Waste for Knowledge: An IoT-Driven Educational Reward System

Khuat Duc Anh, Nguyen Minh Duc, Vu Phung Anh, Nguyen Thuy Linh, Dao Ba Hoi, and Phan Duy Hung(✉)

FPT University, Hanoi, Vietnam
{anhkd3,hungpd2}@fe.edu.vn, {ducnmhe163477,anhvphe161648, linhnthe163546,hoidbhe161691}@fpt.edu.vn

Abstract. Wastes should not be wasted - it might be opportunities for a brighter future. That is the idea behind Waste4Knowledge, an IoT-driven kiosk that turns discarded items like plastic bottle aluminum cans into opportunities for children to learn and grow. The system incentivizes children to recycle waste materials by rewarding them with items, stationeries, or access to education contents. It uses IoT sensors and an ESP32 microcontroller to check the recyclables and hand out rewards without a hitch. Its modular hardware design, combined with Firebase software, allows real-time data tracking, enabling administrators to analyze recycling trends, adjust reward strategies, and optimize the user experience dynamically. By integrating recycling and education, the W4K system offers opportunities to underprivileged children, fosters environmental responsibility, and inspires positive community behavior. Its adaptable design positions it as a scalable solution for sustainable development initiatives worldwide.

Keywords: Recycling for education · Waste-for-knowledge · IoT-based kiosk

1 Introduction

Children are the future of the country and the foundation for sustainable development of each country. Many studies have shown that countries that do not prioritize education for children often have lower levels of socio-economic development. In addition, research from Harvard Family Research shows that family involvement plays an important role in accompanying children in the learning process and future development [1]. Currently, many children around the world still lack access to adequate and quality education. According to UIS data, at the end of the 2018 school year, approximately 258 million children and adolescents were out of school [2]. In Vietnam, statistics from 2011 show that there are about 2.8 million children in difficult circumstances, including orphans, disabled children and concentrated laborers under the age of 16. In addition, a number of charitable organizations have also developed support programs such as education and food and living expenses. These programs not only help children in difficult circumstances access education but also contribute to improving their lives [3]. Without these programs, children will still face difficulties in life and lack access to education, which not only harms them but also affects the development of society [4].

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025 Workshops, LNCS 15895, pp. 67–79, 2026.
https://doi.org/10.1007/978-3-031-97651-3_5

The purpose of this project is to bring about positive change in the community and focuses on three main objectives. The project aims to raise awareness of environmental protection and encourage recycling and especially convey this message to the younger generation to understand the importance of environmental protection. In addition, the project aims to expand access to education by providing children and disadvantaged communities with meaningful educational resources such as learning materials and materials. Finally, the project strives to promote positive social actions, encouraging people to participate in meaningful programs and activities by providing practical and long-term rewards.

Globally, Reverse Vending Machines (RVMs) are machines that allow users to exchange recyclable items for rewards, with the ability to recognize, sort, and process used cans and plastic bottles [5]. However, these machines are quite expensive and lack educational purposes, leaving users uncertain whether it is worth spending their time to use them. In contrast, there are a number of free libraries such as Little Free Libraries that promote a culture of reading and sharing items as well as contributing to education and community connection [6]. Although it is effective in encouraging reading, it does not address the issue of environmental protection. In Vietnam, there are programs such as Aquafina's Rebirth Stations that have been using RVM technology to recycle plastic bottles and provide rewards. However, the model does not target children [7]. Expanding the program to engage younger audiences could further promote environmental awareness and sustainability.

Waste4Knowledge (W4K) kiosk system utilizes sensors to identify recyclable materials and employs the ESP32 as the central control unit, ensuring seamless connectivity and management of components such as sensors, display screens, and reward dispensing systems. The system consists of three compartments – the central compartment, storage compartment, and delivery compartment. The software for W4K system is deployed on Firebase, enabling real-time data processing and smooth integration with IoT devices. These technologies ensure efficient operation, optimized data management, and an enhanced user experience.

This paper is further divided into the following main sections: System Architecture, Hardware, Mechanism, Software, and Conclusion.

2 System Architecture

The automated resource-sharing kiosk system integrates cloud computing for efficient data management while ensuring security through user card verification and control sensors. The system architecture, based on IoT principles, simplifies access to educational resources and optimizes the user experience, as illustrated in Fig. 1 Current IoT platforms offer supporting features that enable users to build systems with minimal effort, making them suitable for diverse applications [8], such as this kiosk system.

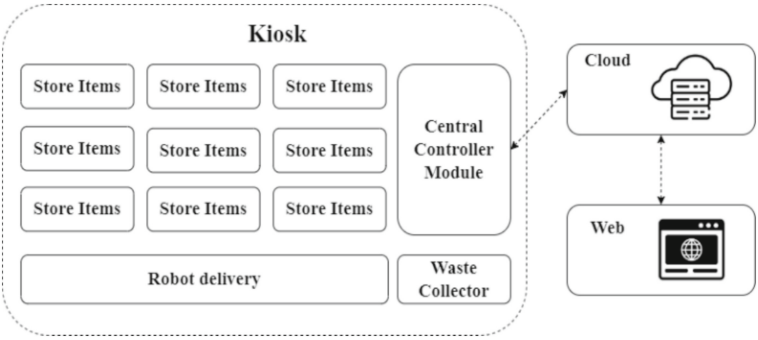

Fig. 1. Architecture Diagram

The kiosk is designed with an additional feature for recycling, encouraging environmental awareness. The system with RFID was evaluated and proved superior to the conventional kiosk system [9]. The waste collector feature with sensor operates independently, allowing children to contribute recyclable materials and receive corresponding rewards or educational resources. This creates a multifunctional experience that combines both education and environmental protection within a single system.

Cloud computing eliminates the need for on-site servers, reducing infrastructure costs and simplifying maintenance. Resource-sharing data and user interactions are securely stored in the cloud, ensuring real-time synchronization across system components. This architecture not only rationalizes data management but also supports scalability as the system expands. The cloud platform enables remote monitoring, allowing administrators or staff to track system performance and promptly issues. The kiosk system is managed through a web interface, which provides administrators with tools to update resource data and track user activities. This user interface facilitates efficient data handling and generates real-time usage reports, ensuring smooth system operation. The kiosk has three compartments: a resource drawer, a central display compartment, and a resource support compartment. The central screen compartment manages user authentication and processes commands from the web interface. The resource-pushing compartment is equipped with an autonomous mechanical system designed to push objects out of the compartment quickly and efficiently, helping user experience needs seamlessly.

3 Hardware

This study divides the Kiosk into three main compartments for ease of installation, repair and maintenance. The central module controls user identification, receives input from the keyboard, sends commands to the item-pushing and item-supporting modules, and powers for all compartments. Manti Banik's research highlights the advantages of RFID in libraries, noting its speed and ease of setup and maintenance [10], making it the ideal choice for user identification in the item-borrowing process.

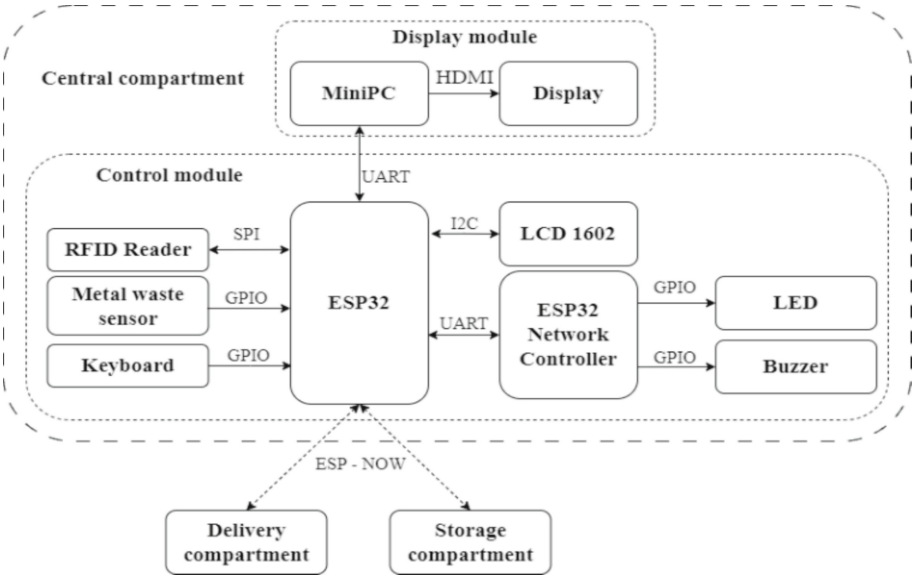

Fig. 2. Structural diagram of the central compartment

The central module is controlled by an ESP32, which connects to a mini PC via a COM port and a screen displaying the web interface for user interaction. Inputs include an RFID reader for user identification and a keyboard for operations like logging out and selecting items. ESP-NOW is a connectionless Wi-Fi communication protocol developed by Espressif, designed to allow direct, low-latency between devices without the need for a central router or Wi-Fi access point. Full information about ESP-NOW can be found in [11]. That is why this study chose the ESP-NOW for communication between the MCUs. The power input is a 220V AC source protected by an MCB circuit breaker to prevent overcurrent, with adapters providing power to the screen and mini PC. The power converter transforms the 220V AC input into a 12V DC output to power the item-pushing and item-supporting modules. Additionally, the system integrates a metal waste sensor to detect and differentiate recyclable metal waste, such as aluminum cans. At this stage, after assessing the balance between the cost of sensor technology, waste storage, and ensuring simplicity for wide development and deployment, we decided to include only the metal waste (discarded soda cans, beer cans…) treatment module in the system. Other types of waste, plastic bottle waste is high in quantity, while glass bottle waste is heavy in weight, would require more complex and larger infrastructure, and are being considered for future system upgrades. Figure 2 illustrates the connection structure diagram of the computer screen module.

Figure 3 illustrates the structural diagram of the item-pushing module. The item-pushing module stores items and pushes them out when selected by the user. To save energy while maintaining performance, this study uses the ESP32C3 chip, which has a unique ID and receives commands wirelessly via ESP-NOW from the ESP32 in the central module. Upon receiving a command, the chip controls the DC motor through an L298N driver board. A limit switch is pressed when the item falls, stopping the motor. To protect the pushing mechanism, two limit switches are installed at the front and back, along with firmware programming to stop the motor when it reaches the maximum travel distance, preventing damage to the mechanical structure.

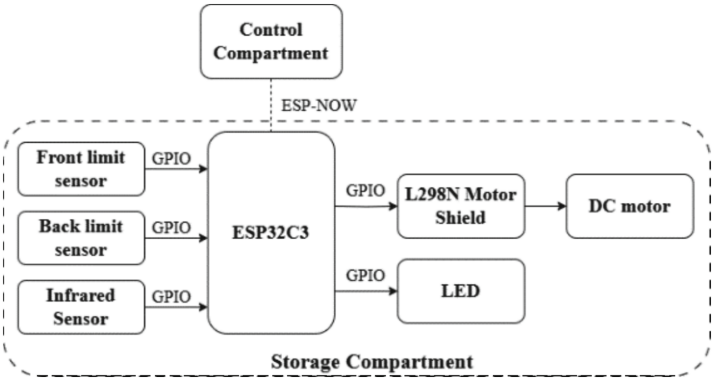

Fig. 3. Structural diagram of the storage compartment

Figure 4 illustrates the main algorithm diagram of the Kiosk. The algorithm diagram outlines the operational process of the IoT item kiosk for a smart library. It uses ESP-NOW, a proprietary wireless communication protocol developed by Espressif Systems for devices using the ESP8266 and ESP32 microcontrollers [12]. This protocol enables direct data transmission between ESP devices without relying on a Wi-Fi network, ensuring fast, efficient data transfer with low latency and minimal resource consumption for a smooth user experience. The main processing flow starts in the central compartment, which sends data to the execution compartments. Each compartment, including the item-pushing and item-supporting modules, has a distinct processing flow to maintain functionality.

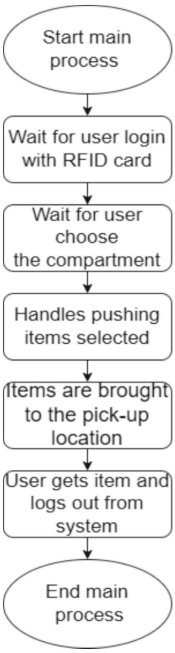

Fig. 4. Main algorithm diagram of Kiosk

Figure 5 illustrates the algorithm diagram of the central module. Upon startup, the system establishes a Wi-Fi connection to access the Firebase real-time database. Once connected, the ESP32 monitors user input through either the RFID reader or the metal waste sensor. If the metal sensor detects recyclable waste (discarded soda cans, beer cans…), the system immediately records the transaction and updates the Firebase database. Users are then prompted to select a reward based on the amount of waste deposited. If no waste is detected initially, the system waits for the user to swipe their RFID card to log in (as shown in Fig. 6). For registered users with RFID cards (e.g., children issued NFC-enabled citizen IDs), the system links the deposited waste to their personal account, enabling personalized tracking and reward accumulation. To ensure inclusiveness, if a user deposits waste without an RFID scan—such as homeless or unregistered children—the system automatically assigns an anonymous ID to the transaction. This allows all users to participate and receive rewards, regardless of formal identification status. After login, users can interact with the system via a keypad: number keys are used to select specific rewards, and pressing "#" logs the user out. Upon selection, the system communicates with the appropriate compartment to dispense the chosen item. When "#" is pressed, the ESP32 resets to await the next user interaction.

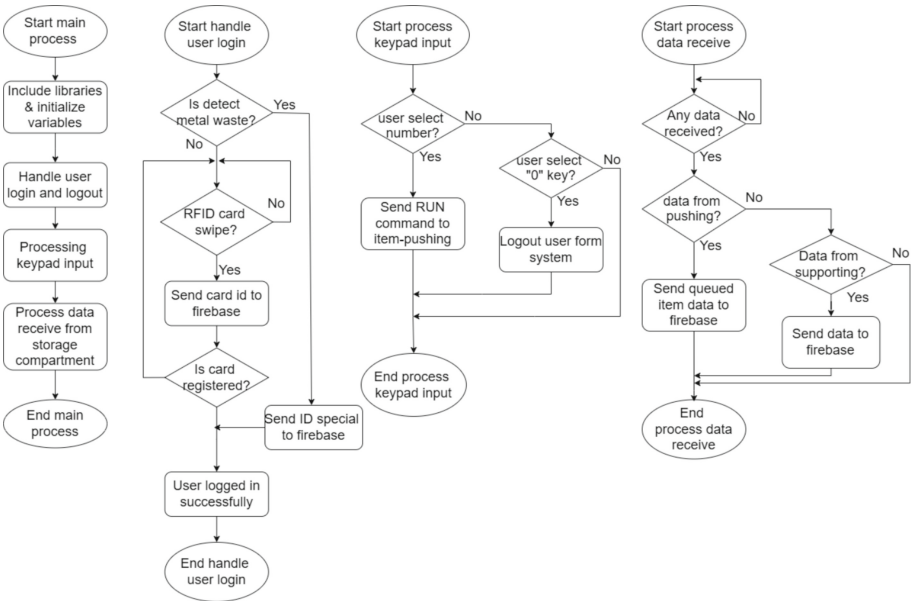

Fig. 5. The central module algorithm diagram

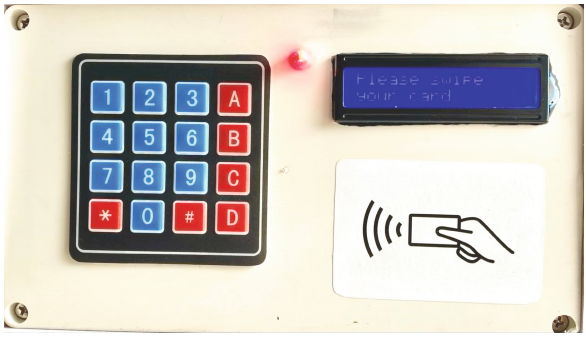

Fig. 6. Control Panel with Keypad and RFID Reader

Figure 7 illustrates the algorithm diagram of the item-storage module. When data is received, the ESP32-C3 processes the data, verifies the ID and command. If the ID matches and the command is RUN, the motor runs; if the command is STOP, the motor stops. While the motor is running, a millis function is used to manage situations where the motor runs for too long. The limit point functions handle the cases where the pushing mechanism reaches its maximum or minimum point, causing the motor to reverse and return the mechanism to its initial position before stopping.



Fig. 7. The item-pushing module algorithm diagram

4 Mechanical Design

The mechanical design of the system comprises four primary components: the storage compartment, the PC compartment, the delivery compartment, and the waste storage, which collectively form the item kiosk frame (Fig. 8). The storage compartment houses the item-pushing module, which utilizes a threaded rod, bearings, and a motor to efficiently push items out at a fixed angle of 65 degrees - optimized for stability and adaptability to items of varying sizes and weights. The PC compartment includes a screen

for user interactions, such as item selection and card swiping, and displays community-related messages. The delivery compartment, made of durable materials, aids the item-pushing module by transferring items to the collection area for easy retrieval. The waste compartment efficiently collects and stores recyclable materials.

Preliminary tests conducted in a controlled lab environment confirmed the mechanical reliability of the W4K system. The item-pushing module demonstrated a 96% success rate across 100 delivery cycles, while the metal waste sensor achieved 98% detection accuracy. User interaction simulations reported a 95% successful task completion rate, validating the system's usability and mechanical robustness for real-world deployment.

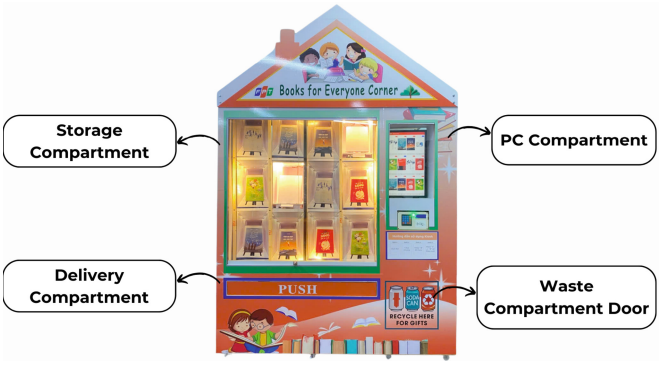

Fig. 8. W4K Interface

5 Software

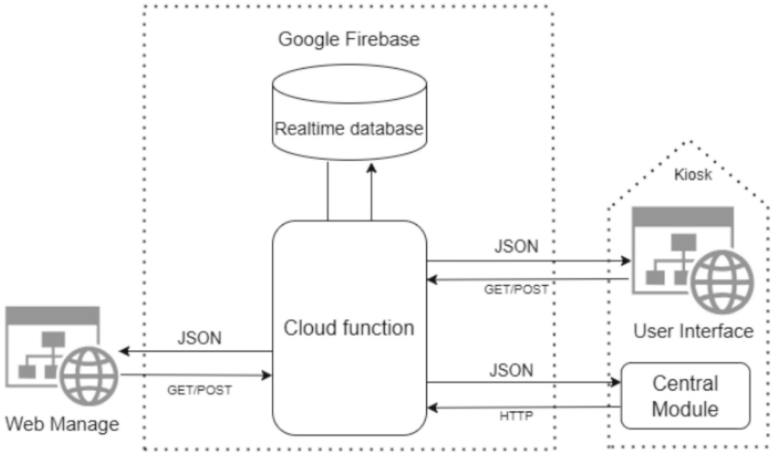

Fig. 9. Firebase Architecture

5.1 Google Firebase

Firebase, part of the Google ecosystem, is ideal for small and medium IoT projects due to its real-time data synchronization, robust security, and scalable features at affordable costs [13]. Its seamless integration with Google services simplifies deployment and management, making it suitable for applications like automated kiosks. In an IoT system with multiple connected devices, Firebase ensures quick synchronization, stability, and an optimized user experience for educational resource-sharing kiosks for children. Figure 9 illustrates the Firebase Architecture of W4K. The kiosk system connects to Firebase's real-time database via cloud functions, enabling seamless data exchange between the user interface, central module, and web management platform.

5.2 Website

The system includes a user interface on the kiosk and a management module. The website is built using ReactJS and deployed via Firebase Hosting, leveraging Realtime Database functions to handle data quickly and efficiently. Firebase Storage is used to update and store images, ensuring that image resources are always available and synchronized. Due to Realtime Database, data performance is optimized and updated in real time, supporting the entire item-borrowing process seamlessly and accurately Fig. 10. Use Case Diagram – Website Application this diagram illustrates the interactions between users and the website application, highlighting the key functionalities and processes involved in the item-borrowing system, including data management and real-time updates through Firebase services.

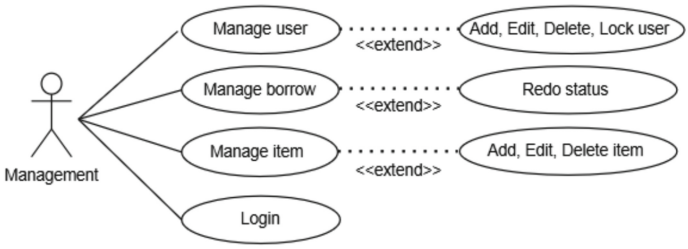

Fig. 10. Use Case Diagram – Website Application

The management interface on the website offers features such as storing user information, listing available items in the kiosk, and tracking transactions. Data is automatically synchronized to the cloud when children interact with the kiosk, ensuring that information is always up-to-date. The management page clearly displays user activities, recycling history, and the current status of the kiosk, allowing administrators to easily monitor and assist when needed. The real-time tracking system enables adjustments to the reward strategy and optimizes the user experience.

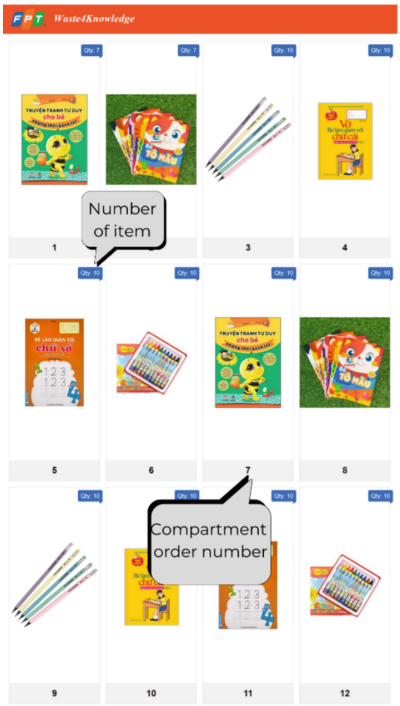

Fig. 11. Management interface

The user interface screen is displayed directly on the kiosk, making it easy for children or those in need to use the system. The interface is designed to be simple and easy to understand, with clear images and easy-to-follow steps. This ensures that children can use the kiosk quickly and enjoyably. As shown in Fig. 11. Management Interface, the design focuses on ease of use and accessibility, ensuring that both kiosk operators and children can easily navigate the system.

6 Conclusion and Future Works

This paper presents W4K, an IoT-enabled educational reward kiosk that transforms recyclable waste into learning opportunities for children. By offering practical incentives like school supplies and educational materials, the system simultaneously promotes environmental protection and broadens access to education. Its modular hardware, IoT integration, and cloud-based analytics ensure adaptability to different community needs while providing data for continuous improvement.

Moving forward, we plan real-world deployments to evaluate user engagement, system stability, and to enrich the reward portfolio with local cultural elements. Advanced AI features will also be incorporated to enhance waste recognition and personalize user experiences. Beyond Vietnam, the W4K model is being explored for adaptation in different countries, taking into account cultural, economic, and infrastructural differences. Future research will focus on developing flexible frameworks to support global

deployment. This paper is also a good reference for research directions of IoT [14, 15], Embedded Systems [16, 17].

References

1. Kreider, H.: Getting Parents "Ready" for Kindergarten: The Role of Early ChildhoodEducation. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=8c4734a81fe42bfce659496b6557796132464e49
2. UNESCO: What you need to know about the Right to Education. https://www.unesco.org/en/articles/what-you-need-know-about-right-education
3. Chien Thang, P., Thi Nguyet Trang, T.: Socially disadvantaged children in Vietnam: a self evaluation study with implications for their education. Int. J. Adolescence and Youth, **29**(1) (2024)
4. Balan, J. D. et al.: Educational Resources for Underprivileged Children. In: IRJEMS Int. Res. J. Econ. Manage. Stud. **3**(2), February , pp. 58–61 (2024)
5. Rana, M.E., Shanmugam, K., Yi, K.Q.: IoT Based Reverse Vending Machine to Identify Aluminium Material and Allocate Point Reward. In: Proceedings of the International Conference on Decision Aid Sciences and Applications (DASA), Chiangrai, Thailand, 2022, pp. 645–649
6. Staff, D.P.L.P. and R.: Library and Parks Bring "Little Free Libraries" to Southside Virginia. Virginia Libraries, 59(1) (2013). https://doi.org/10.21061/valib.v59i1.1251
7. Lundell, C., Thomas, J.: PET: Polyethylene Terephthalate – The Ubiquitous 500 ml Water Bottle. In: Di Bucchianico, G., Shin, C., Shim, S., Fukuda, S., Montagna, G., Carvalho, C. (eds) Advances in Industrial Design. AHFE 2020. Advances in Intelligent Systems and Computing, vol 1202. Springer, Cham (2020)
8. Anh, K.D., Huynh, L.D., Hung, P.D.: A Flexible Internet of Things Architecture for Data Gathering and Monitoring System. In: Dang, T.K., Küng, J., Takizawa, M., Chung, T.M. (eds) Future Data and Security Engineering. Big Data, Security and Privacy, Smart City and Industry 4.0 Applications. FDSE 2020. Communications in Computer and Information Science, vol 1306. Springer, Singapore (2020)
9. Andhare, M. et al.: IoT-Enabled RFID-Based Library Management and Automatic Book Recommendation System Using Collaborative Learning. In: Shakya, S., Du, KL., Ntalianis, K. (eds) Sentiment Analysis and Deep Learning. Advances in Intelligent Systems and Computing, vol 1432. Springer, Singapore (2023)
10. Banik, M.: Auto-Identification Technologies in Academic Libraries An Overview. Int. J. Librarianship **8**(1), 127–133 (2023). https://doi.org/10.23974/ijol.2023.vol8.1.274
11. Espressif/API Reference//Networking APIs. ESP-NOW documentation. https://docs.espressif.com/projects/esp-idf/en/v5.3.2/esp32/api-reference/network/esp_now.html
12. Hercog, D., Lerher, T., Truntič, M., Težak, O.: Design and implementation of ESP32-based IoT devices. Sensors **23**(15), 6739 (2023). https://doi.org/10.3390/s23156739
13. Moroney, L.: An Introduction to Firebase. In: The Definitive Guide to Firebase: Build Android Apps on Google's Mobile Platform. Berkeley, CA: Apress, 2017, pp. 1–24. ISBN:978–1–4842–2943–9 (2017). https://doi.org/10.1007/978-1-4842-2943-9 1
14. Anh, K.D., Tung, M.V., Hanh, V.D., Huong, L.M., Minh, N.T., Hung, P.D.: A Collaborative IoT School Bus Monitoring System. In: Luo, Y. (eds) Cooperative Design, Visualization, and Engineering. CDVE 2024. Lecture Notes in Computer Science, vol 15158. Springer, Cham (2024)
15. Anh, K.D., Anh, V.K., Minh, N.D., Khoa, L.N.V., Minh, N.T., Hung, P.D.: SmartTM: An IoT-Based Smart Trash Management System. In: Tsai, Tw., Chen, K., Yamanaka, T., Koyama, S., Schütte, S., Mohd Lokman, A. (eds) Kansei Engineering and Emotion Research. KEER

2024. Communications in Computer and Information Science, vol 2314. Springer, Singapore (2024)
16. Hung, P.D., Duong, P.M., Giang, T.M., Diep, V.T.: Model-Driven Design for Fast Deployment of Embedded Systems. In: Proceedings of the 2nd International Conference of Intelligent Robotic and Control Engineering (IRCE), Singapore, pp. 138–142 (2019)
17. Diep, V.T., Hung, P.D., Tung, T.D.: Energy Saving Solution for Air Conditioning Systems. In: Dang, T., Küng, J., Takizawa, M., Bui, S. (eds) Future Data and Security Engineering. FDSE 2019. Lecture Notes in Computer Science(), vol 11814. Springer, Cham (2019)