POWERCARE: A BATTERY HEALTH MONITORING SYSTEM TO PROLONG THE LIFESPAN OF LEAD ACID BATTERIES FOR 3-WHEELED ELECTRIC BICYCLES

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ABSTRACT

PowerCare: A Battery Health Monitoring System is designed to reduce the cause of battery degradation. of lead-acid batteries used in three-wheeled electric bicycles by preventing overcharging. The system offers monitoring of the voltage and current, alert mechanisms such as alarm and email notification, and an automatic cut-off feature. When the battery charge reaches 90–93% equivalent to 53–54V, a local alarm starts to sound to notify the user. At 95% equivalent of 55V, charging would be automatically stopped, and an email alert is sent, ensuring safe and efficient charging practices. Final testing showed high system accuracy, with 98.12% in voltage monitoring and 94.95% in current monitoring. This helps reduce battery degradation, promoting sustainability and improved performance. The system is cost-effective and suitable for widespread use in low-cost electric mobility solutions. Future recommendations include better sensor calibration and the integration of SMS notifications to improve user accessibility and responsiveness. PowerCare represents a practical step toward smarter battery management in electric vehicles.

1. 0 INTRODUCTION

Electric bicycles (e-bikes) are an eco-friendly and cost-efficient mode of transport that are growing in popularity in the Philippines, ranking 7th globally in e-bike ownership. Despite their advantages, battery degradation—particularly in lead-acid batteries commonly used in e-bikes—remains a major concern, often caused by overcharging. Such degradation not only shortens battery lifespan but can also pose safety risks, including fire hazards, as highlighted by several fatal incidents. Lead-acid batteries, while affordable and recyclable, are vulnerable to misuse and lack advanced protection features. In response, the proposed PowerCare system aims to monitor and manage battery health in real time for 3-wheeled e-bikes. This system seeks to prevent overcharging, extend battery life, enhance user safety, reduce maintenance costs, and minimize environmental pollution caused by e-waste. The study is driven by both practical and environmental needs, making it a valuable contribution to sustainable transportation solutions.

PowerCare is an innovative monitoring system designed to reduce lead-acid battery degradation in 3-wheeled electric bicycles. With the growing demand for sustainable transport, efficient battery management has become crucial. PowerCare helps extend battery life, lower replacement costs, and minimize environmental impact by reducing e-waste. The system delivers real-time data to promote battery longevity and user safety. Early surveys show positive interest in such technology, as it can prevent overcharging and costly failures. Overall, PowerCare aims to enhance sustainability, safety, and cost-efficiency in electric vehicle battery management.

1.1 Objective of the Study

This project aims to design a battery health monitoring system to prolong the battery lifespan of lead acid batteries for the e-bikes, which will be implemented using hardware and software integration. Together with the following specific objectives:

- To design a responsive system for monitoring the voltage and current of a lead acid battery.
- To design a cost-effective and accurate monitoring system that ensures the measures of the voltage and current values.
- To design a system that can display the voltage and current while charging.
- To implement a system with alert alarms and email notifications for the user.

1.1.1 Scope and Limitations of the Project

The study aims to develop a system capable of continuous monitoring while charging the battery of electric bicycles, including data obtained parameters. The PowerCare system focuses on monitoring the voltage and current of lead-acid batteries in 3-wheeled e-bikes to prevent overcharging and reduce battery degradation. It includes features like an alert alarm, auto cut-off mechanism, and email notifications to inform users when charging is nearly complete. Designed for sustainability and cost-effectiveness, it aims to minimize battery replacements. However, the system has limitations—it does not account for environmental factors like temperature, user behavior, or driving patterns, and its email feature depends on internet access. It supports auto cut-off but requires manual activation. For safety, the system is only tested with lead-acid batteries, not lithium-ion types. While PowerCare enhances battery care, it does not make batteries last forever—it simply helps extend their usable life through monitoring and timely alerts.

2. 0 REVIEW OF RELATED WORK

[1] Electric bicycles, or e-bikes, are one of the most popular types of EVs that are now familiar to allow for short-range transport. E-bikes are eco-friendly vehicles that provide a practical and cost-efficient alternative to the high fuel cost since they use batteries compared to traditional cars that use traditional combustion engines. [2] Based on Shah K. (2022), among 17 countries that participated in the statistical metrics conducted, the Philippines ranked 7th place in the population who personally owns an e-bike. In addition, it provided the owner's gender identity of the e-bike. Moreover, [3] the Land Transportation Office (LTO) (2023) states that owning an e-bike is a trend because it has become more popular with the increasing awareness and campaign against environmental pollution. Additionally, there are several popular brands of e-bikes in the Philippines: Keso, NWOW, Honda, Ecooter, and Niu (Ride'n Tech, 2023).

Batteries are the power source of electric vehicles, which influence the unit's overall performance, while battery loss is a common concern in most instances. [4] A battery loss is the battery's decreasing performance, which can shorten the battery's lifespan and hinder the unit's performance. [5] Many lead acid batteries were used for storage in grids, early in the electrification age from 1910 to 1945. Stationary lead-acid batteries must meet higher product quality standards than starter batteries. Typical service life is 6 to 15 years with a cycle life of 1,500 cycles at 80% depth of discharge, and they achieve cycle efficiency levels of around 80% to 90%. Lead acid batteries provide well-developed, well-studied, and low-cost technology that is used in cars as well as trucks. [6] According to Steve (2024), these batteries are used in e-bikes, are cheaper, and recyclable than lithium-ion batteries but do not last long if mistreated. Second, most electric vehicles allow the replacement of batteries, but this is not a cheap affair. [7] Evangelista (2020). The battery in any electric vehicle degrades in a manner that cannot be predicted, this ends up frustrating the owners when the battery dies suddenly, and they are left stranded.

Based on a preliminary survey in Tanauan City Batangas, 5 respondents state that overcharging is the leading cause of battery degradation. Charging batteries beyond their capacity can be dangerous and decrease battery lifespan and overall performance. Overheating of the batteries is a result of overcharge, which may cause unpredictable explosions and leakage of chemicals that pose health risks. [8] The article in Khaleej Times (2024), with the headline ***"Family of five, and three young persons died in lithium battery fires - the e-bike discourse goes global."*** stated that a family of five — including three young children — died in a massive fire that broke out in their residence in the Philippine province of Pangasinan. On Tuesday, the police identified the cause of the blaze: An overcharged electric bike. An investigation was conducted by local fire protection. Authorities revealed that the e-bike was left plugged in overnight on the ground floor of the family's home in the municipality of Pozorrubio. As stated by a fire officer of the Philippine News Agency (PNA), Their electronic bike does not have an automatic switch mechanism that would stop once the charging was completed. Also, a recent news report by the PTV Philippines (2024) states that a family of three died in a fire in Bulakan, Bulacan. Based on the authorities, the cause of the fire was the e-bike that was left plugged in.

3.0 METHODOLOGY

This research employed a prospective research design utilizing the survey questionnaire method, which is an organized communication technique to gather valuable insights from the experts in the field of electric vehicles. The preliminary survey questionnaires were distributed to respondents who are experts in the field of electric vehicles, particularly on e-bikes, to recognize key points, areas of agreement, and any different views. After that, researchers continued to gather new information about this study and adjust questions on the questionnaire, when necessary, to derive enough evidence from it.

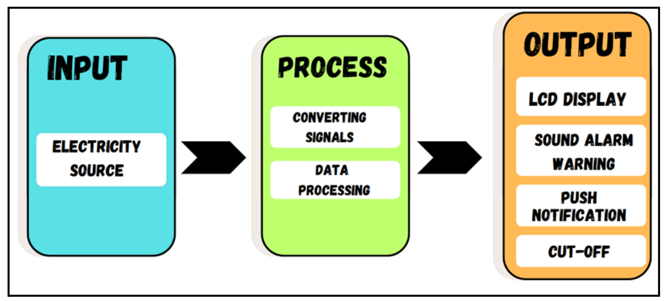

FIGURE 1. *IPO DIAGRAM*

The Input-Process-Output (IPO) process of the system provides a visual flow of direction. The input needed by the system is the electricity source from the power supply that needs to charge e-bikes. The process stage includes the conversion of signals, where the current flow will be converted to supply the microcontroller and the electric bicycle charging process. Lastly, the output shows the result of how the system works, the data gathered by the sensors, which is the voltage and current value that will be shown to the LCD with the display by the microcontroller. The cut-off features will help to prevent overcharging due to this process and may help the battery to consume exactly the voltage and current needed. In addition, the sound alarm and email notification will be an indicator for the user that the charging process is almost done and needs to be unplugged from the outlet, and the notification also notifies the user about the condition of the battery.

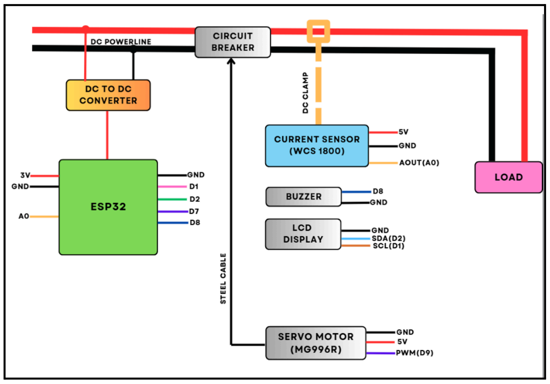

Figure 2. *BLOCK DIAGRAM*

This block diagram shows the power monitoring and control system using an ESP32. A comprehensive explanation of its components and workflow of the system begins with a 220V power supply, which is converted to DC using the electric vehicle charger. The obtained voltage in DC is then reduced further to the required voltage level for the battery of the electric vehicle through a DC-to-DC converter. A second conversion is done to scale down the voltage to 5V; this is using a 48V to 5V converter on the other end, which provides power to the microcontroller while the other components are connected. It is worth mentioning that the ESP32 acts as a microcontroller of the system. It is coupled with numerous sensors, including the current sensors, to prompt the power supply parameters. These sensors determine the set voltage and current levels required and supply the ESP32 with real-time information. Also incorporated in the system is a microcontroller that displays the monitored data on an LCD and it is responsible for sending the email notification that is held to the user.

If the voltage and current readings exceed predefined thresholds, the buzzer is activated as an alert to indicate that the power flow has been stopped, and this is the sign that the e-bike charge is already done. The diagram uses a legend to denote various elements to make it easy to understand the connections and interactions between various parts of the system. Once the data is gathered by the system, the percentage error is determined to test its accuracy.

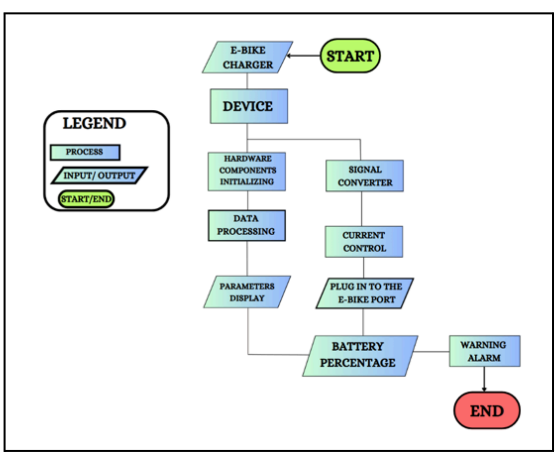

Figure 2. *BLOCK DIAGRAM*

The flowchart illustrates the operational process of PowerCare within the e-bike charging system. The process begins with the connection of the e-bike charger to the researcher's system, which subsequently activates and initializes the main hardware components. A signal converter then adjusts the power signal to align with the battery's voltage, ensuring precise regulation of voltage and current throughout the charging process. Following this, the system collects and analyzes charging data, effectively managing the charging current to prevent overcharging. A real-time parameter display provides the user with charging status updates, prompting them to connect the charger. Additionally, a warning alarm system alerts users to any potential risks. Once the battery reaches full charge, the system exits the charging loop, ensuring a safe, efficient, and reliable charging process.

4.0 RESULTS AND DISCUSSION

Prototype Setup. The table shown above is a list of prototype components, which are categorized into hardware and software.

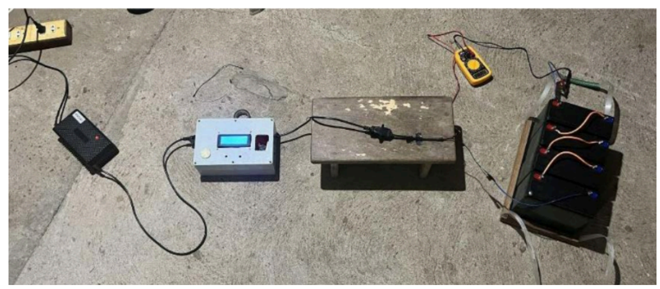

Figure 2. *Prototype Setup (Battery Deployment Set-Up)*

This is the testing setup for our system, designed to monitor the current and voltage while the lead-acid battery is charging. As shown, the system is positioned in the middle of the battery and the charger, which is strategically done to allow continuous monitoring of both voltage and current, including the multimeter to test the actual voltage and current value, to compare to the actual and systematic data gathered while having the testing process. The main rationale of this deployment setup is to facilitate the proper and timely measurement of the energy that flows into the battery during charging. As positioned between the battery and the charger, the system continuously monitors the battery's performance and health during the charging process.

Figure 3. *Prototype External Design*

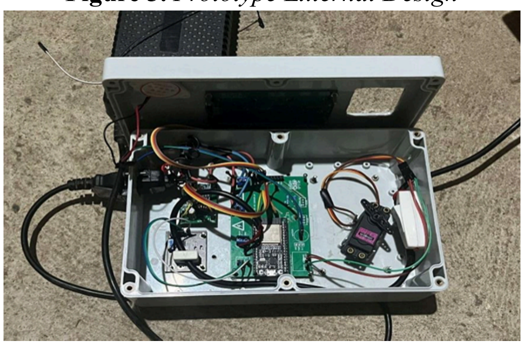

Figure 4. *Prototype Internal Design*

PowerCare system design, which monitors e-bike battery charging to prevent overcharging and extend battery life while managing various electrical components. The system is housed in a compact casing (230 x 150 x 87 mm) and includes an ESP32 microcontroller for data transmission, a WCS1800 current sensor to measure real-time current, and a DC-DC converter to power the microcontroller. Charging control is handled by a switch and servo, and the system uses 3-pin male and female power connectors for direct power input and output during charging.

Table I First Testing

Time	System Reading		Actual Reading		% of Error Voltage		Accuracy	
	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
11:55 PM	49.25	3.04	48.59	2.95	1.36	3.05	98.64%	96.95%
12:10 AM	50.01	2.9	49.06	2.95	1.94	1.69	98.06%	98.31%
12:25 AM	50.75	3.02	49.44	2.95	2.65	2.37	97.35%	97.63%
12:40 AM	51.54	3	49.89	2.95	3.31	1.69	96.69%	98.31%
12:55 AM	51.2	2.75	50.3	2.95	1.79	6.78	98.21%	93.22%
1:10 AM	51.54	2.98	50.44	2.95	2.18	1.02	97.82%	98.98%
1:25 AM	52.37	2.98	50.92	2.95	2.85	1.02	97.15%	98.98%
1:40 AM	52.84	2.9	51.2	2.95	3.2	1.69	96.80%	98.31%
1:55 AM	52.83	3.04	51.48	2.95	2.62	3.05	97.38%	96.95%
2:10 AM	52.01	2.91	51.8	2.95	0.41	1.36	99.59%	98.64%
2:25 AM	52.72	2.98	52.12	2.95	1.15	1.02	98.85%	98.98%
2:40 AM	53.11	3.02	52.41	2.95	1.34	2.37	98.66%	97.63%
2:55 AM	53.64	2.99	52.74	2.95	1.71	1.36	98.29%	98.64%
3:10 AM	54.15	2.79	53.08	2.95	2.02	5.42	97.98%	94.58%
3:25 AM	54.81	2.83	53.67	2.83	2.12	0	97.88%	100%
3:40 AM	55.27	2.63	54.25	2.77	1.88	5.05	98.12%	94.95%

Based on the final testing results, the system achieved an accuracy of 98.12% in voltage monitoring and 94.95% in current monitoring. Overall, the system performs reliably for voltage monitoring, maintaining errors within an acceptable range across all trials. However, its accuracy in measuring current remains inconsistent, with noticeable fluctuations and higher errors in the final testing. The comparison of the first and final trials shows that the system's voltage performance remains acceptable, though increasing errors in current measurements suggest the need for recalibration or improved design. While the system is suitable for voltage monitoring, enhancements are necessary to achieve the same reliability for current measurements.

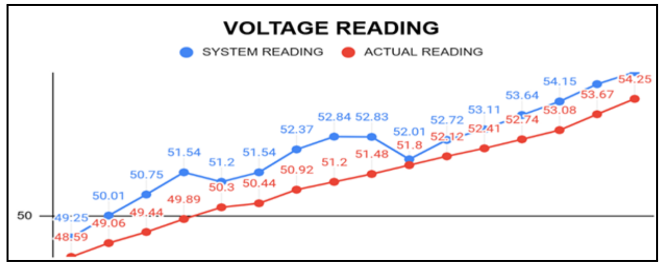

Figure 3. *Graphical Representation of Voltage Reading*

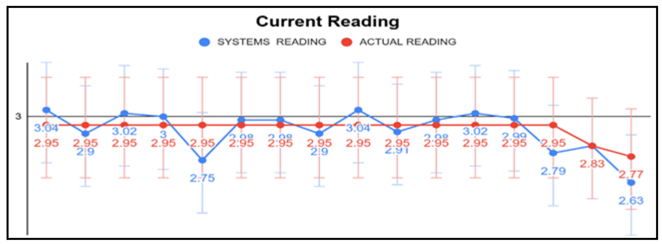

Figure 4. *Graphical Representation of Current Reading*

The following figures show the compiled graphical representation of the Voltage and Current readings of the project. Also, the system performed well in measuring voltage, with low percentage errors indicating reliable accuracy. However, the higher errors in the current measurement, particularly at the beginning of the testing, suggest that further calibration is necessary to improve its performance. While the system effectively captured the general increasing trend in both parameters, its current monitoring capabilities require refinement to ensure consistent and accurate results.

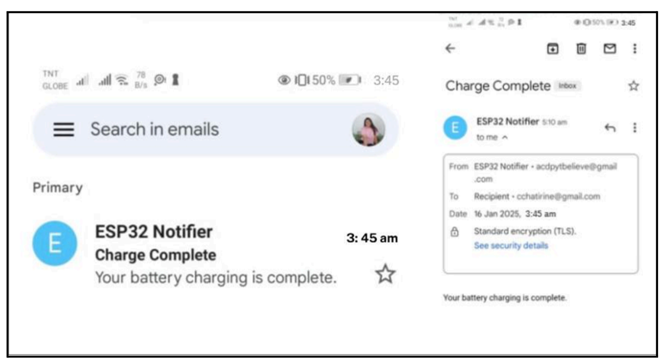

Figure 5. Email / Push Notification

The system is also intended to notify the user through an email notification when the battery charging has been successfully done. This feature simplifies the charging interface by notifying the user of the charging status, thus requiring the user not to monitor whether the device is charging. When the system indicates that the battery is fully charged, the email notice goes off to notify the user of completion time and charging. This is advantageous to the users and for implementing the next steps at the right time.

Table. II. Overall Specifications

Input Voltage V^+	9 V
Frequency	10 Hz
Counting operation	Manual or Continuous
	Upward or Downward
Components	Through-hole technology
Load	0 to 99

This digital counter system operates at 9V with a 10 Hz frequency, supporting manual or continuous counting in upward or downward directions. It uses through-hole components for durability and can count from 0 to 99, making it ideal for various industrial, educational, and experimental applications.

5.0 CONCLUSION

The study successfully achieved its objectives by developing and implementing *PowerCare*, a battery health monitoring system for three-wheeled electric bicycles. The system effectively tracked key battery parameters—voltage and current—during charging, with rigorous testing validating its accuracy and reliability. Voltage monitoring proved highly reliable, with percentage errors below 3% across trials, and a final accuracy rate of 98.12%. Although current measurements exhibited some variability, they remained within an acceptable range, with a final accuracy of 94.95%, based on data from the last time final testing. These results confirm the system's effectiveness in monitoring battery health and preventing overcharging. Its integration of real-time alerts and safety mechanisms supports sustainability by extending battery lifespan and reducing electronic waste. The system's performance and practical applications mark it as a significant contribution to sustainable and efficient electric vehicle use.

6.0 RECOMMENDATIONS

The study recommends that future researchers maintain spare components to avoid delays during testing and ensure all parts meet the system's specifications for optimal performance. Enhancing the system with predictive maintenance, detailed diagnostics, and data-driven algorithms is suggested to boost functionality. Incorporating SMS alerts can ensure users receive notifications even without internet access. To address current measurement inconsistencies observed during testing, better sensors or filtering methods are recommended. Additionally, expanding compatibility to lithium-ion batteries—now common in e-bikes—will make the system more versatile. These improvements aim to create a more reliable, adaptable, and user-friendly battery health monitoring system for broader real-world applications.

7.0 ACKNOWLEDGMENT

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9.0 ABOUT THE AUTHORS

We are a group of 4th-year engineering students from FAITH Colleges, united by our passion for innovation and teamwork. With backgrounds in Computer and Electronics Engineering, we focused our academic journey on developing practical tech solutions and contributing to the growth of intelligent systems and sustainable engineering practices.

10.0 APPENDIX

Appendix A - Initial Survey

No.	Questions	Answer
1	In your opinion, how important is it to monitor the health of electric vehicle batteries?	
2	In your opinion, how can a monitoring system help extend the life of electric vehicle batteries?	
3	How often do you experience battery problems with your electric vehicle?	
4	What is the reason why the battery gets replaced?	
5	How often are you able to replace a damaged battery in your e-bike?	
6	What are the possible causes/reasons for an e-bike battery to get damaged?	
7	Have you ever replaced an e-bike battery due to overcharging?	
8	What are the signs that an e-bike battery is damaged?	
9	In your opinion, can having a monitoring system help extend the life of electric vehicle batteries?	
10	Recommendations to avoid battery damage in e-bikes?	

Appendix B - Performance Criteria

Functionality	PowerCare effectively monitors key battery parameters in 3-wheeled e-bikes to determine battery health and prevent degradation, helping users identify when maintenance or replacement is needed.
Adaptability	PowerCare is modular and compatible with most e-bike brands, provided they use the same port type. This allows for easy integration without compromising performance.

Appendix C - Criteria for Users Operating the Device

1. Clear user manual and safety instructions
2. Recommended age for operation (20+)
3. Supervision guidance for minors
4. Pre-use and post-use safety checks