled. The chosen route is as follow:

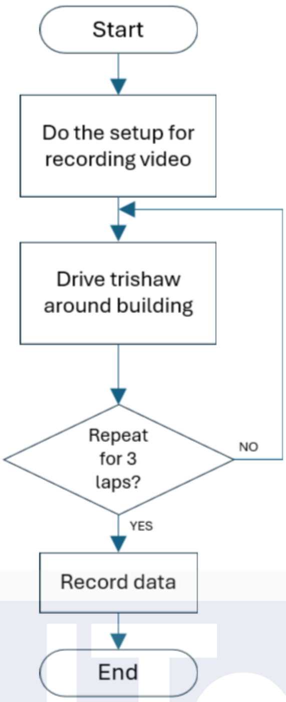

Figure 3-16: Flowchart Overview of Experiment 3 Part 3

Figure 3-17: Route of Road near FTKE's Building

Instrument Tools :

1. Battery Voltage Indicator
2. Application of Strava
3. GPS trackers

Procedure:

1. The starting and ending point of this experiment is decided.
2. The setup to record the video of changing currents is set as below.

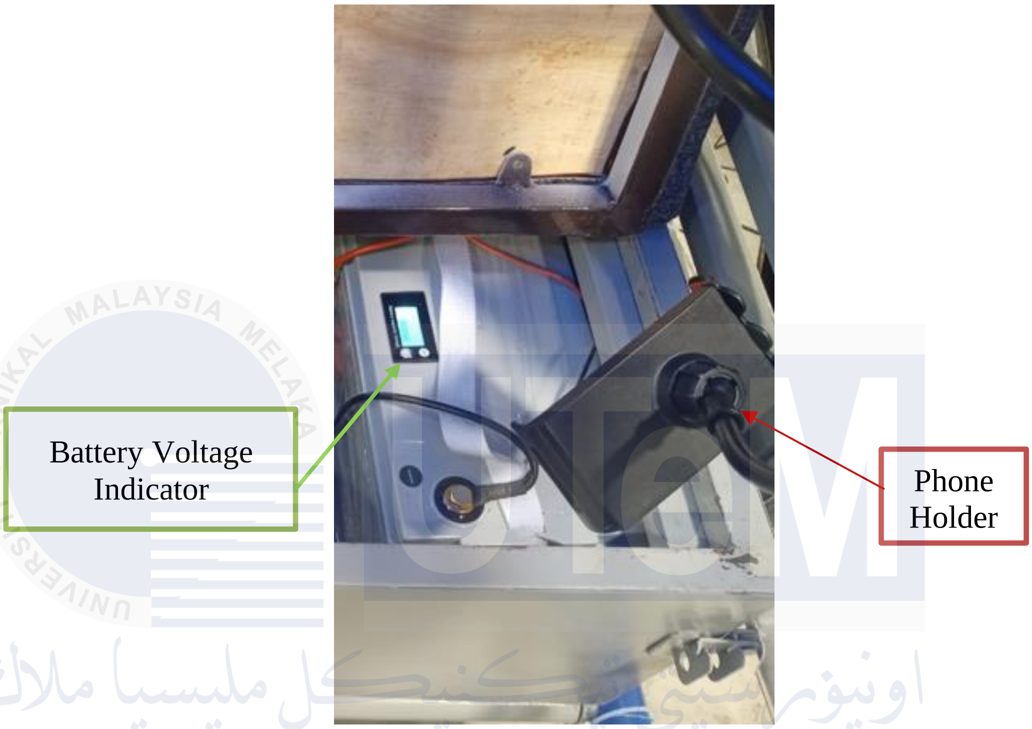

Figure 3-18: The setup before starting Experiment 3 Part 3

3. GPS trackers is connected to the Strava Apps.
4. The initial voltage reading is recorded.
5. The GPS trackers and video recorder are started to record when the vehicle is started to move from the designed starting point.
6. The vehicle is driven for 3 consecutive laps, around the FTKE’s building.
7. The GPS trackers and video recorder are stopped to record when the vehicle has fulfilled the 3 consecutive laps and reached the ending point.
8. Then, the voltages of the vehicle throughout the consecutive laps are documented with intervals of 15 seconds for the total of 12 minutes.
9. The voltage vs time curve line is discussed.

3.4 Ethics and Safety

Analyzing the performance of an electrical trishaw involves delving into a complex web of ethical considerations that encompass safety, environmental impact, social equity, and cultural sensitivity. Safety stands at the forefront, as ensuring the well-being of passengers, pedestrians, and other road users is paramount. This entails evaluating the reliability of the vehicle, the effectiveness of its safety features, and adherence to regulations governing its construction and operation. A commitment to safety not only safeguards lives but also upholds the ethical imperative to protect human welfare.

When conducting experiments to analyze the performance of electrical trishaws, ensuring safety through rigorous risk assessment and effective risk control measures is paramount. One significant risk is the possibility of vehicle malfunction or failure, which could lead to accidents or loss of control. To mitigate this, regular maintenance checks should be performed, identifying and addressing potential issues beforehand. Additionally, having backup vehicles on standby and implementing emergency shutdown procedures can minimize the consequences of unexpected failures, enhancing overall safety during the experiment.

Weather conditions pose another risk factor that can impact the safety of the experiment. Adverse weather such as rain, snow, or strong winds can affect the stability and control of the trishaw, increasing the risk of accidents. Monitoring weather forecasts and rescheduling experiments if adverse conditions are expected can help mitigate this risk. Additionally, providing drivers with appropriate protective gear and ensuring the trishaw's tires and brakes are suitable for wet or slippery surfaces can enhance safety in inclement weather conditions.

By meticulously addressing these ethic and safety considerations throughout the experimentation process, researchers can conduct thorough analyses of electrical trishaw performance while minimizing risks to all involved parties. Prioritizing safety not only upholds ethical standards but also enhances the credibility and reliability of the research findings, ultimately contributing to the advancement of transportation technology in a responsible and sustainable manner.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the results of each experiments in Chapter 3 are presented and discussed.

4.2 Results

4.2.1 Experiment 1: Functionality of Electrical Components

Results below shows the measurement of the voltage for each of the electrical components indicating that the components are able to produce its predicted output. However, some of the voltage of the component was not being able to measured using measurement tools because the voltage was too low.

Table 4-1: Measurement Reading of Electrical Components

Component	Voltage (V)
Battery	48.30
Speaker	0.03
LCD display SW900	-
RGB Control Box (Static Mode)	11.50
RGB Control Box (Blinking Mode)	11.40
DC Motor	-
DC Motor Controller	

4.2.2 Experiment 2: Performance Analysis of Trishaw – Speed Test

Figure 4-1 below illustrates the relationship between load mass (kg) and average speed (km/h) for three different speeds, labeled as SPEED 1, SPEED 2, and SPEED 3. The average speed, $Speed_{Avg}$ that are collected during the experiment are organized and further calculate the average of $Speed_{Avg}$, $Speed_{Avg2}$ for each speed. Then, the graph of $Speed_{Avg2}$ is plotted against load mass, m for each speed. The results as follow.

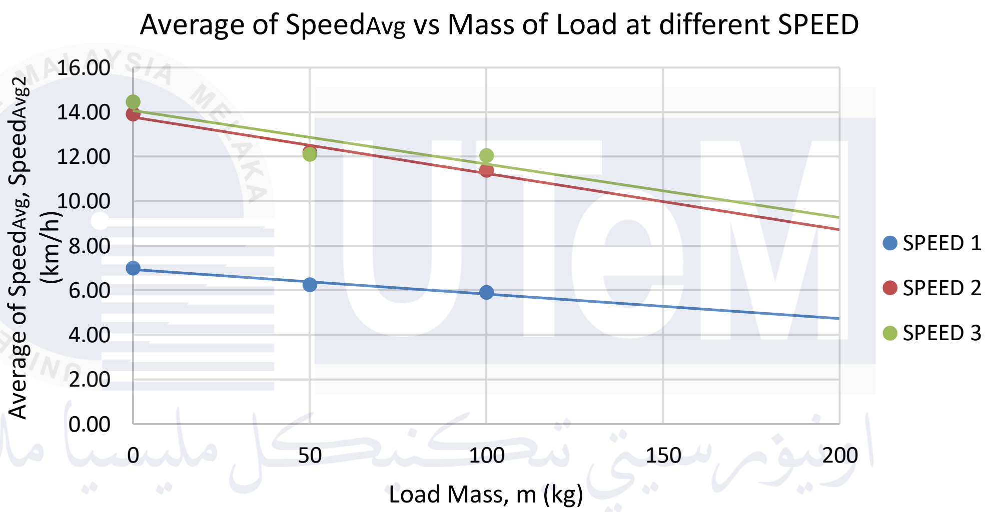

Figure 4-1: Graph of Average of $Speed_{Avg}$ vs Mass of Load at three different SPEED

The average speed of all three speeds shows a decreasing tendency as the load mass increases. With no additional load, SPEED 1 begins at about 8 km/h and falls off gradually, exhibiting a slower rate of drop than the other speeds. When there is no additional load, both SPEED 2 and SPEED 3 begin at about 14 km/h and decline more sharply. This indicates that increasing load mass has a greater impact on higher initial speeds, resulting in a faster speed reduction. The graph shows that increasing load mass has a negative impact on average speed overall, with a more noticeable reduction at higher speeds.

It is seen that the average speed curves for SPEED 2 and SPEED 3 almost touch. This can be explained by the DC motor's efficiency. The performance of DC motor under different loads is largely dependent on their efficiency. It operates within specific efficiency ranges, and its efficiency influences how speed varies when it is subjected to increasing loads. When operating within the motor's high-efficiency range, both the SPEED 2 and SPEED 3 settings may cause the motor to behave similarly in terms of speed under various loads. This is due to the motors' ability to manage increasing loads within this ideal range with little need for speed decrease, resulting in roughly equal average speeds.

Furthermore, a DC motor's torque-speed relationship is usually linear. This implies that if the voltage stays constant, the speed will drop proportionally as the load increases. Their speeds will be near if the voltages is set for SPEED 2 and SPEED 3 result in torque outputs that are comparable for the specified loads. The curves almost overlap because of the linear relationship, which suggests that slight variations in torque owing to load can also result in slight variations in speed.

Finally, the recorded speeds may be affected by the motor load curve and saturation point. DC motor load curves show how load and speed are related to one another. There may be less of a speed differential between settings when the motor is close to its rated capability. Near these saturation values, SPEED 2 and SPEED 3 can be set with almost equal performance, resulting in almost same average speeds under various loads.

4.2.3 Experiment 3: Performance Analysis of Trishaw – Power Consumption Test

In this particular, there are three sub-test that are held which are three different angle of hill, three different cases of road and lapping around the FTKE building.

4.2.3.1 Part 1: Three different angle of Inclination

The change of currents in the recorded video thoroughout the test, is documented with the interval of 1 seconds for 10 seconds. The reasons it is only 10 seconds because the time taken for the vehicle to go uphill at the lowest angle of slope takes about 10 to 12 seconds. Therefore, the average of the currents is calculated through the time for all of the inclination with standardized timeline.

From the Figure 4-2, the graph for all three hills, the average current decreases slightly over time, indicating that as time progresses, the current needed to maintain movement decreases. Around 10 second mark, the currents for all three hills appear to stabilize, with Hill 3 around 14 A, Hill 2 around 12.5 A, and Hill 1 around 12 A. This indicates that the rickshaw have reached a steady-state condition where the force required to maintain motion becomes more constant.

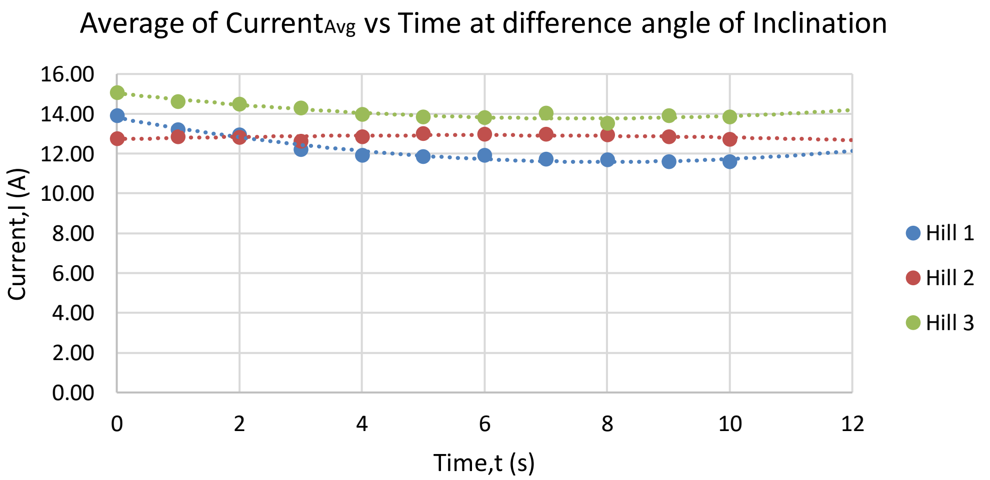

Figure 4-2: Graph of Average of CurrentAvg vs Time at difference angle of Inclination

The differences in the current levels between the hills suggest that the angle of inclination significantly influences the current draw. Hill 3, which representing the steepest inclination of 3.02º, consistently shows the highest current values, indicating that the system requires more power to operate at this angle. In contrast, Hill 1, which shows the lowest current values because of the lowest angle of inclination value of 2.16º. This relationship highlights how increased inclinations demand more effort from the motor to overcome gravitational forces, leading to higher current consumption.

When a system operates on an inclined plane, gravity acts on it in two components; one parallel to the incline and one perpendicular to it. As the angle of inclination increases, the parallel component of the gravitational force, which pulls the system downward along the incline, becomes larger.. As theta increases, the sine of the angle increases, leading to a larger parallel force that the motor must overcome to move the system uphill.

To counteract this increased gravitational force, the motor must generate more torque, which translates to a higher power requirement. The power required by the motor is directly related to the current it draws, according to the equation P=VI, where P is power, I is current, and V is voltage. As the need for power increases to overcome the gravitational pull on steeper inclines, the motor compensates by drawing more current.

DC motors have specific characteristics where the torque required increases with the load. On steeper inclines, the load on the motor increases significantly because it has to work harder to lift the system against the stronger gravitational component. This increased load demands more torque, and to provide this torque, the motor draws more current from the power source. Additionally, motors have efficiency ranges where they perform optimally. Operating outside these optimal conditions, such as under increased load due to higher inclines, can result in the motor operating less efficiently, thus requiring even more current to maintain the desired performance.

The graph from Figure 4-3, it shows that there is a clear positive correlation between the angle of the hill and the average current required. As the angle of the hill increases, the average current needed to move the rickshaw also increases.

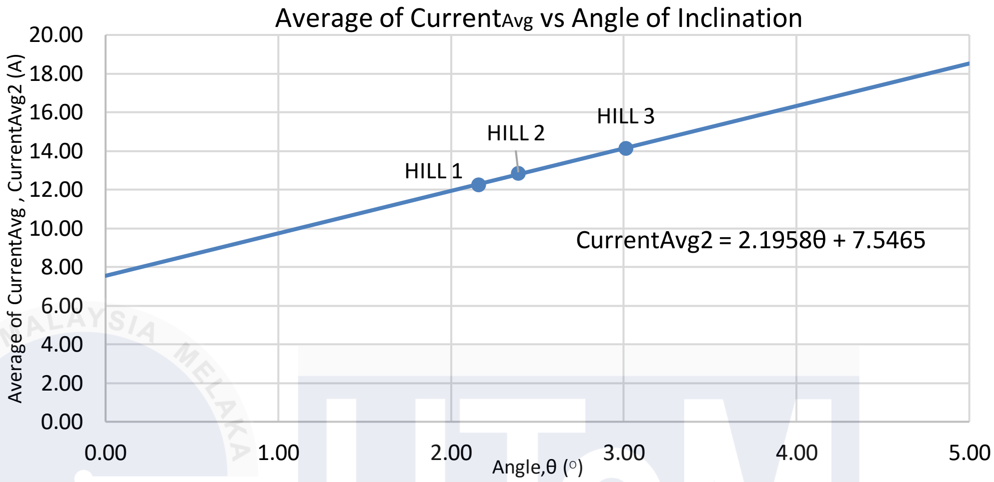

Figure 4-3: Graph of Average of Current$_{Avg}$ vs Angle of Inclination

The steady linear trend demonstrates that both the motor and the system it operates have a reliable and predictable reaction to an increased load caused by steeper inclines. The motor's efficiency remains consistent across various inclinations, resulting in a proportional increase in current draw rather than any unpredictable or nonlinear behaviour. These findings indicate that the motor functions optimally within the tested orientations, ensuring constant and efficient execution.

Given that the DC motor has a rated input current of 31.25A, using this value as the cut-off current it is estimated that the trishaw can function up to an angle of inclination of 10.79º with the current increment per degree of inclination is 2.1958A/θ. However, the excessive weight of the structural design makes it difficult to accomplish this maximum angle value.

The motor's internal components would experience significant mechanical strain due to the constant operating at high inclines. The bearings, windings, and other components of the motor are designed to endure stress within specific limitations that correspond to the rated current. Operating at significantly greater currents speeds up the process of deterioration, reducing the motor's lifespan and raising the chances of mechanical breakdown. The overload structural design is specifically designed to handle temporary overloads and is not capable of mitigating the long-term consequences of constant high-current operation.

In addition, the motor's efficiency decreases while working above its designated current. The design parameters of the motor, such as efficiency curves, are optimized specifically for its rated current. Increased electrical currents result in amplified energy dissipation in the form of heat, hence diminishing the overall effectiveness of the motor. This lack of efficiency results in a greater amount of input power being dissipated as heat instead of being transformed into valuable mechanical energy, hence worsening the problem of overheating.

The motor's safety systems, including heat cut-offs and current limiters, are specifically intended to safeguard it from exceeding safe operating limits. These safety mechanisms would often engage to prevent harm when the motor tries to operate at high inclinations, such as 10.79º. Therefore, the motor would be unable to sustain continuous operation at such extreme angles, as these safety systems would periodically cut it off to avoid overheating and damage caused by excessive current.

4.2.3.2 Part 2: Three different cases of Terrain

Same with previous part, the change of currents in the recorded video thoroughout the test, is documented with the interval of 1 seconds for 6 seconds only because the time taken for the vehicle to go downhill at the lowest angle of inclination takes about 6 to 8 seconds. Therefore, the average of the currents is calculated through the time for all of the cases with standardized timeline.

The graph in Figure 4-4 demonstrates how different terrains impact the current required to move the rickshaw. The graph illustrates the current required by a rickshaw over time for three different terrains: flat or horizontal terrain (Case 1), uphill (Case 2), and downhill (Case 3). Initially, the uphill scenario demands the highest current which is around 15A, while the flat and downhill scenarios require moderate at around 11A and lower currents at around 10A, respectively.

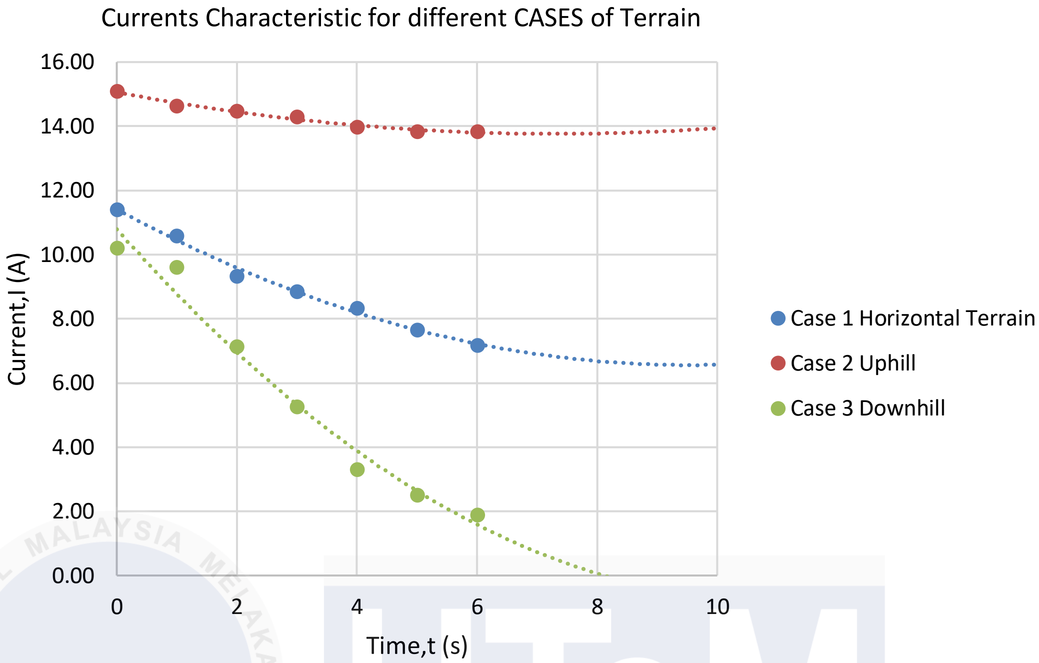

Figure 4-4: Graph of Current vs Time at different CASES

For the horizontal terrain, this pattern indicates that on flat ground, the motor initially requires a moderate level of electric current to overcome inertia and initiate motion. As the system reaches a stable state and remains in operation, the resistance and friction gradually reduce, resulting in a slight decrease in the amount of current being drawn. This indicates that the motor achieves a stable condition in which it functions optimally with reduced power demands following the initial period of starting up.

On the other hand, in a situation when the road is going uphill, the initial electric current is the most out of the three situations, beginning at roughly 15.1A and gradually dropping to about 14A at the end of the specified time period. The sustained high current indicates the motor's need to overcome gravity forces when traveling uphill due to higher demand. The gradual decline over time may be explained by little calibrates as the motor adjusts to a more steady operation. However, in general, the current level remains somewhat elevated due to the continuous requirement to counterbalance the inclination. This shows that a greater amount of energy is needed to sustain movement in opposition to the force of gravity.

In a downhill situation, this sharp decline illustrates that the motor needs much less power as it moves downhill, due to the aid of gravity. Often, the motor can switch to a regenerative braking mode or a no-load situation, resulting in a significant reduction in current consumption. This leads to little energy usage as the system utilizes gravitational forces to maintain its motion.

When comparing different types of terrain, uphill slopes require the greatest and most constant flow of electricity, which indicates the extra power required to resist the force of gravity. The presence of a horizontal terrain indicates a consistent and modest consumption of energy, suggesting a state of equilibrium between overcoming resistance and ensuring optimal performance. Conversely, when it comes to downhill terrain, there is a significant decrease in the current, which emphasizes the lower power needs as the motor takes advantage of the help provided by gravity.

4.2.3.3 Part 3: Travel around the FTKE's building

The graph from Figure 4-5 provides a detailed view of how the voltage varies over time. It displays both the instantaneous voltage measurements and a linear trend line that indicates the overall trend in voltage variation over the full timeline of the laps traveled. By observing the pattern of curve line, the number of laps traveled also can be determine, in this case it is 3 consecutive laps.

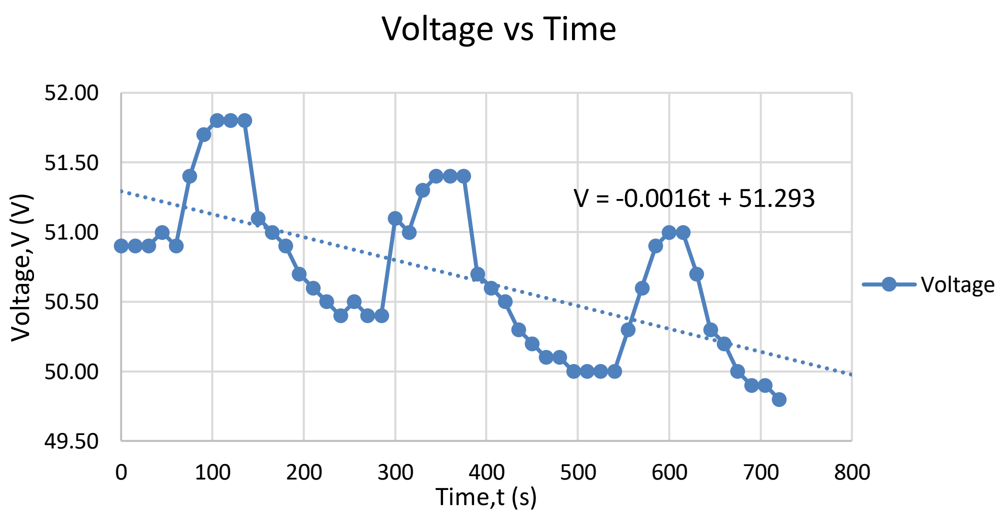

Figure 4-5: Graph of Voltage vs Time for three consecutive laps

Along the graph, there are noticeable variations in voltage, characterized by recurring peaks and troughs. The fluctuations indicate dynamic changes in the power requirements of the system or fluctuations in the effectiveness of the power supplied. As an example, the voltage increases to approximately 51.8V at specific locations and decreases to approximately 51.1V at other locations. The oscillations may arise due to fluctuations in the system's load, with high-demand periods leading to a decrease in voltage and low-demand or recovery periods allowing for an increase.

Although there are regular changes, the linear trend line exhibits a distinct negative gradient, implying a progressive decline in voltage as time progresses. The overall decrease indicates that the system's power supply is undergoing a deficit in energy. This phenomenon displays the inherent discharge process that occurs as a lithium-ion battery gradually loses its stored energy. Alternatively, if the system is consistently relying on a continuous power supply, it could suggest a rise in inefficiencies or an increase in power requirements that the source cannot sustain permanently.

The graph exhibits significant voltage peaks at specified periods, particularly at around 150 seconds, 375 seconds, and 615 seconds. These peaks indicate instances when the system experiences recharging, lower load circumstances, or receives a surge in power supply. The consistent gaps between these peaks reveal the presence of cyclical activities or actions within the system that momentarily decrease the power demand or increase the power intake, so enabling the voltage to regain its normal level.

Considering the nominal operating voltage of the DC Motor is 48V, we can predict that the electrical trishaw can operate for approximately 34.3 minutes. This estimation is based on a voltage depletion rate of 0.0016V/s while continuously driving laps around FTKE's building without making any stop for longer duration. The forecast duration is only 34.3 minutes since the chosen route primarily consists of uphill inclines, which require more strength for handling the load.

4.3 Conclusion

This chapter gives a thorough look at how well the electrical trishaw works and how useful it is. A set of careful tests are used to make this happen. The focus was on how well the electrical parts worked, how fast they went under different loads, how much power they used on different types of terrain, and how the voltage changed over time. The results of these tests give us important information about how the trishaw works and point out places where it could be better.

After looking closely at the electrical parts, it was found that most of them had the expected voltage levels, which means they are working properly. Despite this, some parts, like the speaker, had very low volts that made it hard to get accurate readings. This shows how important it is to have precise and careful measuring tools to fully check the efficiency of all electrical parts.

There was a clear link between the mass of the load and the average speed in the speed tests that were done with different loads. When the load got heavier, the speed slowed down, especially for faster speeds at the start. It's mostly because the DC motor is very efficient when working with different loads, there is a link between power and speed, and the motor is very close to its saturation point.

An experiment that tested how much power the trishaw used on different types of hills and terrains showed that steeper hills needed more current because they needed more power to counteract gravity. This makes it clear that the average power needed is related to the angle of the hill. The flow of electricity was clearly different on flat, rising, and falling ground, as shown by experiments. Because of gravity, conditions that were going downhill needed the least amount of current and conditions that were going uphill needed the most. These points must be noted in order to get the most out of power control and efficiency. Looking at voltage changes over time also showed changes caused by changing load conditions and changes in how well the power source works. These changes, along with a general downward trend, show that there is still a lack of energy. Based on this trend, the trishaw should be able to run around the FTKE building for about 34.3 minutes before it hits the 48V cut-off voltage.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In summary, this study provides a comprehensive understanding of the operation and assessment of an electric trishaw. The project's concept and justification were introduced in Chapter 1, emphasizing the need for an effective and sustainable mode of transportation. The challenges with fuel consumption, pollution, and the functionality of traditional trishaws under various load and terrain conditions were highlighted in the problem statement. The goals were set to analyze its components and gauge its effectiveness.

A thorough review of the literature on the design of three-wheel vehicles, performance analysis techniques, and the lack of studies in this field was provided in Chapter 2. Due to its practicality and reliability in assessing performance, the study concluded that the experimental testing approach is the most suitable for this project. The methodology for the project was covered in full in Chapter 3, which also included conducting experiments to investigate performance and evaluating the operation of electrical components. The electrical components are put through testing to make sure they meet the criteria.

The results of the performance analysis were reported in Chapter 4. The results of the speed test showed a distinct and direct correlation between the mass of the load and the average speed, with higher weights resulting in slower speeds. The power consumption test revealed that different terrains had different effects on current consumption, with steeper inclines requiring more current due to higher power demands. An analysis of the voltage over time showed oscillations brought on by shifting load circumstances, which predicted an approximate operating period of 34.3 minutes to reach the 48V cut-off threshold.

Finally, the study provided useful insights into the operation of electric trishaws under various conditions. The results pinpoint certain areas where efficiency and power management can be improved, ensuring the dependability and effectiveness of the trishaw in real-world situations.

5.2 Recommendations

Using advanced analytical methods such as Finite Element Analysis (FEA) and machine learning models significantly enhance the performance analysis of three-wheel electric vehicles. Detailed stress, temperature, and vibration tests made possible by FEA help to identify structural weaknesses, areas expected to be under great stress, and overheating dangers. This knowledge helps to build strong parts that increase consistency and lifespan under several running environments. By estimating performance indicators like battery life and range, identifying outliers indicating of possible problems, and optimizing power management for maximum efficiency and long range. These approaches are to ensure the optimal performance, provide informed design decisions, and improve the general reliability and effectiveness of three-wheel electric vehicles.

Setting up like a black box in transportation, the three-wheel electric vehicle's data logging system continuously gathers real-time data on performance criteria like speed, power consumption, and environmental variables. Detailed analysis both during and after vehicle operation is made possible by this extensive data collecting, therefore helping to identify problems and maximize performance. This approach improves inspection capability and maintenance by ensuring the accuracy and security of the data, therefore giving a dependable and complete understanding of the vehicle's behaviour under many circumstances. Eventually, this method produces more effective troubleshooting, improved performance analysis, and more general vehicle dependability.

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