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Development of IoT-based Monitoring of the Lithium-Ion Battery Pack for a Two-Wheeled Vehicle Ecosystem

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Abstract: Electric bicycles with two wheels are increasingly popular as a convenient mode of short-distance transporta-tion. To enhance mobility and promote the use of eco-friendly energy around campus areas, conventional bicycles can be transformed into electric ones using a conversion kit. The main challenge lies in creating a design that is easy to install (plug-and-play) and compatible with various bicycle models. Moreover, monitor-ized battery condition is an advantage to inform the user. A key advantage of this concept is the inclusion of a universal battery pack equipped with an IoT-based monitoring system. This study aims to design an IOT based battery pack conversion kit powered by a 576 Wh of $LiFePO_4$ lithium-ion battery type. The battery pack is tested by experiment to obtain the performance of the energy storage for a converted e-bike. Experiment results indicate that battery pack of 50 cm × 16 cm × 14 cm dimension with the total weight of 4.5 kg can perform as the energy storage for a converted two-wheeled electric vehicle. The test achieves the speed of 500rpm with 1A current.

Keywords: Electric bike; Battery; Internet of Things (IoT); Lithium-Ion 4

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1. Introduction

The growing concern over climate change has heightened public awareness of the environmental consequences of human activities, particularly within the global transportation sector. This sector is experiencing a significant transition from fossil fuel–powered vehicles to electric mobility solutions. Among these alternatives, electric bicycles (e-bikes) have become increasingly preferred due to their economic advantages, health benefits, reduced environmental footprint, and effectiveness in alleviating urban traffic congestion [1,2].

Vocational education namely Politeknik Negeri Jakarta (PNJ) wants to develop a green campus concept by implementing green technologies in their daily activities. The road to access building in PNJ campus are not a long and complicated path (nearly 1.5 km from the gate in front of the campus to the building at the back of the campus). Several studies and products have been developed focused on green technologies for electric vehicles [3] and battery swapping stations [4]. One of the initiatives to encourage environmentally friendly practices within campus areas is to promote sustainable mobility by walking or cycling for short-distance travel. However, this approach may not be feasible for all members of the academic community, particularly in areas with hilly or uneven terrain. Consequently, additional mechanical assistance, such as the integration of an electric motor into bicycles (e-bikes), is necessary to support user mobility.

The cost of owning an e-bike can also pose a challenge for students [5]. However, several universities have begun implementing rental or sharing systems to increase accessibility and promote sustainable mobility on campus [6]. However, the motor-bike they are using are commonly new bikes, or owned by companies as part of business collaboration with campuses. An idea of utilizing personal bikes that are owned by academicians is developed. A practical solution is to convert conventional bicycles into electric bicycles using a conversion kit assembled by PNJ academicians. This approach has not been developed by campus in Indonesia. It is more feasible and also economical than purchasing a new e-bike for creating the green campus. Furthermore, those bikes will be integrated with application for mobilities in campus to monitor e-bike services.

A crucial component in converting a conventional bicycle into an e-bike is the battery, which supplies power to the electric motor. The battery pack serves as the primary energy source and has a significant influence on the e-bike's range, performance, weight, and overall cost. Lithium-ion batteries have emerged as the preferred option for e-bike energy storage systems due to their high energy density, long life cycle, and superior power-to-weight ratio compared to other rechargeable battery types [7].

Accordingly, this research focuses on designing a lithium-ion battery pack that optimizes performance, safety and reliable for converted e-bike applications for PNJ campus. The study investigates the battery's configuration, management system, and performance characteristics of IOT based monitoring battery pack. The main objective of this paper is to develop an IOT monitored lithium-ion battery pack for an e-bike conversion kit so that the conversion of e-bike can be effectively integrated into conventional bicycles.

2. Materials and Experiment Methods

The method of this research uses a qualitative approach that aims to analyze the performance of the product The main focus of this research is to ensure the IOT based monitoring system can be implemented and beneficial for the user. The system will be validated by clients or users to assess the level of feasibility and ease of use.

At the initial stage of developing a green transportation environment, it is essential to establish a universal and plug-and-play system that enables the conversion of conventional bicycles into electric bicycles. An e-bike generally consists of three key components: an electric motor, a controller, and a battery. While controllers and motors are readily available from various online marketplaces at different price points depending on their features, the battery remains a major challenge due to its relatively high cost and limited lifespan.

Therefore, this research was conducted through several stages, namely Identify specifica-tion and configuration of battery pack, assembling and testing.

A. Identifying the specifications and configuration of the $LiFePO_4$ lithium-ion battery pack.

The battery specifications were determined through a market survey aimed at select-ing the appropriate battery type, dimensions, and design parameters. The selection process was based on data collected from the top three best-selling e-bike models listed on popular online marketplaces—Tokopedia, Shopee, and Blibli. The survey results indicate that a 48V Li-ion battery with a capacity ranging from 8 to 12 Ah is the most commonly used configuration. Lithium-ion 32700 cylindrical cells were selected for this study due to their optimal balance between energy density (200–250 Wh/kg), cost-effectiveness, and market availability. Each cell possesses a nominal voltage of 3.2–3.3 V and a rated capacity of 12 Ah, making it suitable for mid-range electric bicycle applications that require both performance stability and safety.

The battery pack employs $LiFePO_4$-based lithium-ion 32700 cylindrical cells, each measuring 32 mm in diameter and 70 mm in height. The selection of this cell type was guided by a market survey of the top three commercially available e-bikes, which identified 48 V systems with capacities ranging from 8 Ah to 12 Ah as the most common configuration.

The number of battery series obtained by this equation [8]:

$$Series\ Battery = \frac{Voltage\ of\ Motor}{Voltage\ of\ Battery} \quad (1)$$

The capacity follows this equation:

$$Capacity\ of\ Battery = 1.3x \frac{Energy\ used}{Voltage\ of\ Battery} \quad (2)$$

where 1.3 constant is put for 70% Depth of Discharge to preserve the battery sustainability.

Moreover, the battery requires parallel configuration using the equation:

$$Parallel\ Battery = \frac{Capacity\ of\ Battery}{Cell\ Capacity} \quad (3)$$

To achieve a nominal system voltage of 48 V and a total capacity of 10 Ah, a 15S2P configuration (15 cells in series and 2 in parallel) was implemented. The resulting specifications are as follows:

- Nominal Voltage: 48 V
- Total Capacity: 10 Ah
- Energy Storage: 576 Wh

To account for thermal expansion and heat dissipation, spacing between adjacent cells was incorporated into the pack layout as recommended in [9]. Consequently, the internal battery pack dimensions were determined to be approximately 45 cm × 12.5 cm × 9.5 cm, with an estimated total weight of 4.5 kg.

B. Assemble the battery pack.

A Battery Management System (BMS) required in order to assemble the battery pack. The BMS is designed to ensure operational safety and longevity by providing protection against overcharging, over-discharging, overcurrent, and excessive temperature conditions [10], [11]. A commercially available universal BMS with integrated Bluetooth functionality was selected for this application, enabling real-time monitoring and datatransmission. The BMS module is mounted on the side of the battery. The Figure 1 shows the battery pack module.

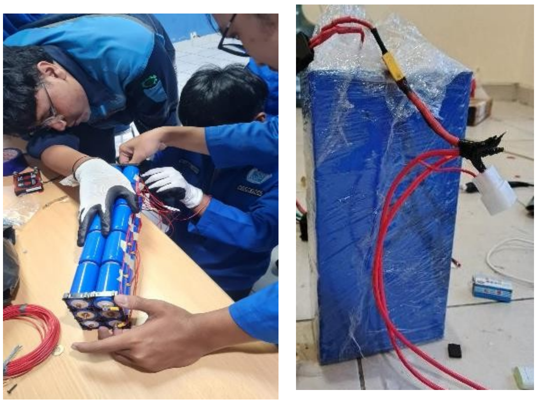

Figure 1. IOT-based Li-Ion Battery pack module

The Figure 2 shows a block diagram of a system that converts a conventional bicycle into an electric bicycle. The system consists of a 48V Li-On battery as the power source, which supplies electricity to a 500W controller that regulates power distribution to a 500W BLDC (Brushless DC) motor. The motor serves as the main drive for the bicycle's wheel. Further-more, the throttle is used to control the motor speed based on user input, with its signal directly connected to the controller to adjust the power delivered to the motor. This dia-gram provides an overview of the basic workflow of the system.

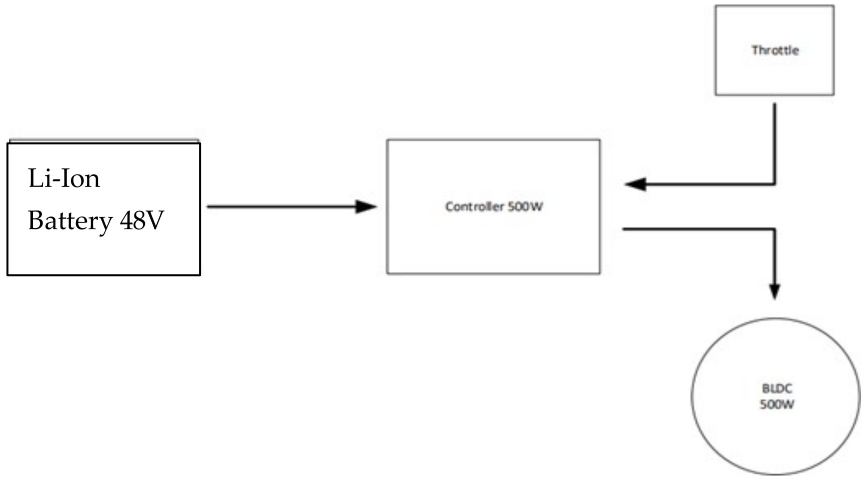

Figure 2. The connection diagram of battery and the e-bike system.

The battery pack module complete with the BMS is attached with the folded bike frame integrated with the controller the motor. A 500W Brushles DC (BLDC) motor hub as the driving tool is then connected to the controller. The Figure 3 shows those selected components.

Figure 3. A bike frame, motor hub and Battery Management System.

The connection (wiring) system is shown in Figure 4 The image illustrates a wiring diagram of the control system for converting a conventional bicycle into an electric bicycle. This diagram illustrates the connections between the main components: a 48V 12A battery as the power source connected to a 500W controller through a relay and contact switch to control the power flow. The controller regulates power distribution to the 500W BLDC motor via phase wires (yellow, blue, green) and Hall sensors for rotor position control. Additionally, the throttle is used to control the motor speed based on user input, while the speed mode allows adjustment of the desired speed level. All these components work in an integrated manner to convert electrical energy into mechanical power that drives the bicycle.

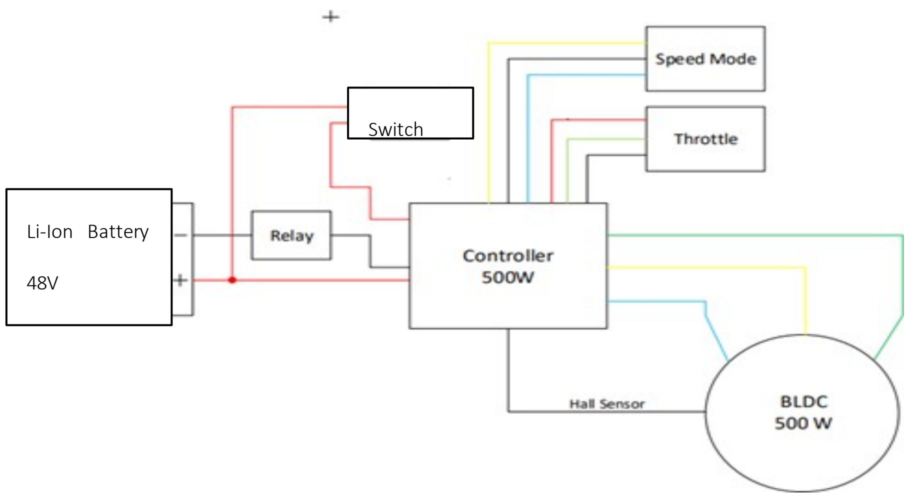

Figure 4. Wiring diagram of the e-bike

C. Testing the battery pack performance.

The performance test consists of several observations namely maximum speed test, max-imum range. It is necessary to monitor the voltage value at the beginning (initial) and the final (after test). Those two voltage monitors can be achieved by these several steps:

Initial Voltage Test

1. Check the battery condition to ensure it is fully charged.
2. Use a multimeter to measure the voltage at the battery terminals before the bicycle is operated.
3. Record the measurement result as the initial voltage.

Final Voltage Test

1. After completing all tests, remeasure the battery voltage using a multimeter.
2. Record the measurement result as the final voltage.
3. Compare it with the initial voltage to determine the voltage drop.

Furthermore, the steps of the performance experiments are divided into two observations namely off-site (mobile) and on-site. The first observation requires the system to be dynamic since the e-bike travels to a determined route as seen on Figure 5.

Figure 5. Trajectory of the e-bike dynamic test.

Maximum Speed Test

- Ensure the electric bicycle is in ready condition and the battery is fully charged.
- Place the bicycle on a straight and flat test track.
- Turn on the electric bicycle and set it to the maximum speed mode.
- Record the highest speed achieved using a speedometer or another measuring de-vice.

Maximum Range Test

- Ensure the battery is fully charged before starting the test.
- Use a safe test track suitable for the environmental conditions.
- Operate the bicycle until the battery is completely depleted and the bicycle can no longer move.
- Record the distance traveled using a distance measuring device.

Meanwhile the second observation conducted on static condition to obtain the data. The data can be used to obtain the control performance of the converted e-bike system. It consists of two measurement namely current and speed test. The steps are explained as follow:

Current Test at Maximum Speed

- Lift the rear wheel of the bicycle so that it does not touch the ground.
- Connect a multimeter set to current measurement mode (ammeter) to the electric mo-tor circuit.
- Run the bicycle until it reaches maximum speed without any load.
- Record the current reading displayed on the multimeter.

Three-Speed level Test

- Lift the rear wheel of the bicycle so that it does not touch the ground.
- Set the bicycle speed mode to the first level and run the motor until stable, then record the speed.
- Repeat the above step for the second and third speed levels.
- Record the speed results for each mode.

3. Results and Discussion

In the maximum speed test of the converted electric bicycle, the data showed that the bike was able to reach a top speed of 37.6 km/h. During the test, the bike covered a distance of

3.73 km in 20 minutes and 42 seconds, resulting in an average speed of 10.8 km/h. Addi-tionally, the test recorded an elevation gain of 22 meters, with the highest elevation reach-ing 84 meters as shown in the Figure 6.

This maximum speed demonstrates the optimal performance of the 500W BLDC motor, supported by a battery pack module as the power supply. The data indicates that the elec-tric bicycle has adequate performance for use on flat roads as well as on routes with slight elevation. The test also confirmed that the speed control via the throttle operated as de-signed, providing a good response when the bike was accelerated.

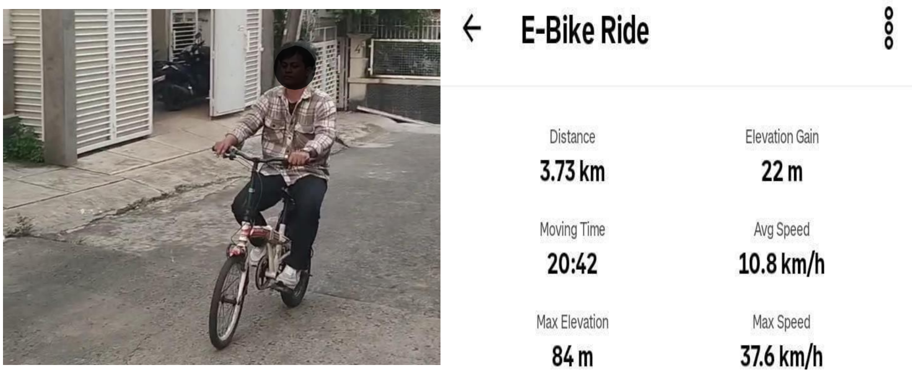

Figure 6. Dynamic performance test

Figure 7. Performance measurement.

In the current test conducted when the electric bicycle reached its maximum speed under no-load conditions are shown in Figure 7, the data showed that the current flow at the first speed level was 0.28 A, at the second speed level was 0.78 A, and at the third speed level reached 1.09 A.

These current values indicate that the 500W BLDC motor system and the controller oper-ate efficiently in regulating power consumption when the bicycle is in a no-load condition. The increase in current corresponding to higher speed levels demonstrates a linear relationship between motor speed and electrical current demand.

The results also suggest that the power consumption remains within safe limits, supporting the overall stability and efficiency of the system. This test provides an overview of the system's performance under no-load conditions and can serve as a reference for further analysis under loaded conditions.

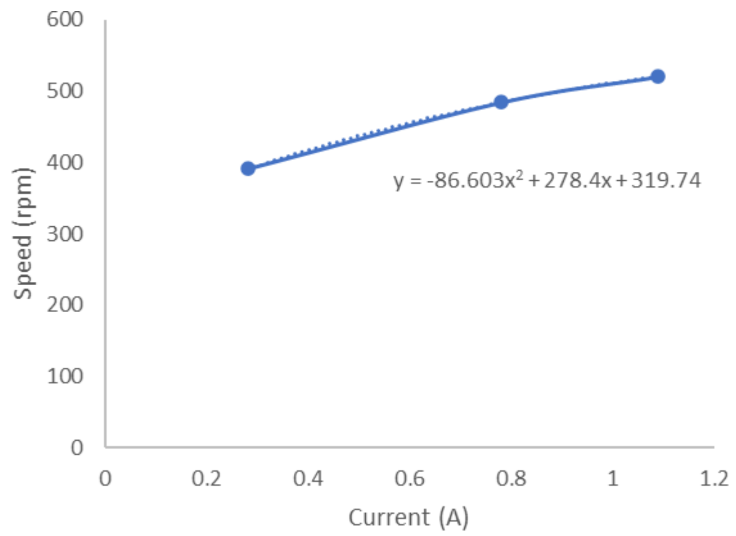

Figure 8. Speed and current relationship curve.

The maximum speed for this e-bike using this type of motor-hub can reach up to more than 500 rpm with 1.1A current as seen on Figure 8. Based on the curve generated, the relationship between Speed and Current can be formed an equation represented as:

$$\boldsymbol{Speed} = -\mathbf{86.603}\boldsymbol{Current}^{2} + \mathbf{278.4}\ \boldsymbol{Current} + \mathbf{319.74}$$

4. Conclusion

The Li-ion battery pack design using IOT of 4.5 kg weight with the strength and flexibility. It is tested with the converted e-bike for several assessments. The level speed shows that it requires 1A current for a speed of 500rpm. The maximum speed reached 37.6 km/h. Moreover, the bike performance can be monitored a distance of 3.73 km in 20 minutes and 42 seconds. The battery pack performance is sufficient to be used in this campus academician mobilities. Moreover, it is more convenient to monitor the energy status using the IOT. Therefore, those values show that developing the IOT battery pack for supporting converted electric-bikes in this campus are potential to be implemented.

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