The smart e-bike ecosystem integrates internet of things and artificial intelligence

Tole Sutikno[1], Hendril Satrian Purnama[2]
[1]Master Program of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Embedded System and Power Electronics Research Group, Yogyakarta, Indonesia

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ABSTRACT

The smart e-bike ecosystem, a combination of internet of things (IoT) and artificial intelligence (AI), has transformed urban mobility. This study aims to shed light on the transformative potential of the smart e-bike ecosystem in the context of urban transportation solutions. It includes real-time navigation, crash detection, and a smart electric drive to encourage sustainable practices and reduce reliance on traditional vehicles. The use of smart locks and parking beacon systems creates a safe and efficient urban infrastructure, encouraging e-bike use. This approach reduces traffic congestion and carbon emissions. IoT frameworks in smart e-bikes improve the user experience and contribute to urban mobility solutions. Real-time monitoring of critical parameters, such as battery levels, speed, and maintenance requirements, keeps riders informed and safe at all times. IoT-enabled features, such as navigation assistance, shorten travel times and improve the efficiency of urban transportation systems. The evolution of smart e-bikes is consistent with the anticipated improvements of 6G networks, which promise to transform communication infrastructures. AI-powered features such as real-time navigation and crash detection make rides safer. The use of smart electric drives and cloud server technology promotes a data-driven approach to transportation. Future research and development should look into the use of advanced localization techniques to improve user experience while addressing accuracy and energy consumption issues.

Corresponding Author:

Tole Sutikno
Master Program of Electrical Engineering, Universitas Ahmad Dahlan
Yogyakarta, Indonesia
Email: tole@te.uad.ac.id

1. INTRODUCTION

Changes in transportation technology have sparked changes in personal travel, offering new ways to improve city living. At the center of this change is the smart e-bike system, which connects the internet of things (IoT) and artificial intelligence (AI) to change the biking experience. Features like real-time maps, crash alerts, and a smart electric motor not only make biking safer easier but also help promote eco-friendly practices by lessening the need for regular cars. In addition, smart locks and a parking signal system create a safe and effective city setup, making more people likely to use e-bikes and even conventional bike. This all-encompassing method encourages a smarter commuting environment, leading to less traffic jams and fewer greenhouse gases. By using IoT and AI, the smart e-bike system offers a strong example for future urban transport options.

The smart e-bike ecosystem is a mix of advanced technologies made to improve city travel. Key parts include smart locks and systems for monitoring in real-time that secure and make e-bikes easy to access. With IoT sensors, these e-bikes provide navigation and crash alerts, which greatly enhance safety for riders. This is very important in smart cities, where blending transportation improvements and city planning is critical for effective public transit [1]. Also, the ecosystem backs shared transport services with tools like the bike share IoT device, which makes renting easy and helps manage bike fleets using cloud technology. Overall, these parts not only meet user needs but also help in achieving goals of sustainability and urban efficiency found in modern smart city designs [2].

The use of advanced technologies is changing modern transportation, especially in the smart e-bike area. By using the IoT and AI, these systems improve user experience with features like real-time tracking and navigation, providing both convenience and safety. For example, IoT devices in smart e-bikes offer tools such as crash detection and location tracking, which are key for quick incident response and safety [3]. Additionally, as smart transportation develops, it helps create urban mobility patterns, making traffic management and resource use more flexible [2]. This mix of IoT and AI not only boosts efficiency but also encourages cooperation between city officials and users, supporting an ecosystem that meets the changing needs of urban transportation. Better connectivity thus leads to smarter, stronger city infrastructure.

The smart e-bike ecosystems have been the subject of numerous studies [4]–[6]. Dublin's e-bike sharing system, which consists of 12 stations (eHUBs), has been thoroughly evaluated using a methodology developed by [7]. The eco-efficiency of each eHUB in utilizing local infrastructure, the people in the catchment region, and location to accomplish targeted economic, social, and environmental outcomes is evaluated using data envelopment analysis and six months of real-world riding data. Findings show that the system's eco-efficiency is on the rise. Demand pattern analysis is used in a number of data-driven techniques [8]. To make e-bike sharing systems more affordable and user-friendly, they recommend implementing a new spatial unit. With about 1.5 times more ridership, a 20% reduction in vehicle idle time, and a respectable monthly net retention rate of about 60%, the results show that the derived operational solutions greatly enhance the service. Stilo *et al.* [9] used market reviews and answers from 638 potential customers, primarily from North America and Europe, to determine user preferences for ease and safety. Overall, the findings show that the entire sample size placed equal priority on convenience and safety aspects. The most favored safety and convenience features were "Brake Lights & Indicators" and "Gradient Climb Assist," respectively.

E-bikes are the only option that combines the benefits of inclusiveness and active transportation because of its electric engine and pedal assist feature, which enables riders to go farther. Since the motor helps riders overcome obstacles like steep inclines and the requirement for significant physical exertion, e-bikes are suitable for a wide spectrum of users [10]–[12]. This characteristic enables e-bikes to cover distances that would typically call for private automobiles or multimodal transportation, such as riding a bicycle and taking public transportation in the same area. This makes e-bikes a stand-alone travel alternative in addition to being an inclusive and active form of transportation [13].

McQueen *et al.* [14] investigated how e-bikes might reduce greenhouse gas emissions in Portland. Using local data from an e-bike owner survey and a mode replacement model, they were able to identify e-bike emission characteristics and estimate emissions. Their research shows that e-bikes can significantly lower carbon emissions when used more regularly, making them a feasible way to reduce carbon emissions in urban transportation. Many research focus on estimating the emissions reductions that result from increased use of e-bikes for both public and private transportation. Applying geographical microsimulation to survey data that is anonymous. Philips *et al.* [15] aimed to ascertain the extent to which e-bikes could reduce CO_2 emissions in every community in England. The capabilities of e-bikes and existing walking and riding gadgets were compared in the study. It was shown that e-bikes had the greatest potential to lower CO_2 emissions per person and per small area, especially in rural areas and along the border between rural and urban areas.

Developments in the smart e-bike world show how IoT and AI come together, with each part working well to improve city travel. By looking into smart locks, live monitoring, and crash detection, this study will explain how these new tools not only make using e-bikes better but also help cities be more sustainable. We will discuss intelligent s ystems like smart electric drives and navigation tools to provide a clear picture of how these technologies help meet the goals of smart cities, similar to the successful city strategies mentioned in [1]. Additionally, this analysis will go further than just how things work, exploring the effects of these smart devices on rules and professional work, as highlighted in [16]. In the end, this study aims to show the changing impact of the smart e-bike ecosystem within the larger scene of urban transportation solutions.

2. THE ROLE OF IOT IN SMART E-BIKES

The use of new tech in smart e-bikes makes the user experience better and supports urban transport solutions. With IoT systems, these bikes can track important factors like battery status, speed, and maintenance needs in real-time, keeping riders informed and safe. Additionally, IoT features such as navigation help users find better routes, which can cut down travel times and improve urban transport efficiency. Key advancements like crash detection systems show how IoT can boost safety by quickly sending accident information to emergency services. This is similar to progress in smart city projects that use tech to solve city problems [17]. Also, the growth of smart e-bikes goes along with the expected improvements of 6G networks, which are set to change communication systems, thus enhancing smart mobility setups [18].

2.1. Real-time monitoring of bike performance

Using advanced IoT devices in the smart e-bike system allows for monitoring bike performance in real time, improving user experience and safety. By adding sensors that keep track of things like speed, pedaling efficiency, and battery life, cyclists can get quick feedback to make their rides better. This real-time information is useful for decision-makers and fleet managers, helping them manage fleets and improve operations. Additionally, the information from these systems can lead to better bike designs and maintenance routines, extending the life of e-bikes [19]. The use of data through cloud servers and AI analytics not only makes biking smarter but also helps with environmental issues by supporting a connected, electric, and sustainable mobility system [2]. In conclusion, real-time monitoring is key to improving safety and efficiency in the smart e-bike system. Figure 1 shows the concept of IoT integration and implementation on smart e-bike ecosystem.

The smart e-bike monitoring system (SEMS) is a platform for the real-time acquisition of usage data from electrically-assisted bikes (also called pedelecs or e-bikes). In [5] SEMS was implemented on 30 bikes and collected data during 10 months of real-word trials in the UK. This study details the design and implementation of the hardware and software, discusses the system use and explores features for future design iterations.

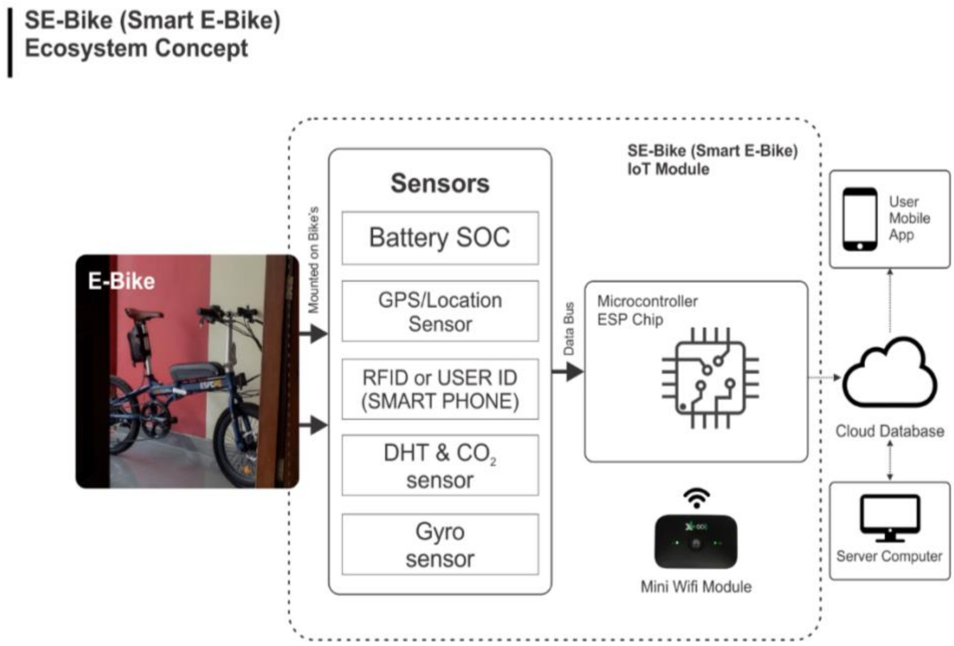

Figure 1. The IoT integration and implementation on smart e-bike ecosystem

2.2. Smart lock technology for enhanced security

As cities put in more smart technologies, better security measures are very important for protecting personal belongings. Using smart lock technology in the smart e-bike system shows a good step forward in security options. These locks let users check their bikes in real time, sending alerts and updates about their status, which helps prevent theft and unwanted access. Additionally, the connection between the smart lock and cloud servers makes security management better, letting users lock their bikes from far away. This kind of control fits into the bigger IoT picture, especially as examples from smart cities show how important it is to share data and have systems work together [20]–[22]. By using strong security features like biometric checks and encrypted communication, smart locks do more than just keep e-bikes safe; they also help create a smarter transportation system, making urban travel safer.

2.3. Integration of bike share IoT devices

New technologies in city travel are changing how bike-sharing systems work. By using IoT devices like smart locks and features for real-time monitoring, cities are improving both user satisfaction and operation. These devices help users find and secure bikes easily, while also providing navigation aids and crash alerts. Additionally, the data gathered by these IoT devices can be used to improve fleet management and safety. Research shows that using such smart transport solutions is important for making smart cities, showing how connected systems can implement successful methods [1]. Also, using low-power wide-area networks (LPWAN) technologies and other methods for finding locations boosts the precision of bike-sharing services, giving answers that fit the changing needs of city commutes [1]. Therefore, adding IoT devices to bike share programs is essential in the smart e-bike framework.

3. THE IMPACT OF AI ON USER EXPERIENCE

In the fast-changing world of smart e-bikes, AI greatly improves user experience with custom and effective solutions. AI features like live navigation and crash alerts make rides safer and more fun, changing how users interact with their e-bikes. Plus, using IoT gadgets such as smart locks and parking signals gives riders more convenience and safety. This connection helps create a more involved and aware user group since their experiences improve with ongoing data sharing between the e-bike and a central cloud system. Also, new ideas like vehicle distribution in shared mobility services show how AI can make fleet management better and increase user happiness, demonstrating its ability to change urban transport and support people in smart cities [1], [19]. As a result, using AI not only enhances user experience but also promotes the sustainable growth of urban transport systems.

3.1. Real-time navigation and route optimization

The mix of new tech and transport systems has changed how people move in cities, especially with smart e-bikes using IoT and AI. These new tools help with live navigation and route planning, which is important for making riders more efficient and safer. With real-time data, e-bikes can change their paths based on things like traffic jams, weather, or road blockages, making trips quicker and easier. Also, as seen in smart transport systems, better connections from future networks like 6G will make route planning tools more dependable, allowing e-bikes and cloud servers to share data instantly [18]. Plus, new location methods using LPWAN tech can make position data more accurate, helping users with navigation [19]. Together, these features not only help individual trips but also assist in wider traffic control and eco-friendly goals.

3.2. Crash detection and safety features

The use of new technologies, especially IoT and AI, changes city travels a lot, bringing new safety features to smart e-bikes. These e-bikes have advanced crash detection systems that can quickly detect accidents, informing emergency services and the riders' emergency contacts right away. These improvements make using the e-bikes better and greatly increase the safety of city transport. Digital mapping and real-time information systems also help prevent accidents by giving riders important information about traffic patterns and dangerous areas, helping them choose better routes. Additionally, looking at the larger picture of infrastructure, the mix of digital and tech changes gives an advantage in safety innovations, making smart e-bikes important in changing how people travel in cities [23], [24]. These improvements lead the way for future projects that aim to create safer and more efficient city environments.

3.3. Smart electric drive for improved efficiency

In the last few years, using new technologies in transportation has become more common, especially in the design and use of electric drive systems. Smart electric drive systems increase the efficiency of e-bikes by using real-time data and connectivity through the IoT. These systems allow constant communication between the e-bike and its surroundings, making it possible to monitor performance and battery status all the time. Additionally, smart electric drives support adjustable power management, which helps to optimize energy use depending on how riders act and the terrain, thus reducing waste. However, the potential of these systems is limited without strong networking and computing power, like what is expected from future 6G technologies, which will improve the speed and reliability of data sharing in vehicle networks [18]. This combination creates an environment where better efficiency not only benefits individual riders but also supports broader urban sustainability goals [25].

4. THE FUTURE OF SMART E-BIKE ECOSYSTEMS

As cities face more traffic and pollution problems, smart e-bike systems are a promising answer that mixes new technologies to improve getting around. By using IoT gadgets and AI, these systems can keep track of bike conditions in real-time, allowing for quick repairs and less downtime. Additionally, features like smart locks and crash detection improve safety and build user trust in shared mobility options. This setup supports an active mobility system, reflecting trends in smart city projects where innovation plays a key role in solving city issues, as noted in [17]. Also, with 6G technology coming soon, better connectivity will greatly improve user experiences, enabling smooth navigation and communication between e-bikes and smart systems, as mentioned in [18]. In the end, these developments indicate a major change in transportation, leading to greener and more efficient city environments.

4.1. Cloud server integration for data management

Adding a cloud server to the smart e-bike system improves how data is managed by making communication and real-time information analysis smooth. By using cloud technology, data from many places-like smart locks, navigation tools, and crash sensors-can be gathered and processed well. This method allows for new services that go beyond single IoT systems, encouraging partnerships among different groups and leading to smarter urban mobility options. Additionally, as noted in the studies, good data sharing and decentralizing data analysis across cloud, fog, and edge systems significantly boost response times and resource use [22]. Also, using LPWANs increases the precision of location services, which is vital for features such as smart electric drives and parking indicators while also saving energy [2]. This integration not only enhances how well the system works but also helps the smart e-bike ecosystem grow.

4.2. Development of parking beacons for urban mobility

Effective city mobility more and more depends on new technology that solves the complicated problems created by larger city populations. The creation of parking beacons is an important development that improves the user experience in the Smart e-bike system by combining IoT and AI. These beacons can give real-time updates on open parking spots, making the hunt for parking faster and improving traffic flow in the city. By using sensor tech and data analysis, parking beacons can examine detailed data streams, helping e-bike users with better navigation and awareness of their surroundings [19]. Also, as cities move towards being more sustainable, parking beacons can aid in promoting electric vehicles-like bicycles-by finding the best charging spots, which encourages green transport options in urban areas [26]. In summary, putting parking beacons in place is essential for building a smart and effective urban mobility system. Figure 2 shows the concept of smart e-bike parking station design.

4.3. Potential for expansion in smart city initiatives

The use of smart technology in city travel offers big chances for growing smart city projects. As cities search for new ways to handle city issues, the smart e-bike system shows how better transportation networks can support sustainability and efficiency. This system, which includes IoT tools like smart locks and accident detection tools, allows for real-time tracking and route planning, which is important for solving problems like traffic and safety. Also, recent studies emphasize that building smart cities relies on a mix of social and tech advancements, impacting areas like travel and eco-friendliness [17]. Working together among those involved can help spread successful trial projects and use data-based measures, as discussed in the framework created by [17]. In the end, such projects not only enhance the living standards for locals but also help cities compete better on a global scale.

As the meeting of IoT and AI in the smart e-bike space keeps changing, the effects on future study and development are deep. Studying the mix of better location techniques, especially using LPWAN technologies for live tracking and guidance, can boost the user experience while tackling issues of accuracy and battery use [17]. Also, looking closely at pilot projects can help test new features, like crash alerts and smart locks, resulting in major advances in city travel [17]. This layered method not only tries to copy successful smart city plans but also to find new ways for eco-friendly transport solutions. In the end, more examination of these aspects can lead to a more connected, efficient, and safe smart e-bike network that serves the varied needs of communities.

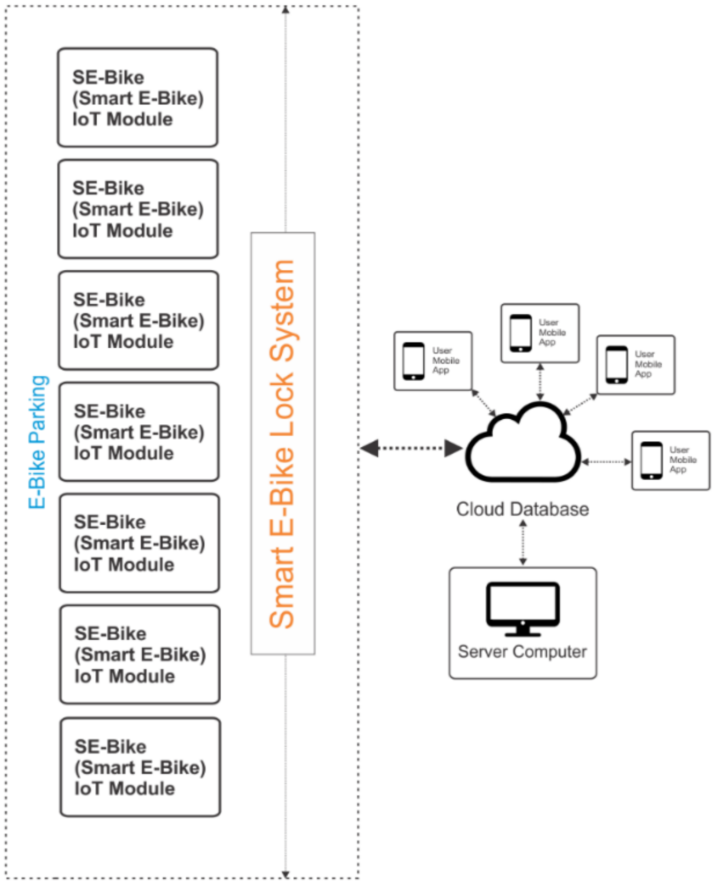

Figure 2. Smart e-bike parking station design

5. CONCLUSION

A smart e-bike system with IoT and AI can improve city travel as cities use more technology. Technology like real-time monitoring and navigation improve routes and user safety in this system. By addressing safety and bike availability, crash detection and smart locks improve user experience. Data shows that economic and environmental factors drive smart city projects, making smart e-bikes essential. Smart electric drives and cloud server technology enable data-focused travel, providing metrics and evaluations for replicating success. Overall, the smart e-bike system is the future of city transport, combining innovation and eco-friendliness to meet today's needs. The smart e-bike ecosystem uses IoT and AI to improve city mobility. Instant access to the best routes and safety warnings from real-time monitoring and navigation features reduces accidents and improves safety. The smart lock and smart electric drive improve user experience and shared mobility system eco-friendliness. Bike-sharing services that use advanced algorithms to place bikes in busy areas demonstrate the importance of coordination and data-driven decisions in transportation systems during shared micromobility research. These developments address urban transport issues and create smarter, more connected cities. Innovations like smart e-bikes show how society is moving toward eco-friendliness and urban mobility. Real-time monitoring, navigation, and crash detection are available in the new e-bike system, which uses IoT and AI. It tackles traffic and pollution in big cities. Intelligent locks and parking signals make bike-sharing programs safer and more efficient, making e-bikes more appealing to city dwellers. These advances have the potential to change our view of transportation, improving accessibility and the environment. For smart e-bikes to grow responsibly, this technology must address privacy concerns and dSigital access gaps. The development of smart e-bikes could transform urban transportation.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Tole Sutikno	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓
Hendril Satrian Purnama		✓		✓		✓		✓		✓	✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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BIOGRAPHY OF AUTHOR

Tole Sutikno is a lecturer and the Head of the Master Program of Electrical Engineering at the Faculty of Industrial Technology at Universitas Ahmad Dahlan (UAD) in Yogyakarta, Indonesia. He received his Bachelor of Engineering from Universitas Diponegoro in 1999, Master of Engineering from Universitas Gadjah Mada in 2004, and Doctor of Philosophy in Electrical Engineering from Universiti Teknologi Malaysia in 2016. All three degrees are in electrical engineering. He has been a Professor at UAD in Yogyakarta, Indonesia, since July 2023, following his tenure as an associate professor in June 2008. He is the current Editor-in-Chief of TELKOMNIKA and Head of the Embedded Systems and Power Electronics Research Group (ESPERG). He is one of the top 2% of researchers worldwide, according to Stanford University and Elsevier BV's list of the most influential scientists from 2021 to the present. His research interests cover digital design, industrial applications, industrial electronics, industrial informatics, power electronics, motor drives, renewable energy, FPGA applications, embedded systems, artificial intelligence, intelligent control, digital libraries, and information technology. He can be contacted at email: tole@te.uad.ac.id.

Hendril Satrian Purnama received his B.Eng. degree in Electrical Engineering from Universitas Ahmad Dahlan, Yogyakarta, Indonesia in 2017. After receiving his degree, he became a member of the Embedded Systems and Power Electronics Research Group (ESPERG), and worked there as a researcher. In addition, he is also active as assistant editor in several international journals in the field of electrical engineering, computer and informatics. His research interests include power electronics, renewable energy technology, robotics, and the Internet of Things. He can be contacted at email: lfriyan220@gmail.com.