A Comprehensive Review of Intelligent Home Automation Systems Using Embedded Devices and IoT

Abdulla Al Tareq [1,*], Md Riad Mostofa [2], Md Juel Rana [3], Md Sadiqur Rahman [4]
[1] Department of New Generation Electronic Information, Hubei University of Automotive Technology, China
[2] Department of Electronic Information Engineering, Zhejiang Normal University, China
[3] Department of Naval, Electrical, Electronic, and Telecommunications Engineering, University of Genoa, Italy
[4] Department of Electrical and Computer Engineering, University of Memphis, USA
Email: [1] abdullaaltareq@gmail.com, [2] riadmostofa07@gmail.com, [3] mdjuelrana.eie@outlook.com, [4] mrhman29@memphis.edu
*Corresponding Author

***Abstract*—The integration of embedded devices and Internet of Things (IoT) technologies is the main subject of this thorough assessment, which examines the development and status of intelligent home automation systems. Intelligent home automation systems provide remote control and automation of household appliances and systems, with the goal of improving the comfort, safety, and energy efficiency of residential surroundings. The different designs and parts of home automation systems such as sensors, actuators, controllers, communication protocols, and user interfaces are examined in this overview. It draws attention to the function of embedded devices, which act as the essential building blocks of these systems by supplying the required connectivity and processing power. The evaluation also covers the use of IoT technologies, which enable smooth device interoperability and communication, opening the door to more advanced automation and control capabilities. Important developments in artificial intelligence, cloud computing, and machine learning that enhance these systems' intelligence and flexibility are also examined. The paper also discusses issues including security, privacy, standards, and user adoption and offers possible fixes as well as future research possibilities. Creating AI algorithms that will help home automation systems comprehend and react to user context and preferences more effectively which can be done soon. We hope that this review will give readers a thorough grasp of intelligent home automation systems and provide insights into their design.**

Keywords*—*IoT, Home Automation, Intelligent, Industry, Embedded Devices

I. INTRODUCTION

Intelligent home automation systems have emerged because of the recent rapid advancements in technology, and its goal is to improve the energy efficiency, convenience, and security of residential surroundings. With embedded devices and Internet of Things (IoT) technology, these systems integrate numerous household systems and equipment, enabling their automation and remote control. Although home automation is not a brand-new idea, the Internet of Things' integration has transformed the industry by facilitating smooth device connection and interoperability, which has led to the development of increasingly advanced automation and control capabilities. The core components of intelligent home automation systems are embedded devices, which offer the processing power and networking required to communicate with a variety of sensors, actuators, and controllers in a house [1]. These gadgets gather and analyze data to allow for real-time home function monitoring and control. By enabling objects to communicate with external systems and with one another over the internet, IoT technologies further improve these capabilities and provide remote access and control via computers, smartphones, and tablets.

Intelligent home automation systems can be used for a wide range of purposes, from basic ones like controlling the lighting and temperature to more intricate ones like energy management, security monitoring, and health monitoring. The development of these systems has been greatly aided by developments in machine learning, artificial intelligence, and cloud computing [2]. These technologies allow these systems to give personalized experiences, learn from user behavior, and adapt to changing situations. There are still several issues with intelligent home automation systems, despite their many advantages and rising popularity. Due to the fact that these systems frequently gather and retain sensitive personal data, which makes them vulnerable to cyberattacks and unauthorized access, security and privacy considerations are of utmost importance. The absence of standard protocols among diverse devices and platforms gives rise to compatibility issues, which in turn cause challenges in the integration of goods from different manufacturers. For users—especially those who are not technologically savvy—this might lead to complicated settings and a challenging learning curve. IoT systems' increased connectivity and data sharing put consumers at risk of cyberattacks, therefore security and privacy considerations are crucial. Widespread adoption is further hampered by the absence of standards for communication protocols and device interoperability. User acceptance and the requirement for clear, user-friendly interfaces are also essential components of these technologies' effective deployment. With an emphasis on the fusion of embedded devices and Internet of Things technologies, this thorough analysis attempts to investigate the development and present status of intelligent home automation systems [3]. It will look at different parts and architectures, talk about important developments and

breakthroughs, and explore problems and possible fixes in this quickly developing sector. We hope that this review will give readers a comprehensive overview of intelligent home automation systems, including information on how they were developed.

II. METHODOLOGY

A multifaceted approach is employed in the methodology for carrying out an exhaustive investigation of the importance and challenges of renewable energy-based microgrids in wireless sensor networks (WSNs) [4]. The first step involves doing a thorough literature research to obtain information from scholarly works, technical reports, and trade journals with an emphasis on microgrid architecture, WSN technologies, integration of renewable energy sources, and related issues. The next step is data collecting, which comprises secondary data from published industry reports and microgrid initiatives as well as primary data from WSN simulations or experiments in microgrid environments. After that, a comparative study is done to find common patterns and best practices, and a thorough examination of a few chosen case studies is done to comprehend the real-world applications, difficulties, and results of integrating WSNs with microgrids for renewable energy [5]. The integration process is simulated using analytical modelling, which takes into account variables including energy production, load balancing, the accuracy of sensor data, communication protocols, and network dependability [6]. Using scenario analysis, one may investigate how various factors affect the functioning of a microgrid while measuring important performance indicators like system dependability and energy efficiency. Following the identification of obstacles in the integration process, potential tactics and solutions are put forth, such as technical advancements, suggested policies, and community involvement programs. To ensure accuracy and dependability, the produced models and conclusions are evaluated using actual data and input from professionals in related domains. Lastly, to add to the body of knowledge and direct further research in this area, the findings and procedures are recorded and shared via scholarly journals and commercial platforms [7].

III. INTELLIGENT HOME AUTOMATION

The way we live is changing due to intelligent home automation, which offers major advancements in security, convenience, energy efficiency, and health monitoring. Fig. 1 shows the smart home automation system. Even if problems with security, interoperability, and user adoption still exist, continuous developments in AI, machine learning, and connectivity will likely solve these problems and propel the expansion of home automation systems in the future [8]. We can design homes that are more intelligent, ecological, and comfortable by utilizing these technologies.

The management of domestic surroundings has significantly advanced with intelligent home automation, which provides improved energy efficiency, convenience, and security. The Internet of Things (IoT) and embedded device integration, which facilitates smooth communication and interoperability across diverse home systems, are major forces behind this development. The main elements, advantages, difficulties, and potential applications of intelligent home automation are examined in this conversation. There are many important elements which are used for making home automation [9].

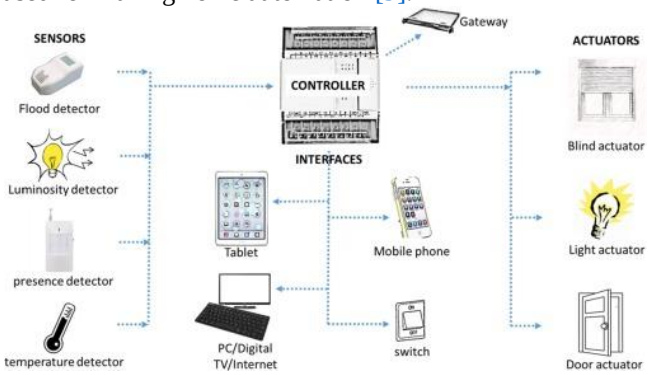

Fig. 1. Smart home automation

- Embedded Devices: These are the essential components that provide home automation systems their necessary connectivity and processing capability. They consist of actuators, sensors, and microcontrollers that keep an eye on and manage daily activities in the home [10].
- IoT Technologies: IoT enables remote access and control by enabling device interconnection over the internet. Sturdy communication between devices is made possible by IoT protocols like MQTT, Z-Wave, and Zigbee [11].
- Actuators and sensors: Sensors gather information on a range of characteristics, including light, motion, humidity, and temperature. Actuators use sensor inputs to do tasks like locking doors, regulating thermostats, and turning on lights [12].
- User interfaces: These let people communicate with the automation system through voice assistants, control panels, and mobile apps. For interfaces to be widely adopted, they must be simple to use and intuitive [13].

IV. EMBEDDED DEVICES

Embedded devices are essential elements of contemporary technology ecosystems, serving vital functions in a wide range of applications ranging from industrial automation to consumer electronics [14]. These devices are distinguished by their modest size, unique functionality, and specialized design that are intended to carry out specific functions within bigger systems. An embedded system has been shown in Fig. 2.

Within a broader system, embedded devices are made to carry out certain duties or functions. Usually, they are designed to be as reliable and efficient as possible when performing these duties. These gadgets frequently have a small, flat physical footprint. This makes it possible for them to be directly implanted into equipment or seamlessly incorporated into bigger systems. Since many embedded devices are made to run on very little power, they are well suited for situations where power sources are scarce, or energy efficiency is crucial [15]. Because embedded devices can process information in real-time, they can react to inputs and carry out tasks quickly. This is important for applications like control systems that need to respond quickly. These usually include memory, input/output interfaces, microcontrollers or microprocessors, and occasionally specialized peripherals like actuators or sensors. Firmware,

or specialized software, is installed on embedded devices and is designed specifically for that device's purpose. Frequently, firmware is designed to be lightweight and reliable.

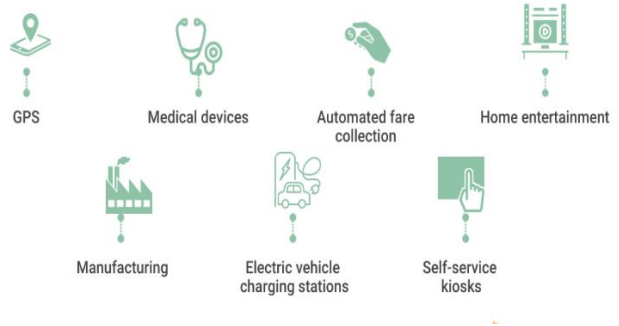

Fig. 2. Embedded systems

Consumer gadgets including smartphones, smart TVs, wearable technology, and home appliances are often equipped with embedded devices. They make features like sensor-based interactions, connection, and touchscreen interfaces possible. Embedded devices are used in industrial settings to monitor processes, control machinery, and gather data for quality assurance, predictive maintenance, and efficiency enhancements. Engine control, navigation, entertainment, and advanced driver assistance systems (ADAS) are just a few of the features that embedded devices use for car electronics [16]. To ensure accurate and dependable operation, embedded devices are essential components of medical equipment such as implantable medical devices, diagnostic tools, and patient monitoring systems. To gather information from sensors, exchange information over networks, and carry out automated tasks based on data analytics, IoT devices significantly rely on embedded systems. Smart household appliances, industrial IoT sensors, and environmental monitoring systems are a few examples [17]. Network routing, protocol administration, and signal processing are all done by embedded devices in the infrastructure of the telecom industry.

As cellular networks, Bluetooth, Wi-Fi, and other wireless communication technologies evolve, embedded devices also do, providing seamless connectivity and incorporation into Internet of Things ecosystems. On embedded systems, the integration of AI and machine learning algorithms is extending features like adaptive behaviour, predictive analytics, and autonomous decision-making. As we move forward in the digital age, embedded devices will continue to be essential in driving technological innovation in several industries. They will also help to improve efficiency, add functionality, and increase the number of linked devices [18].

V. Internet of Things

The term "Internet of Things" (IoT) describes a network of networked items, sensors, and gadgets that exchange data and communicate online. These gadgets can gather, share, and act upon data with minimal human intervention thanks to this ground-breaking idea.

The internet of things (IoT) is a network of real-world "things" that have been outfitted with sensors, software, and other technologies to communicate and share information with other systems and gadgets via the internet shown in Fig. 3.

Important IoT components include These are integrated into commonplace items or gadgets to gather information on a range of factors, including motion, location, temperature, humidity, and more. IoT devices send data to other devices or centralized systems using a variety of communication protocols, including cellular networks, Bluetooth, Zigbee, Wi-Fi, and RFID [19]. IoT devices send data to other devices or centralized systems using a variety of communication protocols, including cellular networks, Bluetooth, Zigbee, Wi-Fi, and RFID. Real-time or very real-time processing and analysis of the collected data allows for the autonomous trigger of activities, decision-making, and the extraction of actionable insights. Cloud platforms are frequently used by IoT systems to store and analyze massive amounts of data, providing scalability, flexibility, and remote information access.

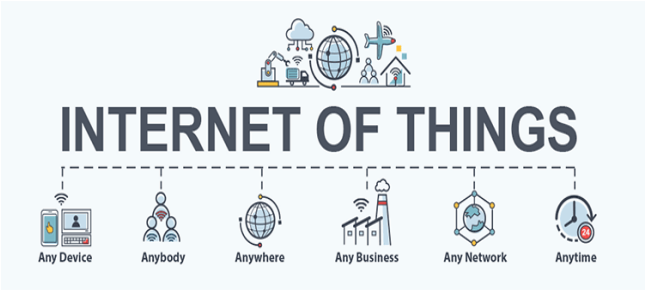

Fig. 3. Internet of things architecture

The Internet of Things (IoT) improves convenience and energy efficiency by enabling automation and remote control of household appliances, lighting, security cameras, and thermostats. IoT enables supply chain optimization, asset tracking, predictive maintenance, and real-time production process monitoring in manufacturing and industrial environments. Smart medications, wearable health devices, monitoring patients from afar, and healthcare asset management are all made possible by IoT technology, which also enhances operational effectiveness and patient outcomes [20]. Across a range of industries, automation and data-driven insights improve productivity, streamline operations, and cut waste. Proactive intervention, predictive maintenance, and well-informed decision-making are made possible by real-time data analytics. Businesses and consumers alike can save a lot of money because to IoT-enabled efficiencies in energy use, maintenance, and operations. Wearable technology, connected cars, smart homes, and other IoT-enabled products improve comfort, convenience, and personalization in day-to-day living [21].

Strong security standards and procedures are required as a result of the growth of connected devices, which makes them more susceptible to cyberattacks and data breaches. Smooth integration and scalability may be hampered by incompatible IoT platforms and devices as well as a lack of defined protocols [22]. It takes specialized knowledge and resources to manage extensive Internet of Things deployments, data integration, and system interoperability. The Internet of Things brings up issues with consent, data ownership, and the moral ramifications of automated decision-making. The Internet of Things is a force that is transforming daily life and many businesses by providing never-before-seen levels of connection, automation, and

data-driven insights [23]. IoT is evolving because of continuous technological and standardization breakthroughs, even in the face of persistent obstacles like security, interoperability, and complexity. This is opening the door to more intelligent, interconnected ecosystems and an efficient, sustainable future [24].

VI. CHALLENGES

There are a few issues that must be resolved for a complete and useful examination of intelligent home automation systems that use embedded devices and Internet of Things technology. To tackle these obstacles, multidisciplinary methods incorporating knowledge of electronics, software development, cybersecurity, communication protocols, user experience design, and regulatory compliance are needed [25]. To yield significant insights, recommendations, and developments in the area, a thorough assessment of intelligent home automation systems must carefully take these problems into account. The wide variety of devices, protocols, and standards on the Internet of Things and home automation domains is one of the main obstacles. The employment of disparate communication protocols and standards by different manufacturers (e.g., Bluetooth, Z-Wave, Wi-Fi, Zigbee) complicates interoperability and system integration [26].

As linked devices proliferate, security flaws and privacy hazards grow in importance. To safeguard user privacy and stop illegal access to home automation systems, strong encryption, authentication procedures, and secure data transfer are essential [27].

Device responsiveness, network connectivity, and embedded device reliability all have a significant impact on the performance and dependability of home automation systems [28]. The user experience and functionality of a system can be impacted by problems like software flaws, network failures, and delay in data transfer.

Complexity of Integration: System design, configuration, and troubleshooting skills are needed to integrate a variety of components, such as sensors, actuators, controllers, and user interfaces, into a home automation system [29]. It is very difficult to manage this complexity while maintaining smooth functioning and user-friendly interfaces [30].

VII. DISCUSSION

A thorough examination of embedded devices and Internet of Things (IoT)-based intelligent home automation systems includes a thorough investigation of the systems' development, elements, uses, advantages, drawbacks, and potential future directions. From basic automated chores to complex ecosystems made possible by embedded devices and Internet of Things technology, intelligent home automation systems have seen tremendous evolution [31]. In the beginning, home automation was only concerned with basic features like HVAC and lighting control by remote. Microcontrollers, sensors, actuators, embedded systems, and communication protocols have all advanced, enabling these systems to perform sophisticated functions including energy management, security monitoring, and health monitoring. These systems' fundamental components are embedded devices, which offer the connectivity and processing power required for real-time data processing and control [32]. These gadgets are specifically made for certain uses in the home, and they easily integrate with the current infrastructure because of their small size and low power consumption.

By enabling remote devices and system control via smartphones or voice commands, intelligent home automation systems improve convenience [33]. This includes controlling lighting, changing temperature settings, and keeping an eye on security cameras from any location. Automation systems reduce energy use by using motion sensors to regulate lighting, adjusting HVAC systems based on occupancy or weather, and incorporating renewable energy sources like solar panels and energy storage systems. Smart locks, security cameras, and motion detectors are examples of integrated security systems that improve home security and peace of mind by offering real-time alerts and remote monitoring. With the ability to track vital signs like blood pressure, heart rate, and level of activity, IoT-enabled devices can offer important information for the care of the elderly and people with long-term illnesses. IoT device interconnectedness creates worries about cybersecurity flaws and data privacy. To safeguard user information, it is essential to have strong encryption, authentication procedures, and frequent security updates. The smooth integration of various automation systems and components may be hampered by non-standard communication protocols and device compatibility [34]. Widespread adoption may be hampered by the difficulty of setting up and configuring home automation systems. Improving usability and user acceptance requires intuitive controls and user-friendly interfaces.

The concept of home automation has evolved significantly over the years, transforming from basic, manually controlled systems to sophisticated, intelligent networks integrated with advanced technologies like the Internet of Things (IoT) and artificial intelligence (AI). This evolution reflects broader technological advancements, changing consumer needs, and a growing emphasis on energy efficiency, security, and convenience. The many parts of a home automation system cooperate to monitor, regulate, and automate numerous aspects of the living space. With the use of these parts, customers can frequently remotely or automatically regulate lighting, security, climate control, entertainment systems, and more. A home automation system's central processing unit, often known as a hub or gateway, is its brain. It controls the data and command flow between all connected devices by serving as their main point of contact. Although there are many advantages to home automation systems, there are also a lot of difficulties and worries. The primary concerns are security and privacy, since these systems gather private information that may be compromised or accessed by unwanted parties. These systems' complexity and usability, along with problems like device compatibility and a steep learning curve, can be a barrier, especially for non-techies. Furthermore, potential customers may be discouraged by the high initial and recurring costs, and system reliability is frequently questioned because of probable downtimes and software bugs.

The capacity of home automation systems to improve convenience, security, energy efficiency, and general quality of life has led to their growing popularity. With the

integration of several gadgets and technology, these systems enable homeowners to remotely operate and keep an eye on their properties or through automated procedures. With the help of home automation systems, homeowners can remotely or automatically adjust the lighting in their entire house in response to predetermined triggers, such as the time of day or occupancy. Economically speaking, the expanding home automation market spurs creativity and raises real estate prices. Positive effects also extend to health and well-being, as mechanisms that support stress reduction and health monitoring are implemented. But as these technologies advance and become more ingrained in our daily lives, issues like the digital gap and moral questions about autonomy and data privacy will still need to be addressed.

An in-depth analysis of embedded devices and Internet of Things (IoT)-based intelligent home automation systems demonstrates how they are revolutionizing residential living [35]. This analysis offers insights into how these systems address important concerns like interoperability, usability, and sustainability while enhancing convenience, efficiency, and security through an examination of their evolution, components, applications, benefits, obstacles, and future directions. Intelligent home automation systems have the potential to significantly impact how modern households interact with their surroundings and use resources as technology advances.

VIII. CONCLUSION

A thorough analysis of intelligent home automation systems that make use of IoT and embedded devices highlights their significant influence on contemporary living spaces. We have examined the development, elements, uses, advantages, difficulties, and prospects of these systems during this review, emphasizing their capacity to revolutionize a few facets of residential life. From their humble beginnings as simple remote-control systems, intelligent home automation systems have come a long way to become complex ecosystems that optimize energy use, improve security, and provide customized user experiences. Embedded devices are the backbone of technology because they have the processing power and connectivity needed to work together with a variety of home systems. These gadgets allow for real-time home environment monitoring, analysis, and control thanks to their sensors, actuators, and microcontrollers. Even with these developments, there are still a number of important factors to take into account, including cybersecurity threats, platform and device compatibility problems, setup and usability difficulties, and so on. To sum up, as smart home automation systems develop further, they have the potential to completely change the way we use our living areas by providing previously unheard-of levels of security, comfort, and efficiency. These systems have the potential to make houses smarter, more sustainable, and more connected by utilizing embedded electronics and Internet of Things technology, ultimately improving the quality of life for people all over the world.

REFERENCES

[1] W. A. Jabbar *et al*., "Design and Fabrication of Smart Home With Internet of Things Enabled Automation System," *IEEE Access*, vol. 7, pp. 144059-144074, 2019, https://doi.org/10.1109/ACCESS.2019.2942846.

[2] O. Taiwo, A. E. Ezugwu, "Internet of Things-Based Intelligent Smart Home Control System," *Security and Communication Networks*, vol. 2021, no. 1, pp. 1-17, 2021, https://doi.org/10.1155/2021/9928254.

[3] G. Marques, R. Pitarma, N. M. Garcia, N. Pombo, "Internet of things architectures, technologies, applications, challenges, and future directions for enhanced living environments and healthcare systems: a review," *Electronics*, vol. 8, no. 10, p. 1081, 2019, https://doi.org/10.3390/electronics8101081.

[4] M. A. Halim, M. S. Akter, S. Biswas, M. S. Rahman, "Integration of Renewable Energy Power Plants on a Large Scale and Flexible Demand in Bangladesh's Electric Grid-A Case Study," *Control Systems and Optimization Letters*, vol. 1, no. 3, pp. 157-168, 2023, https://doi.org/10.59247/csol.v1i3.48.

[5] M. R. Zaman, M. A. Halim, M. Y. A. Khan, S. Ibrahim, A. Haque, "Integrating Micro and Smart Grid-Based Renewable Energy Sources with the National Grid in Bangladesh-A Case Study," *Control Systems and Optimization Letters*, vol. 2, no. 1, pp. 75-81, 2024, https://doi.org/10.59247/csol.v2i1.76.

[6] Z. Li, A. Khajepour, J. Song, "A comprehensive review of the key technologies for pure electric vehicles," *Energy*, vol. 182, pp. 824-839, 2019, https://doi.org/10.1016/j.energy.2019.06.077.

[7] A. B. Yadav, "Gen AI-Driven Electronics: Innovations, Challenges and Future Prospects," *International Congress on Models and methods in Modern Investigations*, pp. 113-121, 2023, https://www.conferenceseries.info/index.php/congress/article/view/1609.

[8] F. Ahmad *et al*., "Advances in graphene-based electrode materials for high-performance supercapacitors: A review," *Journal of Energy Storage*, vol. 72, p. 108731, 2023, https://doi.org/10.1016/j.est.2023.108731.

[9] M. H. S. Lipu *et al*., "Intelligent algorithms and control strategies for battery management system in electric vehicles: Progress, challenges and future outlook," *Journal of Cleaner Production*, vol. 292, p. 126044, 2021, https://doi.org/10.1016/j.jclepro.2021.126044.

[10] M. Y. Chowdhuri, E. Khatun, M. M. Hossain, M. A. Halim, "Current Challenges and Future Prospects of Renewable Energy: A Case Study in Bangladesh," *International Journal of Innovative Science and Research Technology*, vol. 8, no. 4, pp. 576-582, 2023, https://ijisrt.com/assets/upload/files/IJISRT23APR301.pdf.

[11] W. Kassab, K. A. Darabkh, "A–Z survey of Internet of Things: Architectures, protocols, applications, recent advances, future directions and recommendations," Journal of Network and Computer Applications, vol. 163, p. 102663, 2020, https://doi.org/10.1016/j.jnca.2020.102663.

[12] P. Chanak and I. Banerjee, "Internet-of-Things-Enabled SmartVillages: An Overview," *IEEE Consumer Electronics Magazine*, vol. 10, no. 3, pp. 12-18, 2021, https://doi.org/10.1109/MCE.2020.3013244.

[13] Q. Xue, X. Zhang, T. Teng, J. Zhang, Z. Feng, Q. Lv, "A comprehensive review on classification, energy management strategy, and control algorithm for hybrid electric vehicles," *Energies*, vol. 13, no. 20, p. 5355, 2020, https://doi.org/10.3390/en13205355.

[14] S. Bansal, D. Kumar, "IoT ecosystem: A survey on devices, gateways, operating systems, middleware and communication," *International Journal of Wireless Information Networks*, vol. 27, pp. 340-364, 2020, https://doi.org/10.1007/s10776-020-00483-7.

[15] S. Wu, M. Liu, A. K. Y. Jen, "Prospects and challenges for perovskite-organic tandem solar cells," *Joule*, vol. 7, no. 3, pp. 484-502, 2023, https://doi.org/10.1016/j.joule.2023.02.014.

[16] A. R. Dehghani-Sanij, E. Tharumalingam, M. B. Dusseault, R. Fraser, "Study of energy storage systems and environmental challenges of batteries," *Renewable and Sustainable Energy Reviews*, vol. 104, pp. 192-208, 2019, https://doi.org/10.1016/j.rser.2019.01.023.

[17] H. Zhang *et al*., "Modeling the impact of nickel recycling from batteries on nickel demand during vehicle electrification in China from 2010 to 2050," *Science of The Total Environment*, vol. 859, p. 159964, 2023, https://doi.org/10.1016/j.scitotenv.2022.159964.

[18] S. Khan, A. Ahmad, F. Ahmad, M. S. Shemami, M. S. Alam, S. Khateeb, "A comprehensive review on solar powered electric vehicle charging system," *Smart Science*, vol. 6, no. 1, pp. 54-79, 2018, https://doi.org/10.1080/23080477.2017.1419054.

[19] I. Ud Din *et al*., "The Internet of Things: A Review of Enabled

Technologies and Future Challenges," *IEEE Access*, vol. 7, pp. 7606-7640, 2019, https://doi.org/10.1109/ACCESS.2018.2886601.

[20] Y. Saleem, N. Crespi, M. H. Rehmani and R. Copeland, "Internet of Things-Aided Smart Grid: Technologies, Architectures, Applications, Prototypes, and Future Research Directions," *IEEE Access*, vol. 7, pp. 62962-63003, 2019, https://doi.org/10.1109/ACCESS.2019.2913984.

[21] H. Liu, S. Bansal, "Metal halide perovskite nanostructures and quantum dots for photocatalytic CO2 reduction: prospects and challenges," *Materials Today Energy*, vol. 32, p. 101230, 2023, https://doi.org/10.1016/j.mtener.2022.101230.

[22] F. Alam, R. Mehmood, I. Katib, N. N. Albogami and A. Albeshri, "Data Fusion and IoT for Smart Ubiquitous Environments: A Survey," *IEEE Access*, vol. 5, pp. 9533-9554, 2017, https://doi.org/10.1109/ACCESS.2017.2697839.

[23] S. Peng, Z. Yang, M. Sun, L. Yu, Y. Li, "Stabilizing Metal Halide Perovskites for Solar Fuel Production: Challenges, Solutions, and Future Prospects," *Advanced Materials*, vol. 35, no. 45, p. 2304711, 2023, https://doi.org/10.1002/adma.202304711.

[24] J. H. Meng, X. H. Zhu, Y. Liu, M. Yang, G. Lu, "Numerical investigation of heat transfer mechanism in an embedded PCM-TEG for better overall performance under the fluctuating heat source," *Case Studies in Thermal Engineering*, vol. 53, p. 103825, 2024, https://doi.org/10.1016/j.csite.2023.103825.

[25] S. Verma *et al*., "A comprehensive review on energy storage in hybrid electric vehicle," *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 8, no. 5, pp. 621-637, 2021, https://doi.org/10.1016/j.jtte.2021.09.001.

[26] S. Sodagudi *et al*., "Renewable Energy Based Smart Grid Construction Using Hybrid Design in Control System with Enhancing of Energy Efficiency of Electronic Converters for Power Electronic in Electric Vehicles," *International Transactions on Electrical Energy Systems*, vol. 2022, no. 1, pp. 1-9, 2022, https://doi.org/10.1155/2022/2986605.

[27] S. Amertet, G. Gebresenbet, "Hybridized Renewable Energy for Smart Vehicle-to-Grid (V2G) Systems," *Energy Exploration & Exploitation*, vol. 42, no. 1, pp. 292-308, 2024, https://doi.org/10.1177/01445987231209770.

[28] L. Maretto, M. Faccio, D. Battini, "The adoption of digital technologies in the manufacturing world and their evaluation: A systematic review of real-life case studies and future research agenda," *Journal of Manufacturing Systems*, vol. 68, pp. 576-600, 2023, https://doi.org/10.1016/j.jmsy.2023.05.009.

[29] A. Mejías, R. S. Herrera, M. A. Márquez, A. J. Calderón, I. González, J. M. Andújar, "Easy handling of sensors and actuators over TCP/IP networks by open source hardware/software," *Sensors*, vol. 17, no. 1, p. 94, 2017, https://doi.org/10.3390/s17010094.

[30] J. Johnson, "Designing with the mind in mind: simple guide to understanding user interface design guidelines," *Extended abstracts of the 2021 CHI conference on human factors in computing systems*, no. 134, pp. 1-2, 2021, https://doi.org/10.1145/3411763.3444997.

[31] C. Stolojescu-Crisan, C. Crisan, B. P. Butunoi, "An IoT-based smart home automation system," *Sensors*, vol. 21, no. 11, p. 3784, 2021, https://doi.org/10.3390/s21113784.

[32] M. M. Rathore, S. A. Shah, D. Shukla, E. Bentafat and S. Bakiras, "The Role of AI, Machine Learning, and Big Data in Digital Twinning: A Systematic Literature Review, Challenges, and Opportunities," *IEEE Access*, vol. 9, pp. 32030-32052, 2021, https://doi.org/10.1109/ACCESS.2021.3060863.

[33] Y. B. Zikria, M. K. Afzal, F. Ishmanov, S. W. Kim, H. Yu, "A survey on routing protocols supported by the Contiki Internet of things operating system," *Future Generation Computer Systems*, vol. 82, pp. 200-219, 2018, https://doi.org/10.1016/j.future.2017.12.045.

[34] S. A. Gbadamosi, G. P. Hancke and A. M. Abu-Mahfouz, "Building Upon NB-IoT Networks: A Roadmap Towards 5G New Radio Networks," *IEEE Access*, vol. 8, pp. 188641-188672, 2020, https://doi.org/10.1109/ACCESS.2020.3030653.

[35] H. RehannoInternet of Things (IoT) in Smart Cities: Enhancing Urban Living Through Technology," *Journal of Engineering and Technology*, vol. 5, no. 1, pp. 1-16, 2023, https://mzjournal.com/index.php/JET/article/view/70.