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IoT and Machine Learning-Based Electric Vehicle Development Strategy to Maximize Vehicle Life and Promote Green Mobility

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Abstract

This research explores innovative strategies for developing electric vehicles based on the Internet of Things (IoT) and Machine Learning with the aim of maximizing service life and encouraging green mobility. In the face of the climate crisis and the increasing need for sustainable energy, electric vehicles offer a potential solution to reduce carbon emissions in the transportation sector. However, the challenges of optimizing battery life and energy efficiency require new, smarter and more connected approaches. This research integrates IoT technology with machine learning to create a more efficient electric vehicle ecosystem. This technology enables extended battery life through better usage management, increased energy efficiency through operational optimization, and predictive maintenance that reduces vehicle downtime. The research methodology includes testing prototypes of electric vehicles equipped with IoT technology, field trials to collect performance data, comprehensive analysis, and data processing to evaluate the effectiveness of the implemented strategies. The research results show that the integration of IoT and Machine Learning in electric vehicles can significantly increase battery life, energy efficiency, and make a positive contribution to green mobility. This development strategy is expected to advance electric vehicle technology in Indonesia, reduce dependence on fossil fuels, and create a cleaner and more sustainable environment.

Keywords: *electric vehicles; internet of things; green mobility; machine learning; sustainable transportation*

1. Introduction

Data from the Ministry of Energy and Mineral Resources of the Republic of Indonesia shows that the transportation industry produces 1.28 million tons of CO_2, which on average increases by 6.7% per year (Wibowo, 2024). Meanwhile, based on data from the International Energy Agency (IEA, 2022), it is known that the global transportation system dominated by fossil fuels contributes 37% of CO_2 emissions. This causes anthropogenic climate change as a greenhouse gas effect due to carbon gas emissions that make global warming increase due to human dependence on fossil fuels and industrial waste (Wawrzyniak & Doryn, 2020). Highlighting this issue has led to high levels of support and enthusiasm around the world to transition to cleaner transportation options to mitigate climate change.

This transition is accelerating the adoption of electric vehicles into the global market to achieve low-carbon transportation, efficiency, and flexibility (Emodi, 2023). Electric vehicles have several advantages over fossil fuel vehicles, one of which is that they do not produce exhaust gases and thus do not contribute more to global warming in Indonesia (Resosudarmo, 2009). It is not surprising that the growth of electric vehicles is increasing from year to year. In addition, the growth of electric vehicles is also signaled as a form of Indonesia's commitment to reduce greenhouse gas emissions in 2030 by 41% along with net zero greenhouse gas emissions in 2060 according to the 2016 Paris Agreement (Subekti, 2022).

In Indonesia, electric vehicles have begun to be favored at all levels of society. However, the development of electric vehicles in Indonesia is also inseparable from various problems, such as battery conditions, charging areas, and remaining battery mileage. Batteries in electric vehicles have various types and specifications (Zain et al., 2023). Meanwhile, most electric vehicles use rechargeable lithium-ion batteries that have constant power (Piao et al., 2012). This type of

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battery has a life cycle that can be shorter due to charging errors such as overcharging or even discharging to zero, which can compromise battery quality. This is in line with the opinion of Wahab (2018), that overcharging a battery can significantly shorten battery life and potentially cause engine damage and vehicle fires.

Therefore, to determine the quality and consumption of batteries in electric vehicles, a monitoring system or monitoring of battery and engine quality is needed. In the context of electric vehicles, IoT is expected to play a role in anticipating battery degradation and engine failure before they become serious problems by conducting advanced data analysis that can detect trends or abnormalities in battery performance (Liyakat, 2023). Monitoring is expected to help technicians detect early damage to induction electric motor bearings (Bisri, 2024). In addition, tracking the location also requires the role of the Global Positioning System (GPS) so that it can send data that provides real-time location and time coordinates to the recipient (Savari et al., 2022).

In addition to using IoT, this autonomous vehicle control management method can use hardware and software integration that utilizes artificial intelligence system algorithms in the form of machine learning so that the system can learn and study various objects and vehicle behavior in various conditions (Arkaan, 2023). System development in this research includes the development of hardware systems (electronic circuits) and software (monitoring applications) which are expected to be able to remotely monitor battery quality, track the performance of electric vehicle devices in real time, especially battery health conditions.

One innovative application of these two technologies is in the management of charging areas for electric vehicles. IoT enables real-time data collection from various connected devices, including vehicles, charging stations, and the power grid. This data is then processed by machine learning algorithms to optimize energy usage, reduce charging time, and maximize operational efficiency (Xia et al., 2021). For example, IoT sensors can be used to monitor the performance of charging stations and determine when devices need maintenance or component replacement.

On the other hand, machine learning plays a role in analyzing the data generated to provide predictions and recommendations for more efficient energy management. These learning algorithms can predict charging demand patterns based on historical and weather data, thereby minimizing potential overloads or power shortages in certain areas (Pritoni et al., 2017). The combination of IoT and machine learning also supports the development of new business models in charging area management, such as dynamic pricing systems that are adjusted to the condition of the power grid and user demand (Khan et al., 2020).

This research aims to address key issues in the use of electric vehicles, such as inefficient charging, battery deterioration, and improved energy efficiency. By integrating IoT technology for data monitoring and machine learning algorithms to analyze charging patterns and battery performance, this research is expected to produce a system that can provide more accurate predictions and recommendations regarding energy management to support global efforts to achieve cleaner and low-emission transportation, in line with Indonesia's greenhouse gas emission reduction targets.

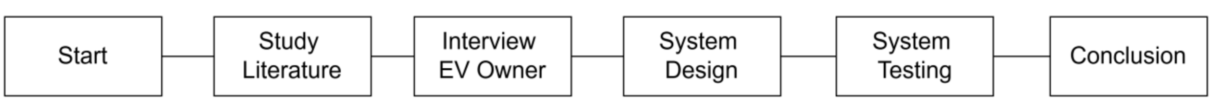

Figure 1. Research Flow

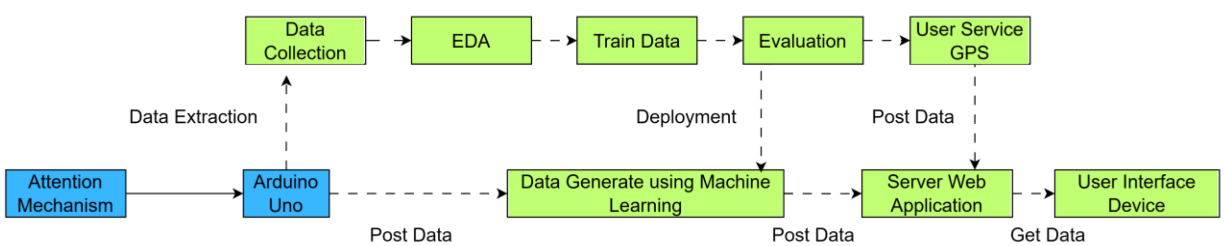

Figure 2. System Design Flow

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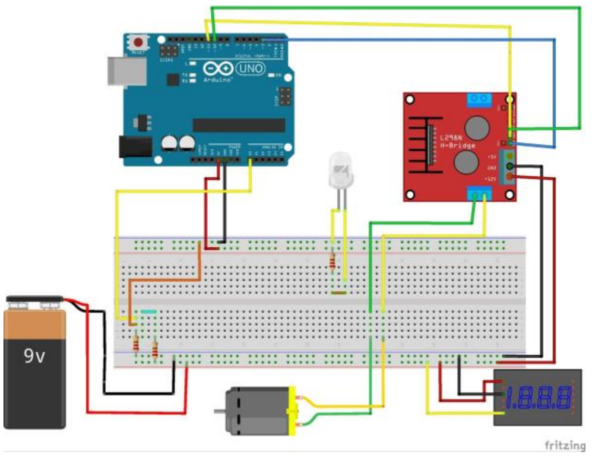

Figure 3. Hardware Set

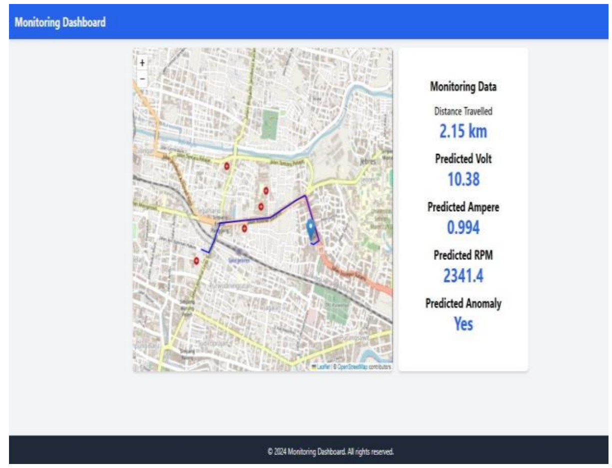

Figure 4. Software

The novelty in this research lies in the integration of advanced technologies to maximize the lifetime of electric vehicles while encouraging green mobility. This innovation includes the use of IoT sensors for real-time monitoring of vehicle conditions, particularly the battery, combined with machine learning algorithms to intelligently analyze the data. This enables more accurate predictions of maintenance needs and optimization of charging patterns, thus extending battery life and reducing energy consumption. In addition, with more efficient data analysis, electric vehicles can be more responsive to environmental and operational conditions, further driving energy efficiency as well as reduced carbon emissions, significantly supporting the transition to green mobility.

2. Materials and Methods

2.1. Tools and Materials

Hardware needs require various tools to build a prototype that can convey data related to battery performance using Arduino Uno R4 to organize the process flow from the hardware side such as receiving data from the battery related to volts, amperes, and anomalies that will be generated and then forwarded to the server using a Wifi module. **Figure 3** are the hardware components used are Arduino Uno R4 for (semi-permanent) prototyping of the entire circuit. Arduino allows users to customize it for this circuit project as it has many connectors that can be attached to many pins directly. In addition, Arduino also has a WiFi module that provides services as a link to the server. L298N controller: Allows users to control the power flow of DC Circuits. The use of the L298N can also be scaled up to make the power flow output controlled by volts or amperes of program-controlled power. Volt & Ampere Meter for assists the developer for the monitoring process aimed at calibrating the volt & ampere measurement system. In addition, volt & ampere is also used by users as a simple monitoring tool directly to indicate the health condition of the battery. Dynamo for real EV simulation tool that is indicated by the changes in volts and amperes found in the battery usage output. Battery going to be the source of power for the kinetic mechanism of all processes in the

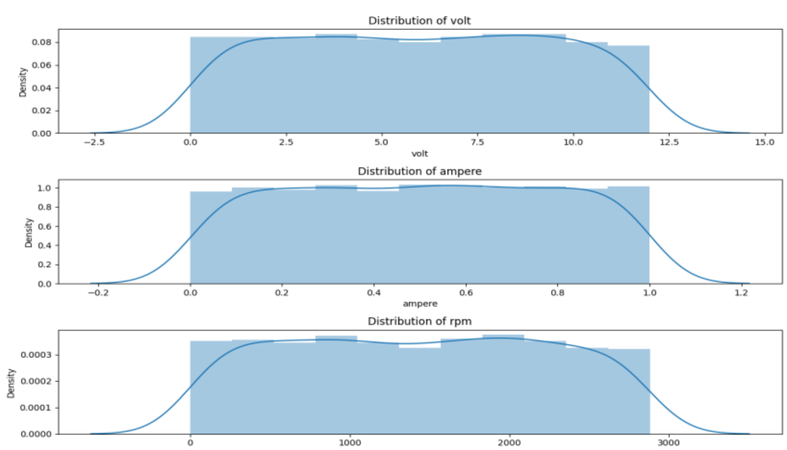

Figure 5. Data Distribution of Datasets

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research/project circuit. In addition, the battery is also used as an object of research by looking for changes in volts and amperage that may be influenced by external factors called abnormalities/anomalies. Breadboard for an optional device that helps developers to make the connection relationship of router pins to other pins easier than using the factory default settings. This device allows users to extend the functionality of the default device beyond that. In prototype development, this tool is very useful to ease the testing process. Resistor is used as a device to limit the electric current in a circuit. In this circuit, the resistor functions as a current limiter, allowing it to record activity or changes in voltage and amperage to maintain stability.

Meanwhile, software requirements are used to build a web-based application system used to monitor information related to user battery performance, user location, and battery performance limits sent from hardware to the website server during use in real time so that users can understand battery conditions (Goh et al., 2023). Visual Studio Code is used so that developers can build programs using framework-based programming languages such as React.js-based JavaScript, Node.js-based JavaScript, Supervised Machine Learning using Flask-based Python, and C++-based device controllers. Arduino IDE builds the program flow from the running hardware. Arduino IDE automatically integrates with C++ thus helping developers to install and configure related libraries more easily for the system workflow. Moreover, this application can push or upload the code easily to the hardware. External API is an alternative for developers who serve multiple services using methods like GET, POST, DELETE, PUT, and PATCH. This project uses external APIs for Geocoding purpose i.e. 'Open Route Service' & 'Thingspeak' as APIs for POST and GET data of battery performance monitoring.

2.2. Methods

2.2.1. Research Flow

The method in this research uses literature studies, interviews with electric vehicle owners, system design, and system testing for the use of IoT in electric vehicles. Data analysis was carried out using descriptive analysis. In the first stage of the research, a literature study was conducted to review the theories relevant to the research. Literature studies are carried out by collecting data and information from various sources, such as research journals and reports from authorized agencies (Birkle et al., 2020).

2.2.2. Data Collection

There are 2 data collection processes, namely interview data on electric vehicle users and data collection on electric vehicle simulations from hardware. Interviews with electric vehicle owners are conducted to find out what problems arise in the use of electric vehicles in terms of time spent and user expectations for improving electric vehicle services.

In addition to interviews, data collection from electric vehicle simulation prototypes is carried out to compile

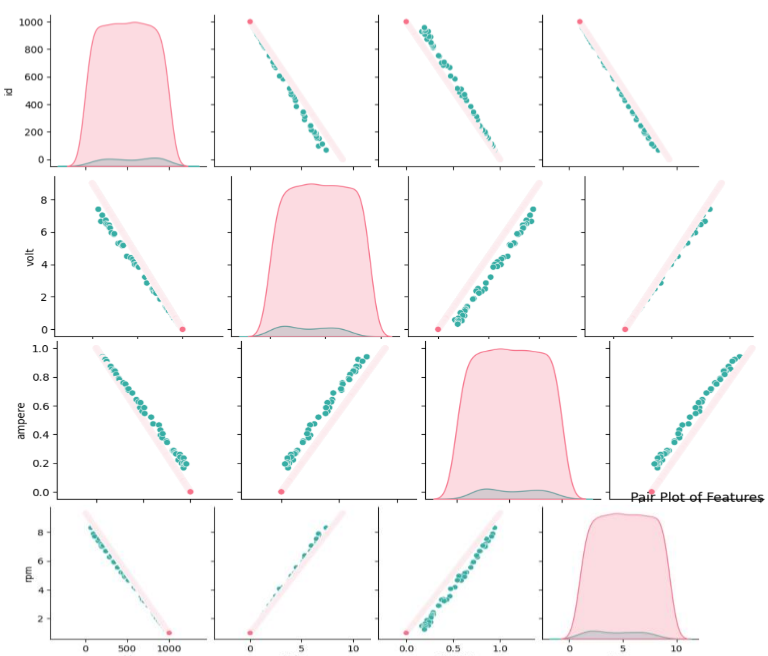

Figure 6. Pair Plot

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machine learning models. Data collection of battery parameters such as volts, amperes, and annual is taken using the resistance limiting method using a 10 ohm resistor. A voltage divider circuit can be used to measure the voltage in a circuit by reducing a higher voltage to a lower voltage that can be measured by a measuring instrument. The formula used to measure is as equation 1 and 2.

$$V_{out} = V_{in} \times \left(\frac{R2}{R1+R2}\right) \quad (1)$$

$$I = \frac{V}{R} \quad (2)$$

V_{Out} is rated volts out or measured, V_{in} is incoming volt value (from battery), R_1 is first resistor, R_2 is second resistor, I is ampere, R is resistor

In addition, there is an RPM calculation that shows the speed of the dynamo movement of our tool. The calculation uses the Motor Constant (KV) guideline which can be calculated in the equation 3.

$$RPM = KV \times Volt \quad (3)$$

RPM is rounds per minute, KV equal to 12V dynamo constant motor (240), Volt is electric current voltage

2.2.3. System Design

System design is done by involving several processes such as hardware assembly, coding software development, and integration between the two. Integration between software and hardware is done by programming hardware and servers to be integrated when used (Eshankulov et al., 2021).

After the implementation process is complete, the next process is system testing. The testing phase includes checking the physical components and program devices. This check is intended to verify that all components and programs are in good condition and ready to use. In the process, experiments are carried out to get the expected results and om Forest” because it has a tree scheme that can find out the gaps or shortcomings of each component and program made.

2.2.4. Internet of Things Model Mechanism

The Internet of Things (IoT) is a technology that connects electric vehicles (EVs) to the internet to enable remote maintenance and control of vehicles. In an IoT-based EV charging system, sensors are installed on some important household components, such as batteries, inverter motors, and energy management systems, which will provide real-time data continuously. IoT is intended to collect data related to maintenance work, such as voltage, current, humidity, and motor rotation speed. This will allow maintenance personnel and technicians to monitor the condition of machines silently and take prompt action when there is a problem. In the implementation of IoT, sensor Data Collection is facilitates data collection from various sensors connected to household components. The data collected includes important parameters such as voltage, current, battery life, and motor speed (RPM). This data is sent in real-time over the internet to a server located there, where any small changes in the parameters can be monitored and checked. Network Connectivity and Cloud Storage is the information obtained from the sensors will be transferred over communication networks, such as 4G, 5G, or Wi-Fi networks, to cloud servers for storage and retrieval over a longer period of time. The cloud servers are fully capable of handling large amounts of data and give remote technicians or operators access to manage the data from any location using web-based applications or customized dashboards. Automatic Settings is one of the important features of

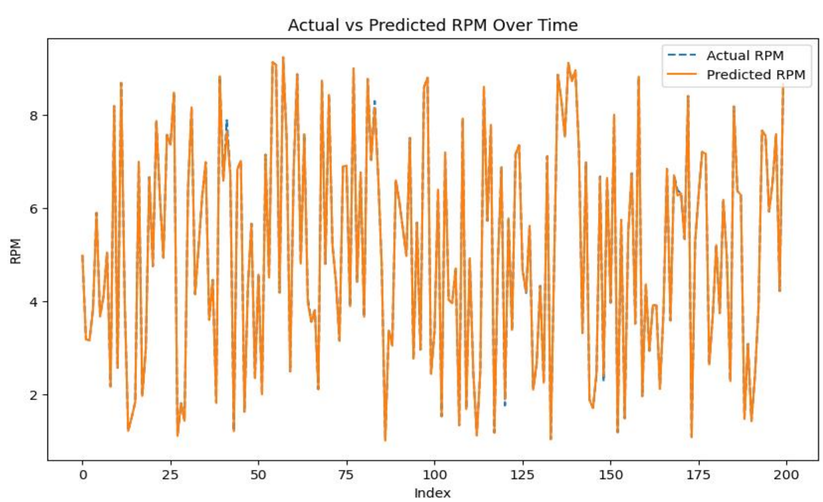

Figure 7. RPM Prediction

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the IoT is its ability to automatically send out notifications when specified parameters exceed a defined threshold. For example, when the battery voltage drops too low or too high, the system will automatically send out a signal to the operator or technician so that necessary repairs can be made quickly and the problem can be addressed sooner rather than later. Data Protection is one of IoT that has a strong data protection system to protect data from tampering or damage. All data transferred from sensors to cloud servers is encrypted to ensure that only privileged parties have access to sensitive customer data. Such a layered security system is essential for protecting data integrity and maintaining confidential information of operational vehicles.

Incorporating the IoT paradigm into list-based maintenance, particularly for public transportation fleets, enables operators to manage fleets more efficiently, minimize downtime, and increase overall maintenance staff productivity. IoT integration also enables more agile work processes, reduces human error, and provides more equitable transportation services to the general public.

2.2.5. Machine Learning Model Mechanism

Machine Learning is a method that is embedded into a software system as a battery usage prediction system. By knowing the predicted value of the use of a battery described using volts, amperes, and anomalies, it can classify the state of the battery whether it is in optimal condition or not. The machine learning algorithm used is “Random Forest” because it has the characteristics of a non-linear relationship between branches and has resistance to outliers so that it can predict with optimal accuracy and small errors. EDA (Exploratory Data Analysis): To determine the distribution of data, missing values, and classification of values from the data collection process. The data will be analyzed descriptively to determine the machine learning algorithm to be used. The step of machine learning includes, train data to study and process captured historical data related to volts, amperage, and anomalies (variables indicating abnormalities/instability

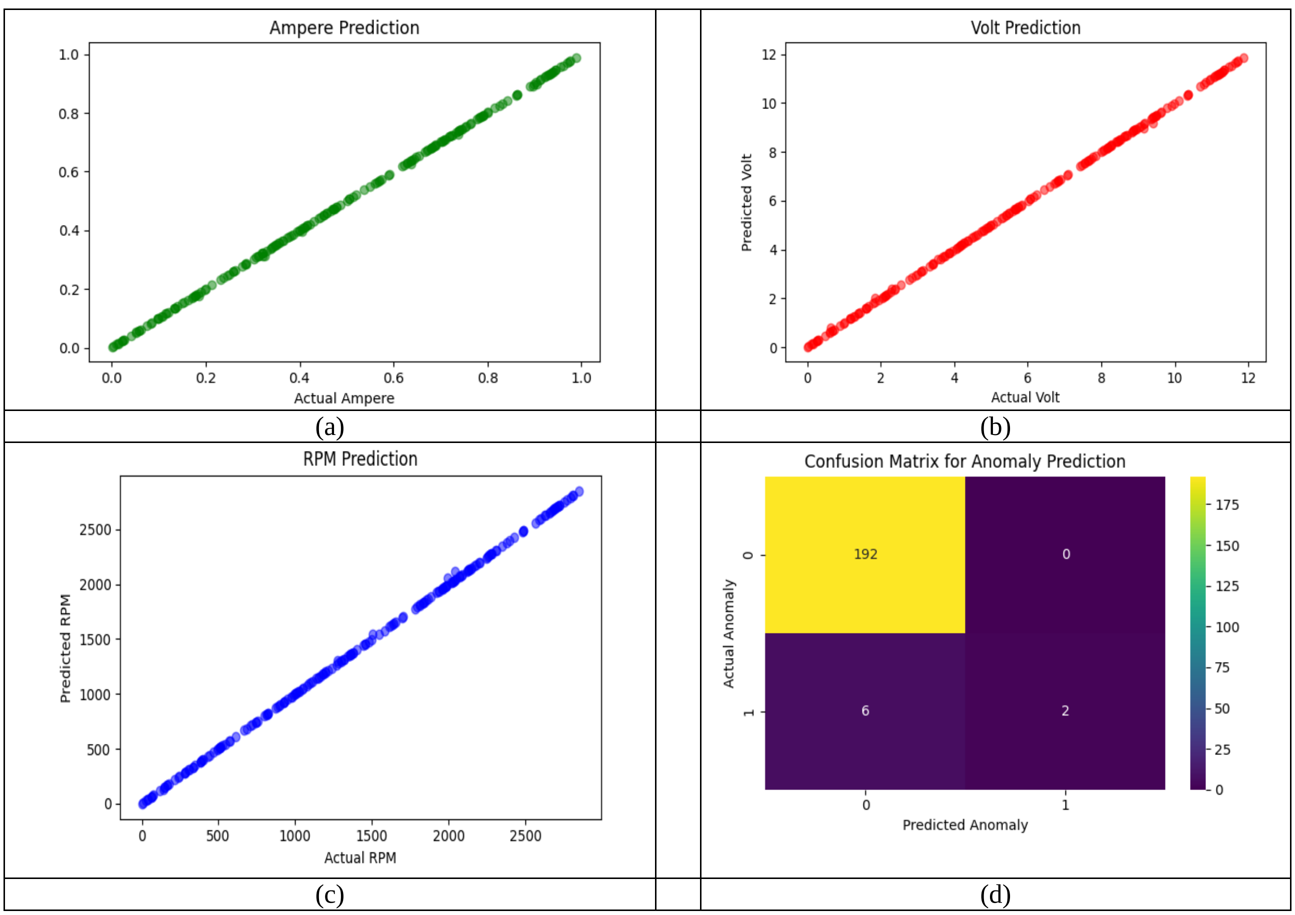

Figure 8. Regression & Confusion Matrix (a) Ampere Prediction, (b) Volt Prediction, (c) RPM Prediction, (d) Confusion Matrix for Anomaly Prediction

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of battery usage from external factors) to determine patterns and relationships between variables to predict the magnitude of future volts, amperage, and anomalies. Model Evaluation in **Table 2** are to performed after the data is trained using F1, recall, and precision. Recall is the value of the proportion of predicted values, precision is the correct predicted value, and F1 is a combination of the two so that the use of the three can ensure the model has a sharp and validated accuracy.

2.2.6. Integration of IoT and Machine Learning

Combining IoT systems with machine learning models is one of the important steps in developing predictive and adaptive maintenance systems in electric vehicles. The IoT system serves as a continuous data collector from sensors installed on the vehicle, such as voltage, amperage, and dynamo motor RPM sensors.

This collected data not only comes from the technical components of the vehicle, but also from direct interviews with electric vehicle users to gain further insight into the problems they often face and their expectations regarding improving vehicle performance. By utilizing this data, machine learning is trained to understand vehicle usage patterns, detect potential malfunctions, and provide timely maintenance recommendations.

3. Results and Discussion

3.1. Electric Vehicle User Interview

Interviews with electric bicycle users regarding battery issues are necessary for several important reasons, such as gaining direct insight from users on how they use electric bicycles on a daily basis and what obstacles they face. The information obtained from the interviews can be used by manufacturers to improve the quality of their products. In addition, the information from the interviews is also useful for policy makers and regulators who want to develop better standards or regulations for electric vehicles. Overall, interviews provide invaluable qualitative data that complements quantitative data and helps create better products that better meet user needs. From the interviews in **Table 4**, it is known that electric vehicles have problems with their batteries, such as reduced mileage, long battery charging duration, battery indicators that prove problematic, decreased battery capacity (drop), and the potential for overheating. Therefore, efforts are needed to manage the condition of electric vehicles, especially their batteries and engines.

3.2. Device Design

The hardware in **Figure 3** is designed using Arduino Uno R4 to drive the dynamo using Motor Controller L298N. Meanwhile, the software in **Figure 4** is designed to be used to provide visualization & data processing of engine speed prediction & anomalies in the dynamo. The software is designed as a web-based application that can monitor volts, amperes, and anomalies in the future. Predictions use machine learning algorithms. In addition, the website also displays the user's position and distance traveled in real-time as digital navigation.

3.3. Simulation Result Analysis

After obtaining data from Hardware and Software simulations, the data can be processed using machine learning algorithms with a series of processes :

3.3.1. Exploratory Data Analysis (EDA)

Data preprocessing is carried out in the form of EDA to provide an overview of the characteristics of the data that has been obtained. EDA can be done in various ways such as using histograms and pair plots.

From **Figure 5**, it can be concluded that the data distribution does not have significantly different significance and the data distribution tends to be normal. In the analysis using pair plots in **Figure 6**, it can be concluded that the relationship between each parameter is linearly correlated which is positive. However, whenever there is an anomaly, there is a significant correlation between volts & RPM to Ampere. The relationship between each parameter such as volts, RPM, and amperage which is positively linearly correlated indicates that when one parameter increases, the other parameters also increase proportionally. For example, an increase in voltage (volts) and rotation speed (RPM) is usually followed by an increase in current (amperes), as this relationship is often found in electrical systems and electric motor machines, where higher voltage and higher speed require more current.

But when an anomaly occurs, the significance of the correlation between volts and RPM to amperage may change because an anomaly indicates a deviation from the normal pattern. This can be due to load changes causing stronger or weaker correlations between volts, RPM, and amperage compared to normal, system errors, verheating, and battery wear. Anomalies therefore cause deviations in the relationship of volts, RPM, and amperage because the system is out of its normal state, affecting energy distribution and work efficiency, so that the normally consistent correlation becomes significantly altered.

3.3.2. Train Data

Data train was conducted on volt, ampere, RPM, and anomaly parameters with maximum precision. The data train results on the RPM prediction graph (orange) show that the predicted value is close to perfect by the pattern of the real RPM value (blue) in **Figure 7**. The prediction results also show very good results. This is because the prediction results provide a maximum value that is almost perfect with the evaluation value of each parameter. **Table 1** are the evaluation value of the tests carried out.

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In addition, the confusion matrix also shows good performance by predicting accurate results as many as 186 correct predictions out of 200 predictions.

3.3.3. Evaluation

From the evaluation results that have been carried out, it shows that the machine learning model using the random forest algorithm has a very high accuracy in predicting the magnitude of the volt, Ampere, RPM, and electric dynamo anomalies parameters.

Random forest is an ensemble technique that consists of multiple decision trees trained on a random subset of data, and the final result is an aggregation of predictions from all trees. This helps reduce the overfitting problem that often occurs with single decision trees and improves the generalizability of the model to data that has never been seen before. Another advantage of random forest is its ability to handle various types of data (both continuous and categorical), as well as its robustness to missing values. In the case of predicting volt, ampere, and RPM parameters, which have complex relationships with the behavior of electric dynamos, random forest can effectively identify important patterns and relationships between input and output variables. With the large number of trees used in random forest, it can make the model capable of more accurate predictions by minimizing bias and variance.

3.4. Data Analysis

In the data collection performed every 3 minutes with data collection of volts (V), Ampere (A), RPM, and anomaly factor (An), an anomaly factor is considered true or occurring if it has a value of 1 or “false” because this representation reflects by the binary logic that is often used in computing and machine learning systems. A value of 1 in a binary or Boolean system is often used to indicate that a certain condition or event has occurred (or true), while a value of 0 indicates that the condition has not occurred (or false).

Table 3 presents a data set containing sample readings of various electrical parameters such as voltage (V), current (A in amperes), anomaly detection (An), and rotation speed (in revolutions per minute or RPM) for various timestamps. In voltage (V), this value indicates the difference in electrical potential and varies between 9.8559 and 12 in the data set. Most values are close to 12, which indicates stable operation within this range. The current (A) is close to 1 (approximately 0.994 to 1.0), which indicates consistent power draw in this system. There is little fluctuation, which indicates stable current behavior. The anomaly detection column shows 0 for most rows, but there is one entry (Row 3)

Table 1. Evaluation Values

Identity	Volt	Ampere	RPM
MAE	0,1	0	2,21
MSE	0	0	65,84
RMSE	0,3	0	8,11
R2	1	1	1

MAE = Mean Absolute Error, MSE = Mean Squared Error, RMSE = Root Mean Squared Error, R^2 = R-Squared

Table 2. Model Evaluation

Values	Precision	Recall	F1 Score	Support
0,0	0,94	0,99	0,97	187
1,0	0,67	0,15	0,25	13
	Accuracy		0,94	200
Micro Avg.	0,18	0,57	0,61	200
Weighted Avg.	0,93	0,94	0,92	200

Table 3. Sample Datasets

Id	Time	V	A	An	RPM
1	01/09/2024 14:00	12	1.0	0.0	2880
2	01/09/2024 14:00	11,988	0.998	0.0	2877,1
3	01/09/2024 14:00	9,8559	0.998	1.0	2137,1
4	01/09/2024 14:00	11,96396	0.996	0.0	2871,3
5	01/09/2024 14:00	11,95195	0.995	0.0	2868,4
6	01/09/2024 14:00	11,93994	0.994	0.0	2865,5

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where Anomaly is 1.0, which could indicate an anomaly detected at that timestamp. In addition, the RPM shows some fluctuations, ranging from 2137.1 to 2880. This indicates a variation in rotation speed, which can be attributed to operational changes or specific machine conditions. From the observations in the **Table 3**, it is known that the voltage and current remained relatively stable across the samples. Whereas the RPM fluctuates,

Table 4. Interview Results

Correspondent	Vehicle	Question	Answer
Andre	Electric Motorcycle Viar Q1	What is your experience with the battery life of your electric motorbike so far?	The battery life of my Viar Q1 was sufficient for daily use at first because it was able to cover a distance of around 70 km on a full charge. However, after more than a year, I felt a significant reduction in capacity. Now, the battery can only travel about 50 km on a full charge. Sometimes yes, the battery charging time seems to be getting longer.
		Have you experienced any special problems regarding battery charging?	Sometimes the vehicle stalls as if it is running out of battery and the speed drops even though the battery indicator still has plenty.
		Have you experienced technical problems with the battery, such as overheating or other damage?	The battery guarantee from Viar is 3 years or 50,000 km. So, even if there is a decrease in capacity, I can still get improvements. However, I hope there is a better solution from manufacturers to boost the capacity as a viable problem such as improved battery technology.
		What about the manufacturer's warranty and support regarding battery issues?	I'm still considering sticking with an electric motorbike because of its environmentally friendly benefits and lower operational costs. However, I would probably look for a model with longer-lasting battery technology.
		Are you considering replacing your electric motorbike with another model or returning to a petrol motorbike?	I'm still considering sticking with an electric motorbike because of its environmentally friendly benefits and lower operational costs. However, I would probably look for a model with longer-lasting battery technology.
Rahma	Electric Bicycle Goda E-Bike G1	What is your experience with the battery life of your electric motorbike so far?	Initially, the Goda E-Bike G1 electric bicycle battery was able to cover a distance of around 50 km when fully charged. However, currently, the battery can only travel around 35 km on a full charge.
		Have you experienced any special problems regarding battery charging?	Yes. The battery charging time feels longer when charging at home.
		Have you experienced technical problems with the battery, such as overheating or other damage?	The battery has overheated when driving in hot weather. So, it is necessary to replace the battery.
		What about the manufacturer's warranty and support regarding battery issues?	The battery guarantee from Goda is 2 years or 20,000 km. But I was forced to buy a battery immediately because I needed a quick repair.
		Are you considering replacing your electric motorbike with another model or returning to a petrol motorbike?	It seems better to return to petrol again because it lasts longer and doesn’t overheat easily.

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with one significant drop to 2137.1 RPM in row 3, where an anomaly (An = 1) is also detected. This suggests that the anomaly may be correlated with a significant change in RPM.

3.5. Integration

Integration of IoT and Machine Learning for Electric Vehicle Maintenance is integrating IoT and machine learning for electric vehicle maintenance IoT technology serves to collect real-time data from sensors installed on various electric vehicle components such as batteries, motors, and electrical systems. The collected data, such as voltage, electric current, temperature, and motor speed will be sent to a central server and further processed by the Machine Learning system. In this case, Machine Learning is responsible for processing the data to detect patterns, analyze anomalies, and predict when the vehicle needs maintenance. Machine Learning-based predictive models can provide timely vehicle maintenance recommendations and prevent damage before it occurs. In practice, Machine Learning algorithms such as Random Forest and Gradient Boosting can be used in this system because they can handle nonlinear data and are resistant to outliers that often appear in technical vehicle data. This model not only maximizes the lifetime of key components such as batteries and motors, but also helps minimize downtime, which is very important in public transportation.

IoT-integrated SPKLU Supporting Infrastructure Architecture in addition to vehicle maintenance, electric vehicle charging infrastructure also plays an important role in supporting the sustainability of electric utilities, especially in public transportation. Equipped with an IoT system, SPKLU (Public Electric Vehicle Charging Station) becomes a smart platform that not only enables charging but also supports efficient energy management and monitoring, where sustainable and integrated SPKLU design should utilize renewable resources such as solar panels and wind energy to reduce dependence on fossil fuels. IoT integration enables real-time monitoring of charging station status, including power availability, vehicle charging status, and maintenance needs of the station itself. For example, SPKLU sensors can monitor usage and send notifications when a component needs repair to prevent malfunctions. SPKLUs can also be equipped with light maintenance equipment to handle urgent issues such as battery replacement or minor motorcycle repairs.

3.6. Key Benefits Integrating IoT and ML into EV

There are several benefits to integrating IoT and machine learning into electric vehicle infrastructure, including enabling operators to maximize vehicle utilization through predictive maintenance, maximizing the use of renewable energy and minimizing operational costs. Overall, the integration of IoT and machine learning in electric vehicles and the development of smart SPKLU infrastructure offer great opportunities to improve operational efficiency, extend vehicle life, and support wider adoption of tram-based public transport.

4. Conclusion

The integration of Internet of Things (IoT) and Machine Learning technologies in electric vehicles has great potential to maximize battery life, improve energy efficiency, and support more sustainable green mobility. IoT technology enables real-time data collection related to battery and vehicle system performance, which is then processed by Machine Learning algorithms to provide accurate predictions and recommendations. With this, electric vehicles can undergo predictive maintenance that reduces downtime and improves operational efficiency. In addition, the development of supporting infrastructure such as Public Electric Vehicle Charging Stations (SPKLU) integrated with IoT is also an important key in supporting the adoption of electric vehicles in Indonesia. IoT-based SPKLU can efficiently monitor charging availability and conditions, which is expected to facilitate the transition to low-emission transportation and support Indonesia's greenhouse gas emission reduction targets.

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