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SMART IOT ENERGY OPTIMISATION AND LOCALISATION MONITORING FOR E-BIKE SHARING

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ABSTRACT: E-bike sharing has emerged as a sustainable and convenient mode of transportation, offering lightweight, energy-efficient mobility solutions. However, existing systems face challenges such as limited input parameters for modeling, leading to inefficiencies in energy optimization algorithms and power assist mechanisms. A significant concern is the rapid depletion of batteries, which reduces the availability of e-bikes, increases operational costs for fleet managers, and impacts user satisfaction. To address these challenges, this project developed a Smart IoT Energy Optimization and Localization Monitoring System that integrates multi-sensor data, IoT connectivity, and advanced data analytics to monitor real-time usage patterns, battery levels, and the location of e-bikes. The methodology involved integrating sensors to collect key data, implementing connectivity for real-time monitoring, and developing an energy optimization algorithm to prolong battery life, improving the efficiency of the e-bike sharing system. The results demonstrated a 15% improvement in energy efficiency, which increased battery state-of-charge (SOC) and extended operational range. Additionally, the system enabled better fleet management by ensuring optimal energy usage and the availability of e-bikes for users. This approach aligns seamlessly with the Sustainable Development Goals (SDGs) by promoting eco-friendly transportation and enhancing user accessibility. The integration of IoT technology has proven effective in overcoming the limitations of traditional systems, offering a scalable and efficient solution for modern urban mobility.

ABSTRAK: Perkongsian e-basikal telah muncul sebagai kaedah pengangkutan yang lestari dan mudah, menawarkan penyelesaian mobiliti yang ringan dan cekap tenaga. Walau bagaimanapun, sistem sedia ada menghadapi cabaran seperti parameter input yang terhad untuk pemodelan, yang menyebabkan ketidakcekapan dalam algoritma pengoptimuman tenaga dan mekanisme bantuan kuasa. Masalah utama adalah penurunan bateri yang cepat, yang mengurangkan ketersediaan e-basikal, meningkatkan kos operasi untuk pengurus armada, dan memberi kesan kepada kepuasan pengguna. Untuk mengatasi cabaran ini, projek ini membangunkan Sistem Pemantauan Pengoptimuman Tenaga dan Lokalisasi IoT Pintar yang mengintegrasikan data multi-sensor, sambungan IoT, dan analitik data lanjutan untuk memantau corak penggunaan masa nyata, tahap bateri, dan lokasi e-basikal. Metodologi ini melibatkan pengintegrasian sensor untuk mengumpulkan data penting, pelaksanaan sambungan untuk pemantauan masa nyata, dan pembangunan algoritma pengoptimuman tenaga untuk memanjangkan hayat bateri, dengan itu meningkatkan kecekapan sistem perkongsian e-basikal. Hasil kajian menunjukkan peningkatan kecekapan tenaga sebanyak 15%, yang meningkatkan status pengecasan bateri (SOC) dan memanjangkan jarak operasi. Selain itu, sistem ini membolehkan pengurusan armada yang lebih baik dengan memastikan penggunaan tenaga dan ketersediaan e-basikal yang optimum untuk pengguna. Pendekatan ini selaras sepenuhnya dengan matlamat pembangunan mampan (SDG) dengan mempromosikan pengangkutan mesra alam dan meningkatkan aksesibiliti pengguna. Integrasi teknologi IoT terbukti berkesan dalam mengatasi kelemahan sistem tradisional, menawarkan penyelesaian berskala dan cekap untuk mobiliti bandar moden.

KEYWORDS: *E-bike, E-bike sharing systems, Energy optimization, Localization monitoring, Smart cities.*

1. INTRODUCTION

Electric vehicles are a superior option for mobility for several reasons. They often feature simpler engines, which make them easier to service, and are lighter, which makes them more economical, resilient, and energy efficient. They also have better options for mobility. Their only emissions come from the facility that produces electricity. However, the adoption of this technology, which has been around since the creation of the first Ford, is incredibly slow. In response to rising traffic, longer and more intense "smog" seasons, and a lack of parking spaces, cities are striving to urge their citizens to use other modes of transportation, such as the bus, rail, or bicycle. Bicycles are the most practical solution and have the finest health benefits for both the commuter and the city. However, the scarcity and restrictions of e-biking systems, as well as the difficulty of reaching the bicycle itself in a dangerous region, are what make using e-bikes difficult today [1].

Most recent studies primarily focus on electric vehicles rather than e-bikes, and they emphasize the hardware platform of those vehicles, including components such as powertrains and charging systems. However, similar research dedicated to e-bike platforms remains limited. In a related study [2], researchers explored the performance of a dynamic wireless charging system for electric vehicles (EVs) with characterization of different ferrite core geometries. These were to improve power efficiency and overcome issues like air gaps and misalignment between the primary coils, which generally cause inefficiency of energy transfer. The study revealed that air gaps and misalignment are the primary sources of lower power transfer efficiency. At the same time, high battery cost is still a major challenge affecting EV deployments, combined with limited driving range and deterrence to mass adoption caused by the virtual lack of static charging stations for consumers. While this study examined dynamic wireless charging for EVs, it highlights critical principles applicable to energy management with electric vehicles that can also be exploited in solving efficiency-related challenges [3].

Numerous cities, nations, and regions have implemented various regulations over the past ten years to encourage sustainable mobility. Bicycles are widely regarded as a cheap, healthy, and ecologically beneficial means of transportation [4]. Implementing bike-sharing programs (BSS) has been associated with substantial financial gains, improved public health, and time savings. As a result, many cities and local governments support and finance BSSs to promote cycling. However, writers call for more research on the topics because the effectiveness and effects of these new services are not fully understood. Another study done by [5] many cities worldwide introduced new, shared mobility modes, such as dockless electric scooters (e-scooters) and electric bikes (e-bikes). Researchers investigated the potential causes of users' distaste for e-bike battery systems, which deters people from using these systems more frequently. They also discussed the challenge of integrating electric bike sharing systems (BSS) with cargo-friendly solutions.

Since they are powered, e-bikes provide unique possibilities for tracking usage and comprehending how they interact with urban environments, which may be helpful for both e-bikers and conventional cyclists. It is essential to have a thorough grasp of how e-bikes are utilized in specific geographical and cultural contexts to comprehend and communicate their potential benefits for sustainable transportation and beyond [6]. Electric bike sharing aims to improve the efficiency and comfort of the current public transportation system. Electric bicycles (e-bikes) have become increasingly popular in China since the 2000s, and over the past ten years, they have also gained favor in Asia. Electric bicycles are typically thought to have more range, speed, and overall improved performance than normal bikes. Bicycling is, however, hindered by difficult geography, long travel distances, high temperatures, poor air quality, and other circumstances requiring physical effort. Therefore, "e-bikeshare" offers the ability to make bikeshare more appealing to people who may not have previously considered it a possibility. By removing some of the obstacles to cycling, electrically assisted bikes are faster, enabling longer trips, and are easier to ride over mountainous terrain [7]. It was discovered that perceived simplicity and functionality substantially predicted the desire to use regular BSSs. The e-bike delivers a competitive travel speed compared to rush-hour driving and public transportation.

According to a study done by [8], a significant obstacle to the widespread use of e-bikes has been recognized as the actual and perceived risks associated with cycling in cities and sharing the road with other motorized vehicles. It was determined that the cyclist was in danger from overtaking automobiles, passing pedestrians, road junctions, and parked vehicles in his or her path. Additionally, they demonstrated that collisions with pedestrians, light vehicles, and other bicycles were the most frequent. Moreover, it was noted that heavy traffic, fast traffic, icy, snowy, and debris-filled roads, as well as the perception of risk from other motorized vehicles, were the main obstacles to cycling adaptation. A type of motor vehicle, longitudinal road lines dividing slow traffic or bike lanes, and the stability of a cyclist in controlling the wheel angle and variation in their speed were proposed as solutions to these problems [9]. This investigation used an e-bike called a "Vektron S10" with four power support levels. The bike had three GoPro cameras for front, left, and rear views, five ultrasonic sensors, GPS, an IMU, a potentiometer, and a datalogger. The impact of road-related factors, such as the kind of road, slope, construction, pavement, type of intersections, etc., was examined.

People across the world are paying more and more attention to the Internet of Things. This concept's core tenet is the dominant presence around users of various things or "smart objects," such as Radio-Frequency Identification (RFID) tags, sensors, actuators, mobile phones, etc., that can communicate with one another and work with their neighbors to accomplish shared objectives thanks to special addressing schemes. Thus, the IoT (Internet of Things) and the increased ability to use less expensive, portable pollution sensors have changed the paradigm of particulate measurement [10]. These advancements have made it possible to collect real-time data that can be used in various scenarios. This new sensor family opens new possibilities for applications that directly involve citizens in monitoring air pollution, from which came the idea of "Canarin II" [11]. An electric bike that is linked to the user's smartphone to assist data gathering and sharing.

Its operational characteristics are analyzed based on the effects of essential parameters such as rider mass, wind speed, and slope. Dynamic equations mimic this bicycle's operation under specific operating circumstances. The fundamentals require a power flow controller for e-bikes to control the energy transfer from the battery to the motor. The motor produces electrical power functions in coordination with the user's mechanical power generated when pedaling, putting both in action. The basic scheme of an e-bike proposed in this paper can be seen in Fig. 1. Suitable power is chosen for the motor of the electric bicycle based on the required power determined by simulation. A previous study investigated the operating parameters of the electric bike in two scenarios: human power alone and human power assisted by an electric motor, to support the simulation study [12]. Data is gathered using LabVIEW programming. To verify the accuracy of the simulations that are being presented, experimental and simulation findings were compared.

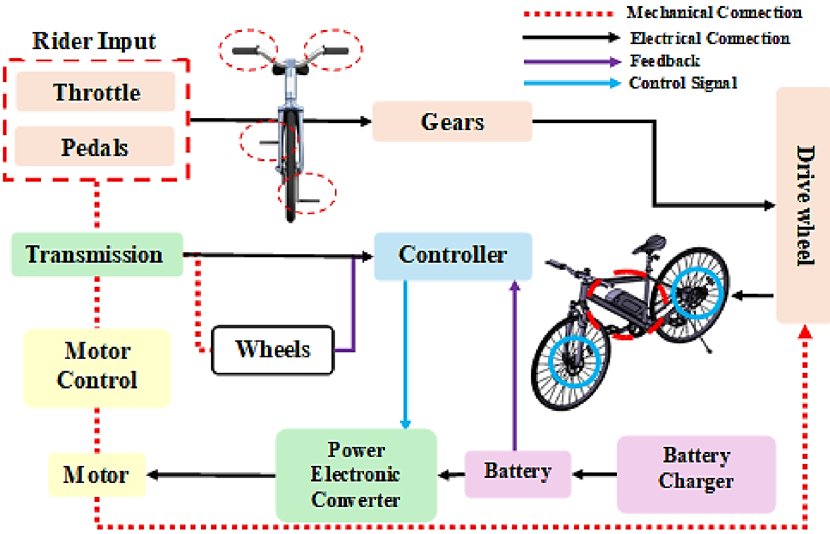

Figure 1. Basic scheme of an e-bike

In 2019, we witnessed the launch of two types of personal light-electronic vehicle sharing systems in the Gdansk, Gdynia, and Sopot metropolitan area (also known as "Tricity"). The first was a public bike sharing system (BSS) called MEVO, which was supported by the metropolitan authorities and had a fleet of 1224 e-bikes [3], [13]. The second category included e-scooter sharing programs offered by three private, rival businesses. No solutions at the time supported freight transfer and were integrated with micro-mobility services. The single BSS introduced in Tricity, the only major city in Europe without traditional bikes, was an electric bike. This gave them a rare opportunity to contrast the actions of users of shared e-bikes and e-scooters in the same setting. Bike ownership, a lack of adequate infrastructure for bike sharing and cycling, adverse weather, rugged terrain, and safety concerns on the road are some of the issues arising from these restrictions. The failure of MEVO can be attributed to several factors. Despite having experience in BSS management, the system's operator did not foresee issues with a somewhat large system that was half free-floating and electric. Implementation and upkeep costs, such as battery charging and fleet rebalancing, surpassed the financial capacity set mainly by the local authorities.

According to [14] it was determined the importance of 23 elements when designing an e-scooter: vehicle size, trunk capacity, seat design, riding range between battery changes, maximum speed, hill-climbing capability, horsepower, handle design, brake function, light brightness, time indicator, tire pressure indicator, constant speed, trip odometer, single trip odometer, battery capacity, revolutions per minute, digital speedometer, average speed, and average electric consumption were design considerations. Electric vehicles powered by batteries still have a lot of problems regarding those from which smart e-bike monitoring system (SEMS) has been developed, as shown in Fig. 2. However, maximizing the driving range of electric vehicles and extending the battery life; addressing the energy needs of electric vehicles both in the short- and long-terms; and increasing regenerative braking energy are the most crucial ones [15].

Figure 2. SEMS was developed to collect real-time usage and sensor data, combining open-source software and open hardware (Kiefer & Behrendt, 2016) [15]

Recent studies come in the form of an annotated dataset and an application study that made use of Artificial Neural Networks (ANN) to implement a driving behavior control system [16], [17], [18]. This work aimed to compare signal processing methods applied to automatically trigger an ANN-based control system based on sensor data collected in real-time regarding driving behavior parameters related to throttle and braking. And steering influencing a gasoline-powered average vehicle. This system delivered driving comfort by modifying the air-fuel ratio (AFR), enabling fuel economy on par with eco-driving mode and maximum engine power in sporty driving mode. While the findings are limited to gasoline engines and did not quantify factors such as the hill grade effect, they indicate increasing importance in having data feedback suited well for fine-tuning vehicle dynamics.

Similarly, our work targets a Smart IoT Energy Optimization and Localization Monitoring system for e-bike sharing. Though our system is not an ANN, it shares the idea of exploiting real-time sensor data to improve energy efficiency with the prior one. This is part of our larger effort to optimize energy management and promote the scalability and sustainability performance of e-bike sharing systems by tracking different parameters relevant to e-bike handover and battery utilization.

The remainder of this paper provides a detailed method for our E-bike sharing system, "I-bike," and a detailed description and assessment of the energy optimization for power consumption and localization monitoring mapping.

2. METHODOLOGY

The methodology for the smart IoT energy optimization and localization system in e-bike sharing is designed to ensure that the development process for this system is effectively done and whole. This method shall integrate both hardware and software, providing coherence from an early design phase to the final implementation of this system. It commences with a careful evaluation of the project specifications, requirements, and bicycle data route information to ensure that every element tallies to enhance energy efficiency and track the location of e-bikes. The NodeMCU ESP8266 will be used as the core controller of the hardware system; it serves as the central communication point to which multiple sensors and other components, including a GPS module and energy monitoring device, are attached. Energy optimization in an e-bike-sharing system can be defined as minimizing the energy consumption of electric bikes while maximizing their availability for use. That could be achieved by enabling hardware-software solutions, which could use data from IoT devices and sensors. This section shows the software and hardware design of the energy monitoring system. Moreover, localization monitoring within an e-bike sharing system involves accurately tracking real-time locations with complete accuracy and oversight. The development of both software and hardware for the localization monitoring system is focused on robust communication module development, efficient data collection strategies, and the utilization of IoT devices and sensors to enable accurate tracking and monitoring. If followed correctly, this systematic approach ensures the system fulfills its main goals while establishing a foundation for further developments toward better energy efficiency and user satisfaction.

2.1. Developing the System

In terms of software, the algorithms developed will optimize energy usage by predicting and adjusting consumption patterns based on the bike's operational parameters and usage patterns. Location tracking is implemented via GPS data synchronized with the IoT cloud for real-time monitoring and data analysis. This IoT platform will ensure that data transfer between the bike and the cloud, including the user interface, happens well and smoothly to attain its intended purpose of accurate tracking and energy optimization. The most critical stage of this development process involves integration and testing, where hardware and software components are integrated to check for compatibility and performance. Various scenarios were simulated to investigate and evaluate how the system responds to various situations, like low battery levels or inconsistent GPS signals. This phase also ensures the system is scalable and integrates perfectly well with the bike-sharing networks and platforms. Throughout the entire process, MATLAB is pivotal, particularly at the analysis and optimization stages. The software is used to formulate the algorithms, simulate systems modeling, and design control systems. The real-time feedback of the MATLAB toolset gives, within the development phase, a scope for data-driven adjustments to be made in the hardware and software parts of the system. In the final stages, the system deploys in a controlled environment to test its performance in real-world cases. The thorough and detailed documentation of all steps taken enables future developments, and the data gained from testing helps to increase scalability and compatibility. Hence, this integration process shall offer a smart, energy-efficient, and user-friendly system to offer a better experience in e-bike sharing systems.

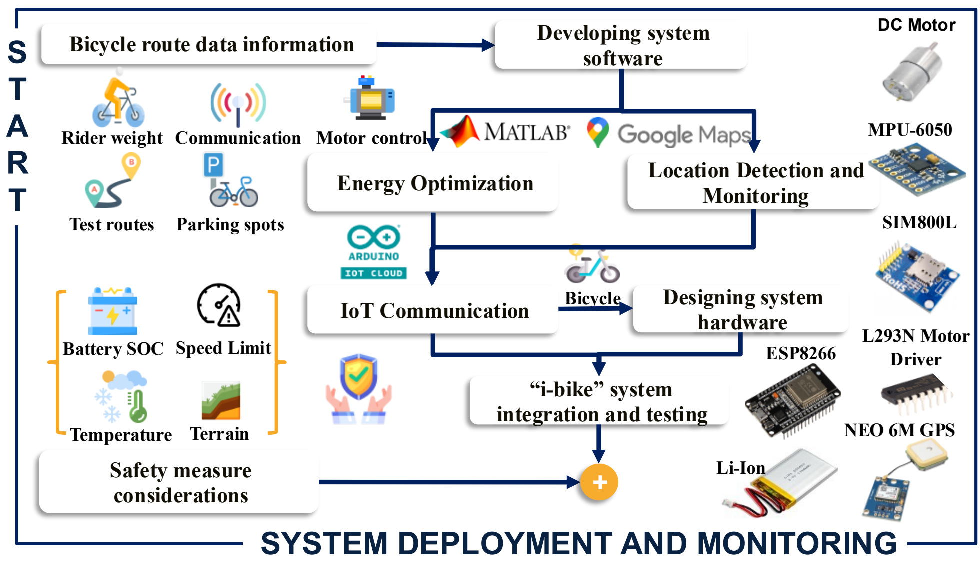

Figure 3. I-bike system monitoring block diagram

Fig. 3 illustrates the methodology for developing and deploying a smart IoT energy optimization and localization system for e-bike sharing, whereby it starts with collecting bicycle route data from sensors and GPS to locate and track the movement and speed of the bicycle on the travel route. The software for the system is designed to handle and manage real-time communication of this data between the e-bike, the cloud, and user interfaces. Operational data is analyzed to optimize energy consumption and utilization, while the GPS-based e-bike detection and monitoring system enables the precise tracking of locations. The IoT communication stage integrates all components, facilitating seamless data transfer and ensuring uninterrupted data transmission. The hardware circuit setup consists of key elements such as NodeMCU ESP8266 (central communication hub), DC motor, Li-Ion battery, MPU-6050 (gyroscope/accelerometer) for motion sensing, SIM800L GSM module for mobile communication, L293N motor driver for motors, and NEO 6M GPS for tracking location. These components have been selected to meet the system requirements of durability, low power usage, and real-time communication needs. Additionally, increasing rider safety is considered by implementing safety measures, such as monitoring environmental conditions. The system is then deployed in a real-world environment, monitored continuously to ensure seamless functionality and readiness for future expansion.

2.2. E-Bike Sharing System Workflow

An e-bike sharing system usually consists of users locating bikes using a mobile app, signing up to access the bike, and organizing their trip. The alarm system, a vital part of the intelligent IoT energy optimization and localization system for e-bike sharing, includes various important hardware and software components. The hardware components consist of motion sensors that identify unauthorized movements or attempts to tamper. These sensors link to a microcontroller NodeMCU, which handles the sensor data and activates the alarm (buzzer) when needed. Furthermore, the system could incorporate LED indicators or blinking lights for visual notifications. The software component needs programming of the NodeMCU to trigger planned responses like sounding an alarm and sending alerts in response to unauthorized access. Moreover, the system can connect with a central control panel or dashboard to control the alarm system's condition. By integrating these parts, the alarm system increases security and discourages theft in the e-bike sharing system. It includes projected battery level, energy efficiency choices, and route tracking. Users can ride a bike to their destination or drop it off at a different station. An E-Bike Sharing System Workflow is further illustrated in Fig. 4.

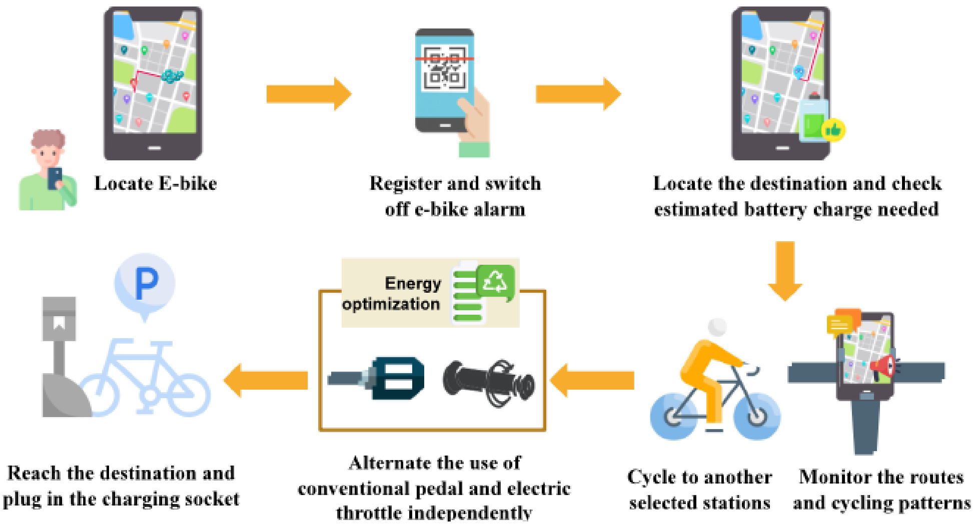

Figure 4. I-Bike Sharing System Workflow

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2.3. IoT Integration for E-Bike Sharing System

An IoT-based energy optimization system can be seamlessly integrated with a localization monitoring system to enhance the overall efficiency and user experience of an e-bike sharing service. By leveraging data collected from sensors and IoT devices, the system can dynamically adjust the e-bike's performance based on real-time factors such as location, battery level, and rider behavior. To achieve this integration, a robust cloud platform like Arduino IoT Cloud is essential for collecting, processing, and storing large volumes of data generated by the e-bikes. Developing a user-friendly mobile application enables end-users to interact with the system and access real-time information. An overall IoT communication diagram is shown in Fig. 5. Frameworks like React Native, Flutter, or Ionic can be employed to create efficient and intuitive mobile interfaces. To ensure the security and privacy of data transmitted between the e-bikes, IoT gateway, and cloud platform, cryptographic libraries such as OpenSSL or Mbed TLS can be implemented. These libraries provide robust security measures to protect sensitive information and prevent unauthorized access.

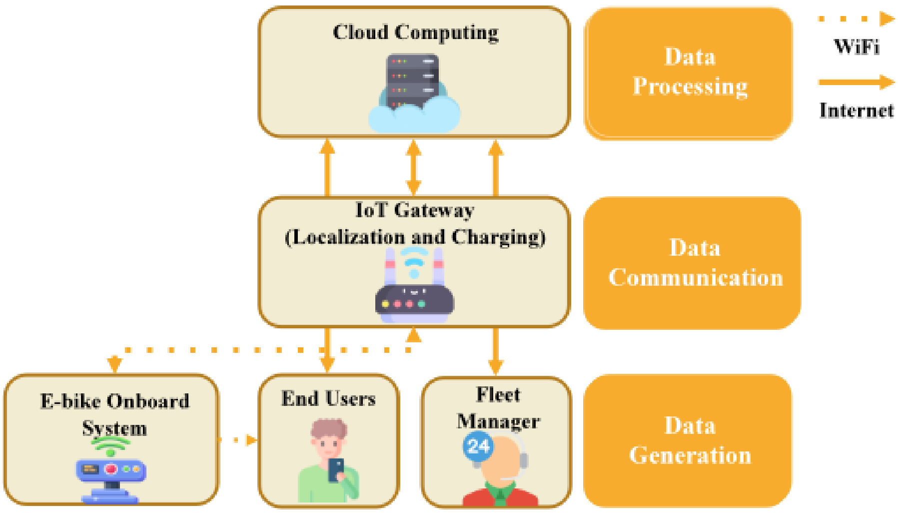

Figure 5. IoT communication diagram

2.4. IoT Connection Flowchart for E-Bike Sharing System

The flowchart shown in Fig. 6 depicts the basic process to be performed by an IoT-enabled e-bike-sharing system for efficient tasks such as battery management, precise localization, and seamless user experience. The working process of the IoT-based e-bike sharing system starts when the user enters the system's dashboard by logging in. In case of a successful login, it triggers the alarm system to be turned off. Once the alarm system has been turned off, the e-bike gets unlocked. The power monitoring panel is checked to assess the charge level in the batteries. If the battery level falls below a predefined threshold level X=20%, it notifies the user to start the bike charging process. Once the battery is sufficiently charged, the system checks the localization monitoring dashboard to know the e-bike destination. Then it continuously monitors battery consumption, adjusting the speed of the motor accordingly. If the gyroscope detects lower acceleration due to climbing uphill, it increases the battery consumption and raises the speed of the motor to maintain optimal speed.

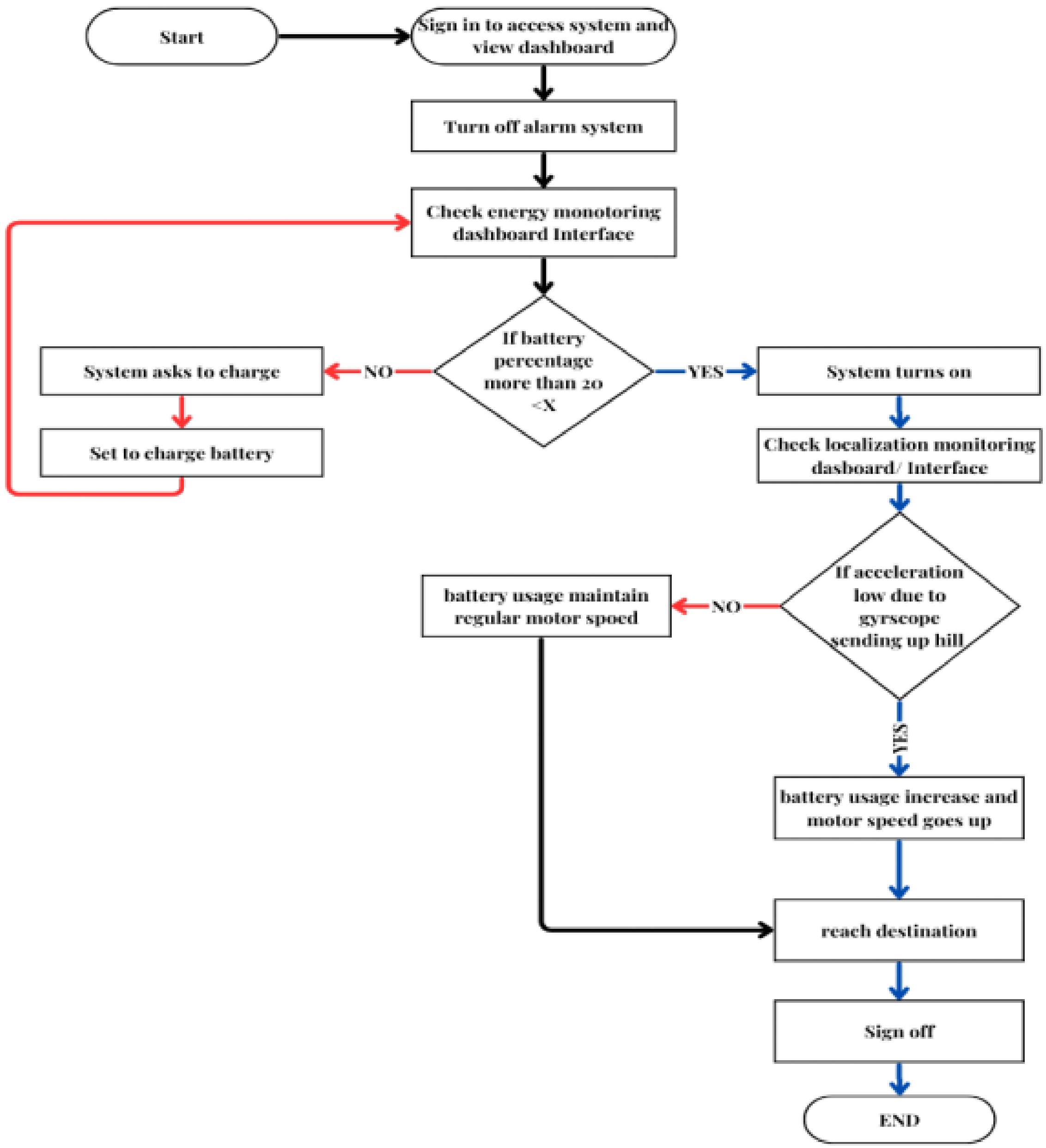

Figure 6. IoT Connection Flowchart for E-Bike Sharing System

2.5. Bicycle Dynamics

The motion of a bicycle follows Newton's second law, which is described by:

$$F_P - (F_R - F_S + F_W) = M \frac{d^2y}{dt^2} \quad (1)$$

Where, F_R is the rolling resistance force, F_P is the propulsion force, F_S is slope resistance force, F_W is the wind resistance force, M is the total mass of the bicycle $M_b$and rider M_R, and x is distance (m). This study uses a DC motor installed in the rear wheel to support riders during pedaling. The dynamics of the DC motor are described by Eq. (2) and Eq. (3):

$$\mathrm{L_a}.\frac{\mathrm{di_a}}{\mathrm{dt}} + \mathrm{i_a(t)}.\mathrm{R_a} + \mathrm{K_b}\,\omega_\mathrm{m} = \mathrm{U_a} \quad (2)$$

$$\mathrm{J}.\frac{\mathrm{d}\omega_\mathrm{m}}{\mathrm{dt}} + \mathrm{T_l} + \mathrm{B_1}\,\omega_\mathrm{m} = \mathrm{K_b}\,\mathrm{i_a(t)} \quad (3)$$

where, i_a is the armature current, R_a is the armature resistance, U_a is the terminal voltage of the DC motor, L_a is the armature inductance, K_b is the back emf constant, J is torque of inertia, B_1 is the viscous friction coefficient, T_l is the load torque, ω_m is the speed motor.

2.6. Bicycle Performance

The power consumed to push a bicycle and rider is primarily due to overcoming air resistance, slope, and friction, as described by Eq. (4) and Eq. (5):

$$P_{total} = P_{drag} + P_{hill} + P_{friction} \tag{4}$$

$$P_{drag} = \frac{C_d . D . A}{2} . (v_g + v_w)^2 . v_g \tag{5}$$

where C_d is the drag coefficient,D is the density of air, A is the frontal area, v_g is ground speed, v_w is wind speed. The power to overcome the slope P_{hill} is calculated using Eq. (6):

$$P_{hill} = 9.81 . G . v_g . M \tag{6}$$

where G is the coefficient of slope. M is the total mass of the bicycle and rider. The power to overcome the friction $P_{friction}$ is calculated using Eq. (7):

$$P_{friction} = 9.81 . R_c . v_g . M \tag{7}$$

where R_c is the coefficient of rolling resistance.

The motion of the e-bike is governed by Newton's second law, considering forces such as rolling resistance, slope resistance, and wind resistance. The power consumed by the e-bike is calculated using Eq. (8):

$$P_{total} = P_{drag} + P_{hill} + P_{friction} \tag{8}$$

where P_{drag} is the power to overcome air resistance, P_{hill} is the power to overcome slope, and $P_{friction}$ is the power to overcome rolling resistance. These calculations are integrated into the energy optimization algorithm to adjust motor output dynamically. For instance, on steep slopes, the system increases motor torque to compensate for increased resistance, while on flat terrains, it reduces power output to conserve energy. This approach ensures efficient energy usage and contributes to the overall improvement in electrical efficiency.

2.7. Gyroscope-Based Energy Optimization Strategies

The IoT-based smart energy optimization and localization system in e-bike sharing involves many advanced hardware-software integrations to help improve the general riding experience and increase energy efficiency. Gyroscopes, integrated with other sensors such as accelerometers, play a crucial role. These updated movement and orientation data are available in real time, thus offering accurate power management tuning. For instance, when the system notices any shifts in speed or direction, it can optimize the motor output accordingly. Such instantaneous adjustments would be critical in keeping energy efficiency uphill or around sharp turns. In the e-bike system, NodeMCU provides the board that controls all functionalities of several other components integrated into the system for proper functionality. The GPS module communicates with NodeMCU through a serial port and will provide the current location in real time. This will be important in tracking the position of an e-bike and mapping the routes taken. The Wi-Fi module enables the NodeMCU to send location, speed, and battery status data to any remote server or cloud services for continuous monitoring and analysis. Also, integrating an OLED 0.96" I2C display gives the rider all the essential current data: speed and battery SOC (State of Charge), so he is always kept informed about his journey.

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The circuit in Fig. 7 has two major parts: the Localization Monitoring System and the Energy Optimization System. In the Localization Monitoring System, the SIM800L GSM module sends all its data to a remote cloud service to track the real-time position. More precisely, it does geographical tracking using the NEO 6M GPS, and for object detection or tampering, it uses an HC-SR04 ultrasonic sensor. Once tampering is detected, a buzzer triggers an alert. Energy Optimization System targets power management and motion control. In the NodeMCU ESP8266, the core coordination among sensors, communication modules, and cloud services is done. Motor speed and torque are managed to optimize energy consumption during operation using an L293N motor driver. This, along with the MPU-6050 sensor that monitors the orientation and movement of the bicycle, allows the system to make real-time adjustments to improve performance while being energy-efficient. The power supply is guaranteed through a rechargeable Li-Ion battery, the consumption of which is monitored very carefully to extend its SOC while sustaining the performance of the system. All these components combine into one robust, energy-efficient system to enhance riders' experience with real-time data displays, optimize energy usage, and ensure safety and efficiency. This system improves not only the aspect of localization and communication but also optimizes energy consumption to enhance performance and sustainability for better e-bike sharing.

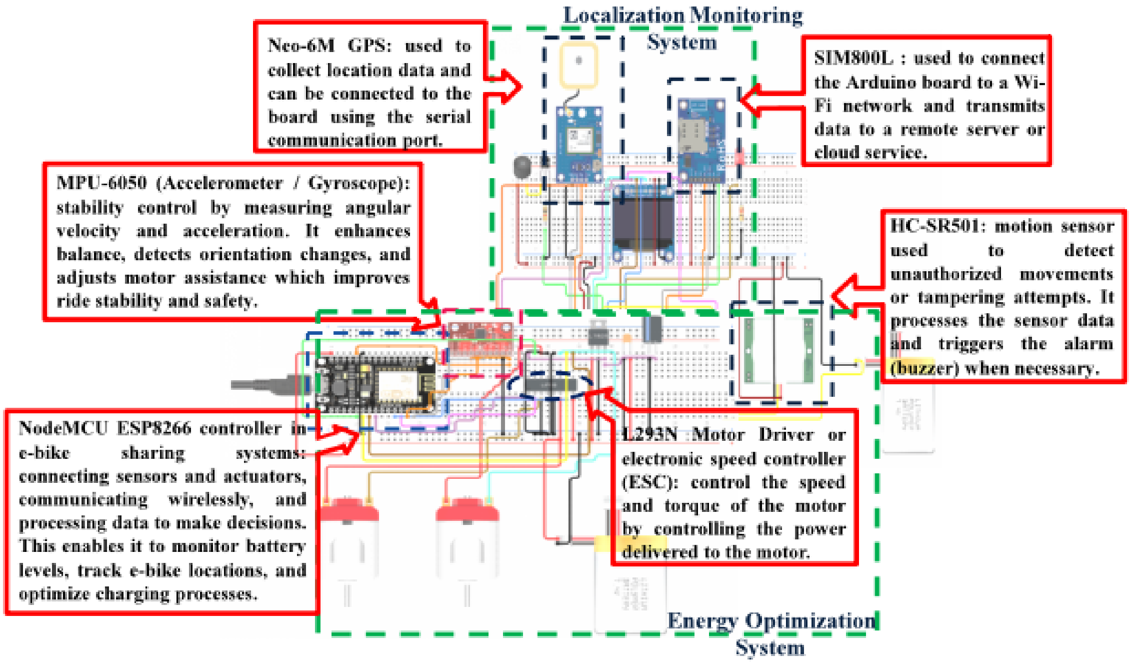

Figure 7. Developed a circuit for energy optimization and localization monitoring systems

2.8. Utilizing MATLAB And Arduino Cloud / IoT for Enhanced Data Processing And Control In E-Bike System Development

Most aspects of the e-bike system were developed and implemented using the powerful and versatile framework of MATLAB/Simulink, specifically Simscape Electrical. Because of its rich toolkit and features regarding data processing, algorithm development, and system modeling, we could analyze and process sensor data efficiently from different components, like the gyroscope of the e-bike and other sensors. All the libraries for processing and analyzing signals and data helped us extract meaningful information from raw sensor data, enabling correct tracking and control of the motion of the e-bike. Its intuitive graphical user interface and simulation capability allowed us to model and fine-tune parameters of the control system for optimal performance and stability of the e-bike. Furthermore, MATLAB is compatible with external hardware and different communication protocols, facilitating seamless integration of the e-bike electronic system for real-time data acquisition and control. Arduino Cloud and IoT enhanced the ability to connect with outside devices, elevating the system's performance, adaptability, and user satisfaction.

The system optimizes battery usage through real-time monitoring and adaptive energy management. Sensors such as the MPU-6050 gyroscope and GPS module provide data on terrain, rider behavior, and speed. This information is fed into an energy optimization algorithm that adjusts motor output to minimize energy consumption. For instance, during uphill climbs, the system increases motor assistance, while on flat terrains, it reduces power output to conserve energy. Additionally, the system employs predictive maintenance by monitoring battery voltage and charge levels, ensuring optimal performance.

In addition to MATLAB, a mobile application and a dashboard user interface were made using Arduino Cloud and Arduino IoT. These platforms make it easy to create a responsive interface that enables users to monitor key e-bike metrics such as location, speed, and battery status. In this regard, Arduino IoT has ensured seamless connectivity of an e-bike with the cloud over real-time data transmission and its control on mobile devices.

3. RESULTS AND DISCUSSION

We start by describing the performance metrics adopted for measuring the system's performance concerning energy efficiency, localization accuracy, and user satisfaction. The obtained results are then presented in detail, together with discussions. The analysis will be conducted from multiple dimensions: effectiveness for energy optimization, localization system accuracy, and influence of user behavior on energy consumption. Furthermore, the segment delves into incorporating gyroscope data for energy optimization, highlighting the improved energy efficiency. The results are carefully examined and critically analyzed for their implications on scalability, sustainability, and overall accomplishment of the e-bike sharing program.

3.1. Integration of Gyroscope and Feedback System for Enhanced Monitoring

First of all, the information from the gyroscope can be used to optimize the operation of the motor. In this case, angular movement and orientation are controlled all the time, which enables the system to make proper adjustments in the operation of the motor by adjusting the motor's power output accordingly. For example, in uphill or heavy terrain conditions, the system is informed of how much assistance the motor has to give. Optimized motor performance decreases the rider's fatigue and enhances comfort during riding. The input from the gyroscope would contribute to optimizing energy and prolonging battery SOC.

Tracing the motion and orientation of an e-bike precisely would intelligently adjust the motor's power consumption according to the nature of the ground and riding conditions. For example, when the gyroscope detects downhill or flat surfaces—downhill being the maximum condition where there is less need for a motor assistance system—it reduces the power output, thus conserving battery energy. In particular, energy optimization enables an increase in e-bike range by enhancing the overall efficiency of battery use. We implemented algorithms in MATLAB that processed and analyzed data gathered from several sensors. In turn, the gyroscope provides information about the angular motion and orientation of the e-bike, which is essential for accurate tracking and control. We will also integrate a feedback control system into the MATLAB model. This will continuously monitor and adjust several parameters, like motor power output, based on real-time sensor data. The e-bike uses a feedback control system for efficient and optimal operation under various riding conditions. Incorporating these sensor inputs into the operational model developed in Fig. 8 has greatly enhanced the stability, control, and energy efficiency of the e-bike. The gyroscope was incorporated with a feedback control system to improve these results with more precise and responsive control.

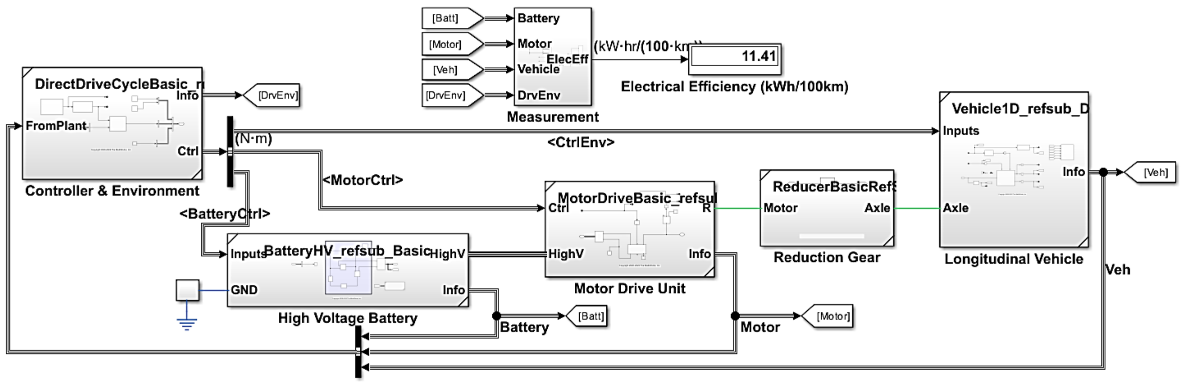

Figure 8. E-bike MATLAB/Simulink new control system with feedback

3.2. Efficiency Calculation and Gyroscope Integration

Calculating electrical efficiency within an electrical drive system, such as a three-phase AC multi-drive, requires detailed behavioral simulation of components like a motor, controller, and inverter. In this respect, Simscape Electrical is one of the best tools for modeling and designing the system to appropriately estimate electrical losses, which is required to calculate efficiency. First, a detailed three-phase permanent synchronous motor drive (PMSM) system, including elements such as the motor, controller, and inverter, is set up. Efficiency will be calculated by setting some main operating conditions, including speed and torque. Significant operating factors influence how the motor will consume and dissipate electrical power. Electrical losses can be measured when running the system under the set operating conditions.

Once the simulations are done, the API (Application Programming Interface) called upon is the Get Power Loss Summary API to extract the electrical losses from the system. The electrical efficiency is calculated by comparing the input power at the system input to its output power, where the difference is the electrical losses. It is a model for calculation efficiency under different conditions. The general rule is that electrical efficiency in such systems can vary from 11% to 15%, as shown previously in Fig. 8, depending on factors such as operating load and system parameters. The integration of extra sensors, such as the gyroscope, increases the completeness of the model in all respects. The system dynamically changes its motor output based on real-time data from the gyroscope on the orientation and movement of the bike. For example, when the gyroscope detects angle changes in the bike while making climbs or sharp turns, the system can adjust motor torque and speed to maintain optimal performance while avoiding unnecessary energy consumption. This would, in return, work to enhance the energy efficiency of the whole e-bike system.

Besides, the results can be used in higher-scale models, such as the simplified PMSM drive block, where the estimated electrical losses would serve as parameters for more efficient simulations. Employing models with detailed loss information, the system will give a more accurate prediction of energy performance in various conditions and improve power efficiency while enhancing the rider's experience. The Simscape Electrical-enabled workflow captures the system's complexities, allowing efficient solutions for energy optimization.

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From the three graphs plotted in Fig. 9, very useful information can be acquired about energy consumption by the vehicle, performance by the motor, and the efficiency in general while it operates. The graph shows three time plots of an electric vehicle's performance: the top graph shows the speed of the vehicle, which rapidly accelerates from zero to a maximum of 40 MPH and then levels off; the middle graph shows battery voltage decreases gradually as the vehicle is in use but with a slight dip around 150 seconds. The graph below depicts the development of motor temperature, constantly growing during the operation of the motor, and then leveling off at around 150 seconds.

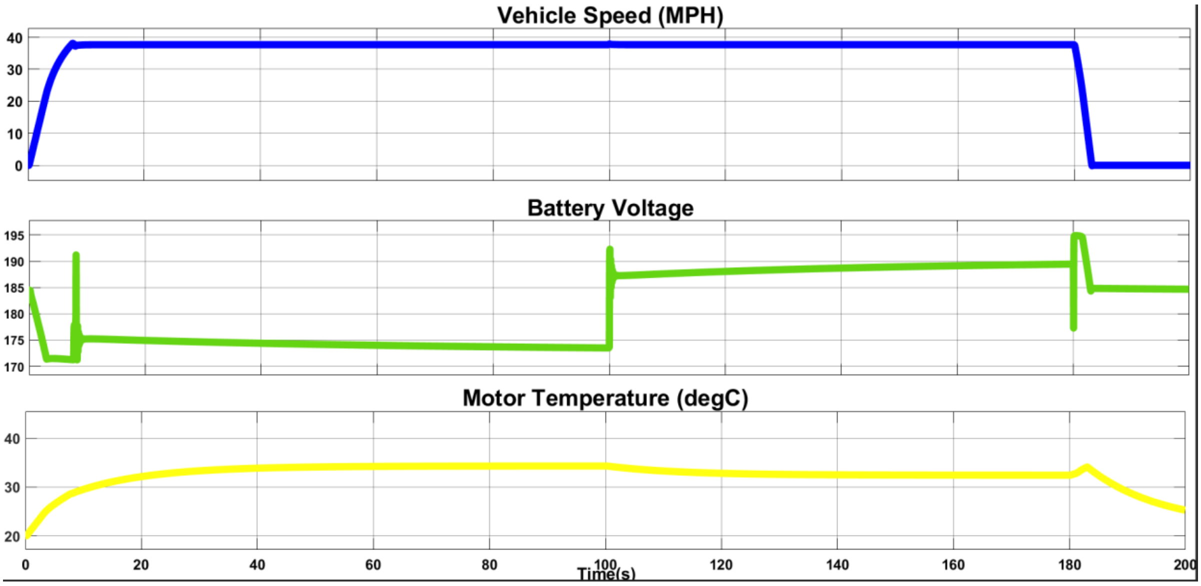

Figure 9. Performance Analysis of e-bike

The graph in Fig. 10 illustrates the mechanical and electrical power consumption of an e-bike as a function of time. Mechanical power output is represented in red and wildly oscillates due to changes in both load and speed. Electrical power input, in blue, has a similar shape but with deviation due to a combination of factors, including the battery voltage and motor efficiency. Energy efficiency can be achieved through the analysis of the relationship that exists between mechanical and electrical power. For example, suppose the mechanical power output is high. In that case, it will also be expected that the electrical power input is equally high because of the increased load the motor has to drive. However, if the electrical power input is way higher than the mechanical power output, energy is lost through some inefficiencies in the system. The differential value of mechanical and electrical power should be minimized to improve the vehicle's general efficiency. It can be done by adopting specific strategies, like optimization in the motor control algorithm, reduction in the electrical losses within the system, and enhancement in the efficiency of energy storing and converting components.

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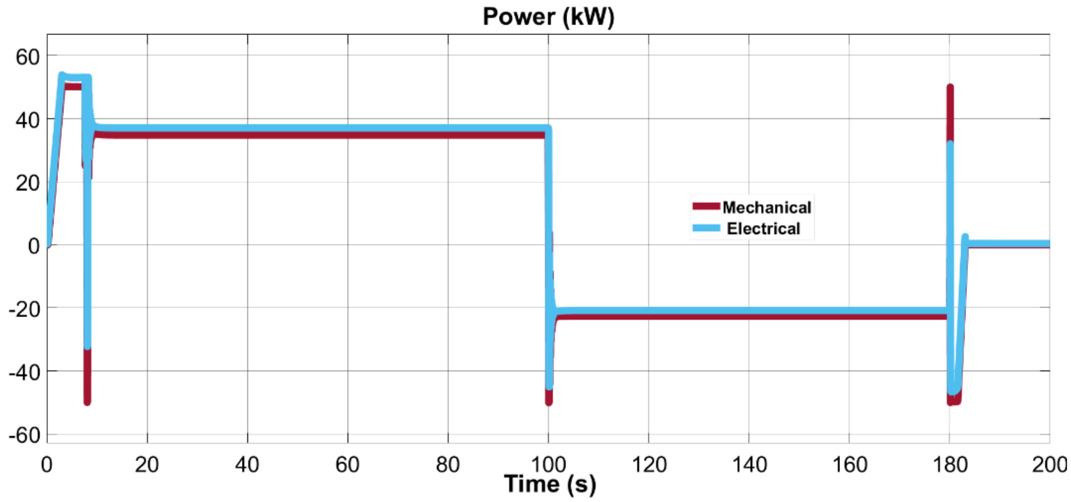

Figure 10. Power Consumption Analysis of the e-bike

Electrical efficiency was improved by integrating real-time sensor data with advanced motor control algorithms. The system dynamically adjusts motor output based on terrain, rider behavior, and battery status. The electrical efficiency is calculated using Eq. (9):

$$Elec_{Eff} = \frac{BattPwr}{VehSpd} \times 100 \tag{9}$$

where $BattPwr$ is the battery power in kWh, and $VehSpd$ is the vehicle speed in km/h. This adaptive approach minimizes energy wastage and maximizes energy conversion efficiency. Experimental results confirmed the efficiency gain by comparing energy consumption before and after optimization under identical riding conditions. Fig. 11 shows the MATLAB simulation subsystem used to calculate battery power ($BattPwr$), vehicle speed ($VehSpd$), and electrical efficiency ($Elec_{Eff}$). The subsystem integrates data from the battery and motor to compute energy consumption and optimize efficiency in real-time.

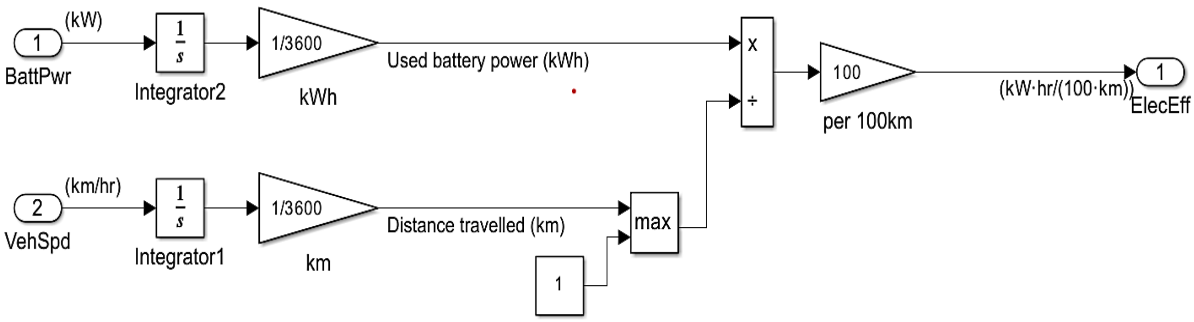

Figure 11. MATLAB simulation subsystem for electrical efficiency

The following graphs in Fig. 12 represent the battery charge and electrical efficiency of an e-bike with respect to time. The graph of battery charge shows that the charge progressively deteriorates as the usage of the electric vehicle increases, but it tends to increase around 1500 seconds. The electrical efficiency graph represents oscillations, although the trend is generally rising with the increase in the time axis. This improvement might be due to various reasons related to tuning the motor control algorithms or because the system has been adapted to a driving condition. The highs and lows of fluctuations in the graph depict how much load was applied to the motor and, consequently, the energy conversion efficiency. These graphs, in conjunction with system simulation results, show the location of optimizations that could be made by enhancing motor control algorithms or employing better energy management techniques. This could be a data-driven approach to improving electric vehicles' performance and energy efficiency for extended range while reducing their environmental impact.

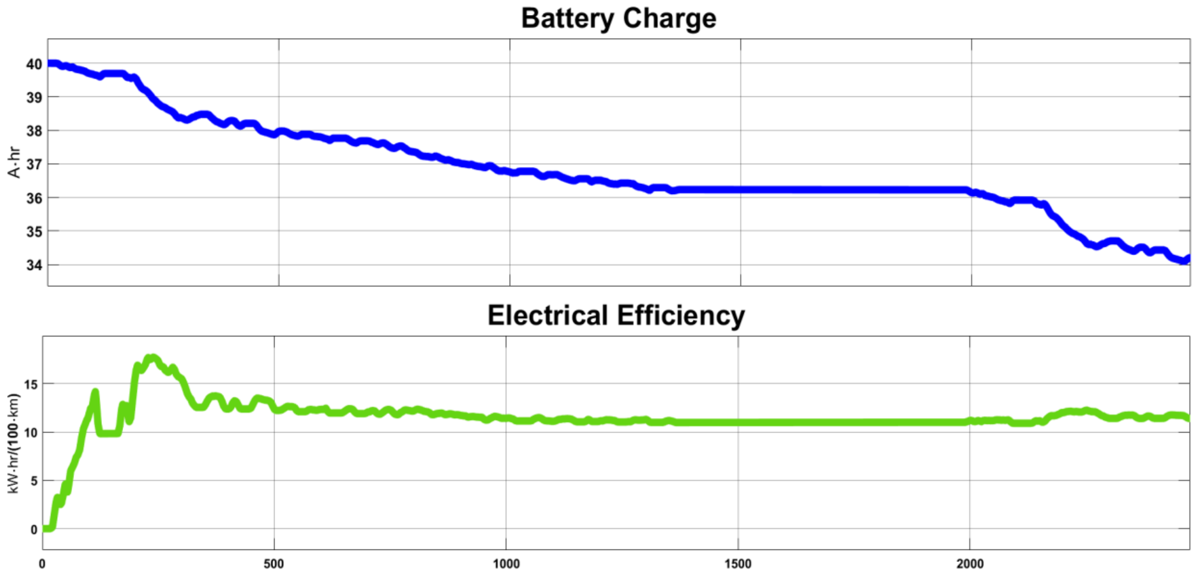

Figure 12. Battery Charge and Electrical Efficiency Analysis

3.3. Prototype Setup

The developed electrical efficiency of the e-bike system is achieved through an optimized control algorithm that intelligently manages power delivery to the motor. The system adapts to various factors, including speed, load, and terrain, for minimal energy dissipation while ensuring the maximum possible conversion of electrical energy into mechanical propulsion. Sensors like the MPU6050 accelerometer/gyro, GPS, current, voltage, and charge allow it to gain real-time operating data and make better decisions. It will precisely enable power output control, making terrain-based adjustments and performing predictive maintenance to ensure the e-bike operates most efficiently. The energy sensor calculates the battery's remaining life and regulates performance for sustained battery management. It also consists of a remote control system that connects to the user's mobile application for conditions and battery locations, among others.

The smart IoT energy optimization and localization system prototype integrated on e-bikes supports the implementation of innovative technology. The hardware will include a carefully chosen array of components comprising a microcontroller board, a GPS module, a gyroscope, and other sensors. These components have been mounted in a case on the collected bicycles, as shown in Fig. 13, offering stability and functionality during operation.

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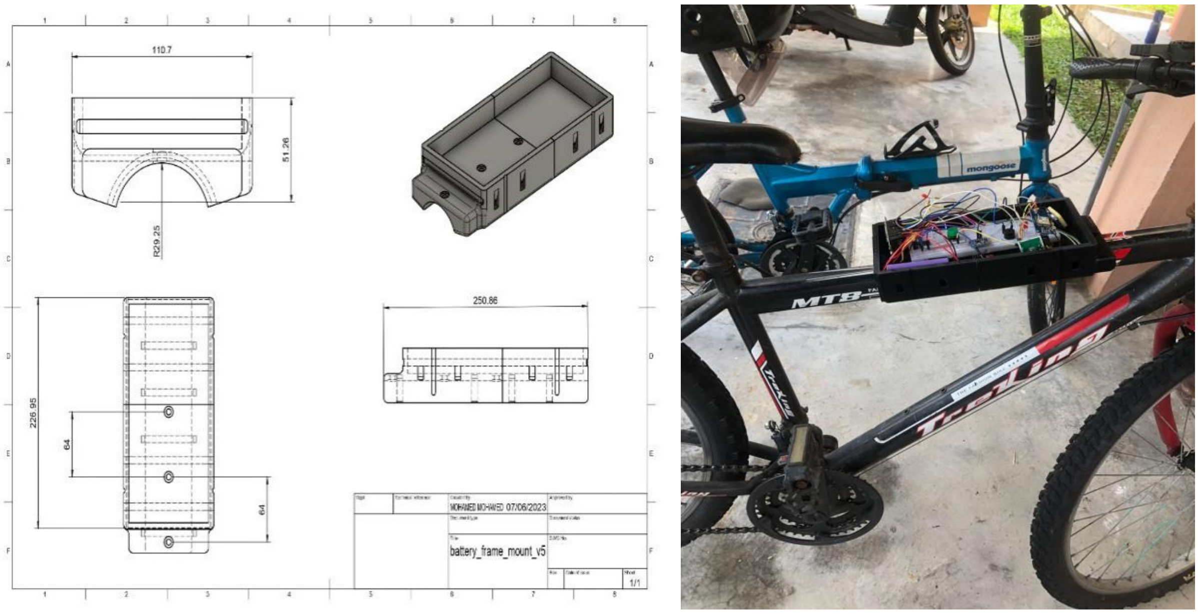


Figure 13. 3D case prototype

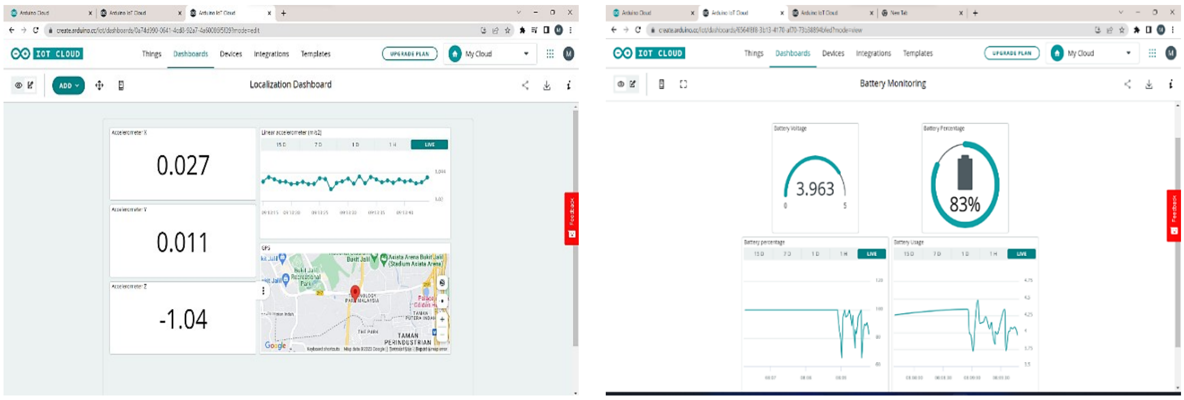
It has been elaborately undertaken to realize the best connectivity with optimum placement of hardware for the detailed design and integration of the prototype. As an integrated result, a system that combines the latest technology and the practicality of bicycles is developed. Fig. 14 shows images of the prototype in action and the appearance of the integrated components and bicycles. These views help better present the prototype and how it would look in real life within the e-bike-sharing system.

Figure 14. Prototype Integration - Showcasing the smart IoT system seamlessly integrated onto a bicycle

3.4. User Dashboard / Monitoring Interface

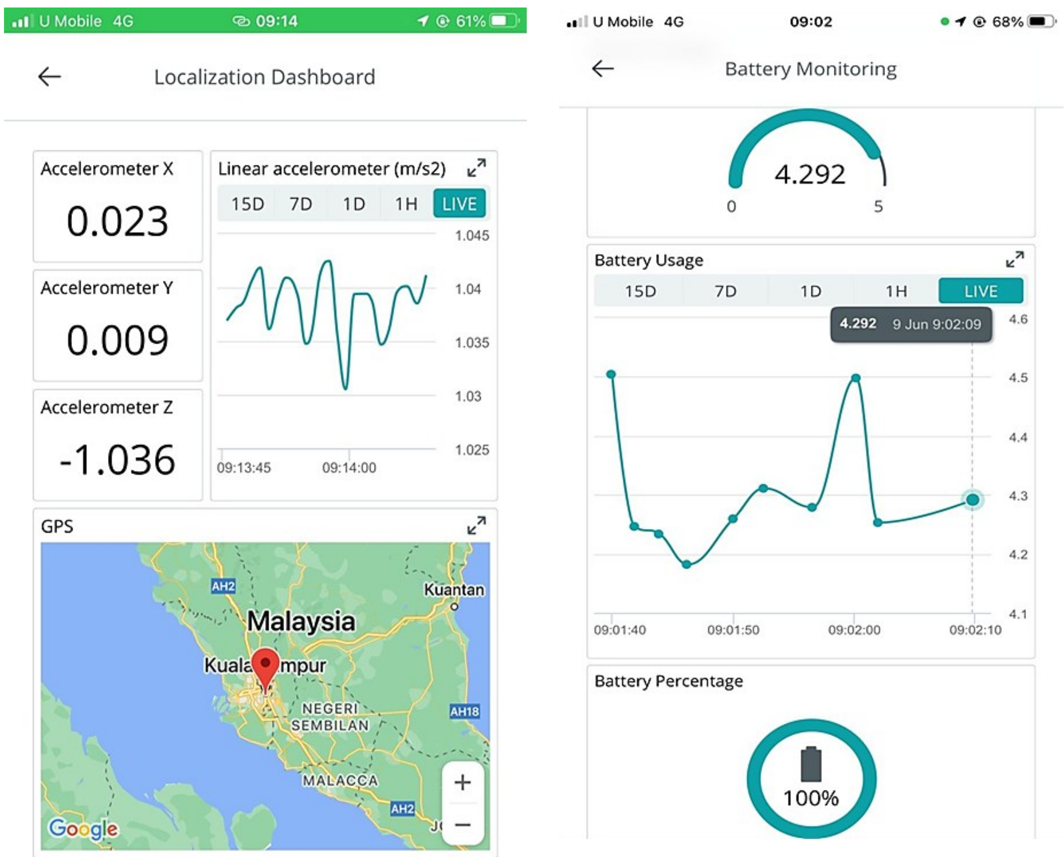
The images below, shown in Fig. 15, present a user interface developed on Arduino IoT Cloud that allows the opportunity to show two types of dashboards designed for e-bike localization and battery monitoring. The Localization Dashboard (a) presents real-time data from various sensors: three-axis acceleration values (X, Y, Z) and a GPS map with the current position of the e-bike. This gives users insights into the bike's position and movement dynamics. The Battery Monitoring Dashboard (b) presents key battery metrics such as voltage and charge percentage. The visual gauges display the battery's current voltage (3.963V) and charge level (83%).

The two graphs plot the battery percentage versus time and voltage over time in detail to track battery status and performance trends in the e-bike. It integrates sensor data with real-time monitoring for effective energy management and enhances usability through mobile-friendly interfacing. Accordingly, Fig. 16 reports the interface of the mobile application in different riding conditions, directly mirroring the localization and battery monitoring dashboards from the user's smartphone.



(a) Localization - Acceleration (b) Battery SOC Monitoring

Figure 15. Desktop Dashboard



(a) Localization - Acceleration (b) Battery SOC Monitoring

Figure 16. Mobile App Dashboard

4. CONCLUSION

In conclusion, the aims mentioned in the design of the communication module strategy for location and speed data gathering, energy profile information evaluation with travel distance optimization, and IoT-based energy optimization system development for e-bike sharing localization monitoring were met by this project.

We implemented and strategized a bright approach in embedding a communication module that would share real-time data on the location and speed of the e-bikes through careful planning and implementation. This was a good backbone for the subsequent energy profile evaluation. We have analyzed energy profiles, optimized the travel distance to find areas of improvement, and implemented intelligent algorithms for optimizing energy consumption for an e-bike sharing system. The optimization ensured efficiency in using the resources and extending battery life for overall sustainability and operational efficiency. Thus, IoT-based energy optimization of e-bike sharing began to be developed for localization monitoring, marking a significant milestone. The advanced technologies of GPS, gyroscope, and other sensors were merged into the e-bikes to perform real-time monitoring and control. Hence, it provided accurate localization, which permitted effective management and optimization of the bike fleet. This would, in turn, help achieve the project's outcomes regarding SDG 11: Sustainable Transportation and SDG 7: Affordable Clean Energy, while promoting innovation (SDG 9) for a greener future.

The project effectively achieved its goals by creating a communication module plan, enhancing energy profiles, and creating an energy optimization system based on the Internet of Things. The results support the progress of energy-saving e-bike sharing systems, encouraging eco-friendly transportation, and improving overall user satisfaction. The successful implementation of the project showcases how IoT technologies have the potential to enhance energy usage and efficiency in shared transportation systems.

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REFERENCES

[1] V. Albuquerque, M. S. Dias, and F. Bacao, “Machine learning approaches to bike-sharing systems: A systematic literature review,” *ISPRS Int J Geoinf*, vol. 10, no. 2, Feb. 2021, doi: 10.3390/ijgi10020062.

[2] S. H. Yusoff, A. A. Abdullah, N. N. Nanda, and A. S. A. Badawi, “PERFORMANCE ANALYSIS ON DYNAMIC WIRELESS CHARGING FOR ELECTRIC VEHICLE USING FERRITE CORE,” *IIUM Engineering Journal*, vol. 23, no. 1, pp. 46–59, 2022, doi: 10.31436/IIUMEJ.V23I1.1663.

[3] T. Bieliński, A. Kwapisz, and A. Ważna, “Electric bike-sharing services mode substitution for driving, public transit, and cycling,” *Transp Res D Transp Environ*, vol. 96, Jul. 2021, doi: 10.1016/j.trd.2021.102883.

[4] L. Stilo, D. Segura-Velandia, H. Lugo, P. P. Conway, and A. A. West, “Electric bicycles, next generation low carbon transport systems: A survey,” *Transp Res Interdiscip Perspect*, vol. 10, Jun. 2021, doi: 10.1016/j.trip.2021.100347.

[5] T. Bieliński and A. Ważna, "Electric scooter sharing and bike sharing user behaviour and characteristics," *Sustainability (Switzerland)*, vol. 12, no. 22, pp. 1–13, Nov. 2020, doi: 10.3390/su12229640.

[6] Shen, W., & Li, J. (2018). Design and Implementation of Parking Monitoring System of Bike Sharing In the Electronic Barrier. *Proceedings of the 2018 Joint International Advanced Engineering and Technology Research Conference (JIAET 2018)*. 2018 Joint International Advanced Engineering and Technology Research Conference (JIAET 2018), Xi'an, China. https://doi.org/10.2991/jiaet-18.2018.6

[7] N. B. Hung, J. Sung, K. Kim, and O. Lim, "A Simulation and Experimental Study of Operating Characteristics of an Electric Bicycle," in *Energy Procedia*, Elsevier Ltd, 2017, pp. 2512–2517. doi: 10.1016/j.egypro.2017.03.723.

[8] C. H. Hsu, B. S. Liu, S. L. Jhuang, and Y. C. Li, "The study of ergonomic evaluation and critical design factors for electric scooter," in *2016 International Conference on Applied System Innovation, IEEE ICASI 2016*, Institute of Electrical and Electronics Engineers Inc., Aug. 2016. doi: 10.1109/ICASI.2016.7539571.

[9] S. Pejhan, M. Agelin-Chaab, M. Yusuf, and D. Eng, "Analysis of ebike dynamics and cyclists' anxiety levels and interactions with road vehicles that influence safety," *Accid Anal Prev*, vol. 159, Sep. 2021, doi: 10.1016/j.aap.2021.106272.

[10] S. I. . Ao, Len. Gelman, D. W. L. . Hukins, Andrew. Hunter, and Alexander. Korsunsky, *World Congress on Engineering : WCE 2015 : 1-3 July, 2015, Imperial College London, London, U.K.* Newswood Limited : International Association of Engineers, 2015.

[11] *Aguiari, D., Delnevo, G., Monti, L., Ghini, V., Mirri, S., Salomoni, P., Pau, G., Im, M., Tse, R., Ekpanyapong, M., & Battistini, R. (2018). Canarin II: Designing a smart e-bike eco-system. 2018 15th IEEE Annual Consumer Communications & Networking Conference (CCNC), 1–6. https://doi.org/10.1109/CCNC.2018.8319221*

[12] Seria, S., Quintero, V., Espinoza, P. A., Pérez, A., Jaramillo, F., Benavides, M., & Orchard, M. (2017). Energy Management of Electric Bicycles Given a Traveling Elevation Profile. *Annual Conference of the PHM Society*, *9*(1). https://doi.org/10.36001/phmconf.2017.v9i1.2390

[13] D. Makurat and K. Wojewódzka-Król, "PROBLEMS OF IMPLEMENTING THE MEVO METROPOLITAN BICYCLE SYSTEM." [Online]. Available: https://doi.org/10.26881.etil.2019.81.11

[14] W. Deleenheer, L. Jáneš, and A. Jayakumar, "DEVELOPMENT OF AN ELECTRIC BICYCLE FOR A SHARING SYSTEM IN PRAGUE," *Acta Polytech CTU Proc*, vol. 12, p. 24, Dec. 2017, doi: 10.14311/app.2017.12.0024.

[15] C. Kiefer and F. Behrendt, "Smart e-bike monitoring system: Real-time open source and open hardware GPS assistance and sensor data for electrically-assisted bicycles," *IET Intelligent Transport Systems*, vol. 10, no. 2, pp. 79–88, Mar. 2016, doi: 10.1049/iet-its.2014.0251.

[16] A. Triwiyatno, S. Munahar, M. Munadi, and J. D. Setiawan, "APPLICATION OF DRIVING BEHAVIOR CONTROL SYSTEM USING ARTIFICIAL NEURAL NETWORK TO IMPROVE DRIVING COMFORT BY ADJUSTING AIR-TO-FUEL RATIO," *IIUM Engineering Journal*, vol. 24, no. 2, pp. 337–353, 2023, doi: 10.31436/iiumej.v24i2.2781.

[17] G. A. Aranda-Corral, M. A. Rodríguez, I. F. de Viana, and M. I. G. Arenas, "Genetic hybrid optimization of a real bike sharing system," *Mathematics*, vol. 9, no. 18, Sep. 2021, doi: 10.3390/math9182227.

[18] M. Giliberto, F. Arena, and G. Pau, "A fuzzy-based solution for optimized management of energy consumption in e-bikes," *J Wirel Mob Netw Ubiquitous Comput Dependable Appl*, vol. 10, no. 3, pp. 45–64, Sep. 2019, doi: 10.22667/JOWUA.2019.09.30.045.

[19] Al-Ali, A. R., Zualkernan, I., & Aloul, F. (2010). A Mobile GPRS-Sensors Array for Air Pollution Monitoring. *IEEE Sensors Journal*, *10*(10), 1666–1671. https://doi.org/10.1109/JSEN.2010.2045890

[20] MathWorks. (2023). *MATLAB (R2023a)*. The MathWorks, Inc. https://www.mathworks.com