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RFID-Based Solar-Powered Portable Phone Charging Station with Bluetooth-Enabled Android Application and Prepaid Credit Management

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ABSTRACT

The increasing dependence on smartphones has created a growing demand for accessible and reliable charging solutions, particularly in areas where conventional power sources are limited. This study developed an RFID-based, solar-powered, portable phone charging station with a Bluetooth-enabled Android Application and prepaid credit management. The system integrates an Arduino Uno R3 microcontroller, an MFRC522 RFID reader, RFID key fobs, an RFID master card, an HC-05 Bluetooth module, a dual-channel relay module, EEPROM storage, an XY-3606 buck converter connected to a 12V solar panel, a 1-female-to-2-male USB splitter, two rechargeable power banks for energy storage, and two 3-in-1 USB charging cables. A developmental research design was employed to develop, construct, and evaluate the prototype's functionality. Unlike traditional charging stations that require direct user interaction with hardware interfaces, the developed system uses an Android application as the primary control interface, allowing users to manage PIN authentication, account balance, charging rates, charging duration selection, and transaction functions via Bluetooth. The system supports both online balance reloading through PayMongo-generated QR payments and offline charging access using previously stored account credits. In addition, the charging station supports simultaneous charging of two mobile devices through independently controlled charging ports, each with its own timer and charging management process. The RFID key fob serves as the user's authentication method, while the master card enables authorized balance loading. Functional testing was conducted to evaluate RFID authentication, Bluetooth communication, balance management, charging control, timer operation, and phone charging capability. Results showed that the prototype successfully performed prepaid charging operations with automated charging control. The integration of solar-assisted power management and mobile application control demonstrates the system's potential as a portable, sustainable, and user-friendly charging solution for schools, public areas, and other environments requiring controlled charging services.

Keywords: RFID Authentication, Android Application, Bluetooth Communication, Solar-Powered Charging, Prepaid Credit Management

INTRODUCTION

Smartphones have become essential devices for communication, education, business, and daily activities (Kuznekoff & Titsworth, 2013). As mobile device usage continues to increase, the demand for accessible charging facilities has also grown, especially in public environments where users may experience limited access to electrical outlets. The availability of charging stations provides a practical solution for maintaining device usability; however, conventional charging facilities often lack secure user identification, controlled access, and payment management systems. These limitations may result in unauthorized usage and inefficient management of charging resources.

Radio Frequency Identification (RFID) technology has been widely implemented in authentication and access control systems due to its ability to provide fast, contactless, and reliable identification (Munoz-Ausecha et al., 2021). RFID-based systems allow users to be uniquely identified through RFID tags while improving security and convenience compared with traditional access methods (Munoz-Ausecha et al., 2021). Because of these advantages, RFID technology has been applied to various automated systems, including prepaid services and controlled-access applications.

Prepaid charging systems provide an effective approach to managing shared charging resources by allowing users to purchase charging services using available credits. Previous studies have demonstrated the feasibility of RFID-based mobile charging systems using microcontrollers and automated control mechanisms (Praveena et al., 2018). However, many existing systems rely on direct hardware interaction or require fixed power sources, limiting portability and user convenience.

The integration of mobile applications provides an improved approach by transferring system interaction from physical interfaces to smartphones. Android applications combined with Bluetooth communication enable wireless control between users and embedded systems, allowing functions such as account management, balance monitoring, charging selection, and device control to be performed remotely (Android Developers, 2025). This approach eliminates the need for additional hardware interfaces such as keypads and displays while providing a more flexible user experience.

This study presents the development of an RFID-Based Solar-Powered Portable Phone Charging Station with Bluetooth-Enabled Android Application and Prepaid Credit Management. The system utilizes an Arduino Uno R3, an RFID reader, RFID key fobs, an RFID master card, an HC-05 Bluetooth module, a dual-channel relay module, an EEPROM storage, an XY-3606 buck converter, a solar panel, two power banks, a 1-female-to-2-male USB splitter, and two 3-in-1 USB charging cables. The Android application serves as the primary user interface for registration, PIN authentication, balance management, charging rate selection, charging duration control, and payment transactions through PayMongo-generated QR codes. The system also supports offline charging operation by allowing users to access charging services using previously stored account balances. The solar-assisted power system improves sustainability by supporting portable operation and reducing dependence on conventional electrical sources. Solar photovoltaic systems provide a sustainable and environmentally friendly energy source for portable electronic applications (Parida et al., 2011)

The study aims to develop and evaluate a portable, secure, and user-friendly charging station that provides controlled phone charging services via RFID authentication, Bluetooth-enabled mobile interaction, and prepaid credit management. The developed prototype may provide a practical charging solution for schools, transportation terminals, community areas, and other public locations that require accessible, managed charging facilities.

METHODOLOGY

Research design

This study employed a developmental research design focused on the design, development, integration, and evaluation of an RFID-Based Solar-Powered Portable Phone Charging Station with Bluetooth-Enabled Android Application and Prepaid Credit Management. The research involved planning, construction, programming, and testing of both hardware and software components to develop a functional prototype capable of providing controlled phone charging.

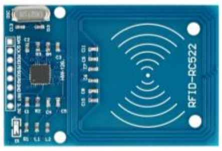
The development process consisted of three major stages: hardware development, software development, and system evaluation. The hardware development involved integrating the Arduino Uno R3 microcontroller, RFID reader, RFID key fobs, RFID master card, HC-05 Bluetooth module, dual-channel relay module, EEPROM storage, XY-3606 buck converter, solar panel, two power banks, a 1-female-to-2-male USB splitter, and two 3-in-1 USB charging cables. The software development involved creating an Android application using Android Studio as the primary user interface for RFID account management, PIN authentication, balance loading, charging selection, timer control, and payment processing.

The completed prototype was evaluated through functional testing to assess the reliability and effectiveness of its key features, including RFID authentication, Bluetooth communication, balance management, prepaid charging, automated charging control, and phone charging. The test results were analyzed to assess whether the developed system met its intended objectives as a portable, sustainable charging solution.

Materials and components

The prototype was developed using hardware and software components selected based on their compatibility, availability, and suitability for implementing an RFID-based prepaid charging system. The Arduino Uno R3 served as the main controller, processing RFID authentication, Bluetooth commands, balance transactions, and charging control. The Android application was developed using Android Studio to provide the main user interface.

Table 1. Hardware and Software Components Used in Developing the RFID-Based Solar-Powered Portable Phone Charging Station

Component	Specification	Quantity	Function
 Arduino Uno R3	ATmega328P Microcontroller	1	Main controller for system operation and relay control
 RFID Reader	MFRC522, 13.56 MHz	1	Reads RFID key fobs and master card authentication
 RFID Master Card	13.56 MHz RFID Card	1	Used for authorized balance loading
 RFID Key Fobs	13.56 MHz RFID Tags	3-5	User identification and account access
 HC-05 Bluetooth Module	Bluetooth Serial Communication Module	1	Enables wireless communication between Arduino and Android application
 Relay Module	5V Dual-Channel Relay Module	1	Independently controls the activation and termination of two charging outputs

 XY-3606 Buck Converter	DC Voltage Regulator Module	1	Regulates voltage supplied to electronic components
 Solar Panel	12V Solar Panel	1	Provides renewable energy support for system sustainability
 Power Bank	Pass-through Charging, 5V USB Output	2	Stores energy from the solar charging subsystem and supplies power for phone charging operations
 3 in 1 USB Charging Cables	USB Charging Output	2	Provides charging compatibility for Lightning, Micro USB, and USB Type-C devices
 USB Splitter Cable	1-Female-to-2-Male 5V USB Splitter	1	Distributes the regulated 5V output of the XY-3606 buck converter to simultaneously charge two power banks
 Android Smartphone	Android Operating System	1	Runs the application interface for system control
Android Studio	Mobile Application Development Environment	1	Used for developing the Android application
PayMongo API	Online Payment Gateway	1	Generates QR-based payment transactions for balance reloading

Figure 1. Completed RFID-Based Solar-Powered Portable Phone Charging Station Prototype Integrating the Arduino Uno R3, MFRC522 RFID Reader, HC-05 Bluetooth Module, Dual-channel Relay Module, Solar Panel, Power Banks, and Android Application Connectivity.

System architecture and operation

The developed system consists of two main subsystems: the hardware charging station and the Android application-based control system. The hardware subsystem is controlled by an Arduino Uno R3 microcontroller and integrates an MFRC522 RFID reader, RFID key fobs, an RFID master card, an HC-05 Bluetooth module, a dual-channel relay module, EEPROM storage, an XY-3606 buck converter, a solar panel, two power banks, a 1-female-to-2-male USB splitter, and two 3-in-1 USB charging cables. The Arduino serves as the main processing unit responsible for RFID identification, balance transactions, Bluetooth communication, charging management, and automated charging control.

The Android application serves as the system's primary user interface and was developed using Android Studio. Through the application, users can perform PIN authentication, account registration, balance viewing, balance reloading, charging rate selection, charging duration selection, charging control, and transaction management. The application communicates with the Arduino via the HC-05 Bluetooth module, enabling wireless interaction between users and the charging station without requiring a laptop or a wired connection.

The system operates through three primary access modes: registered user mode, new user registration mode, and administrator mode. When a registered RFID key fob is tapped on the charging station, the user is prompted to enter the registered PIN through the Android application. Upon successful authentication, the user may view account information, reload balance through PayMongo-generated QR payments, or initiate a charging session. When an unregistered RFID key fob is detected, the application allows the creation of a new user account by assigning a PIN and storing the RFID data in the system database.

Administrator functions are accessed by tapping the RFID master card. The administrator mode allows authorized personnel to perform offline balance loading, view registered RFID cards, monitor the number of registered users, and delete or reset registered cards when necessary. During offline balance loading, the administrator enters the desired amount through the Android application and taps the customer's RFID key fob to transfer the corresponding prepaid credits.

The charging subsystem utilizes a dual-channel relay module connected to two separate 3-in-1 USB charging cables. Before initiating a charging session, users can view each charging port's status in the Android application and select an available port. Each charging port operates independently and maintains its own charging session, timer, and charging control process. This configuration allows two users to charge their mobile devices simultaneously without interfering with each other's charging sessions.

During charging, the user selects a charging package based on the predefined rates. The system verifies whether sufficient balance is available before deducting the corresponding amount from the user's account. Once confirmed, the selected relay module is activated, enabling the corresponding charging port and starting the charging timer. When the selected charging duration expires, the Arduino automatically deactivates the assigned relay module, terminating the charging session. The use of locally stored account information allows charging services to remain available even without an internet connection, provided that a sufficient account balance is available.

The solar-assisted power system utilizes a 12V solar panel connected to an XY-3606 buck converter, which regulates the voltage to a stable 5V output. The regulated output is distributed through a 1-female-to-2-male USB splitter, allowing the simultaneous charging of two power banks. The stored energy in the power banks serves as the primary power source for the charging station, ensuring continuous operation even during periods of low solar availability. This configuration provides a portable and sustainable power source while maintaining stable voltage levels for the control circuitry and charging outputs.

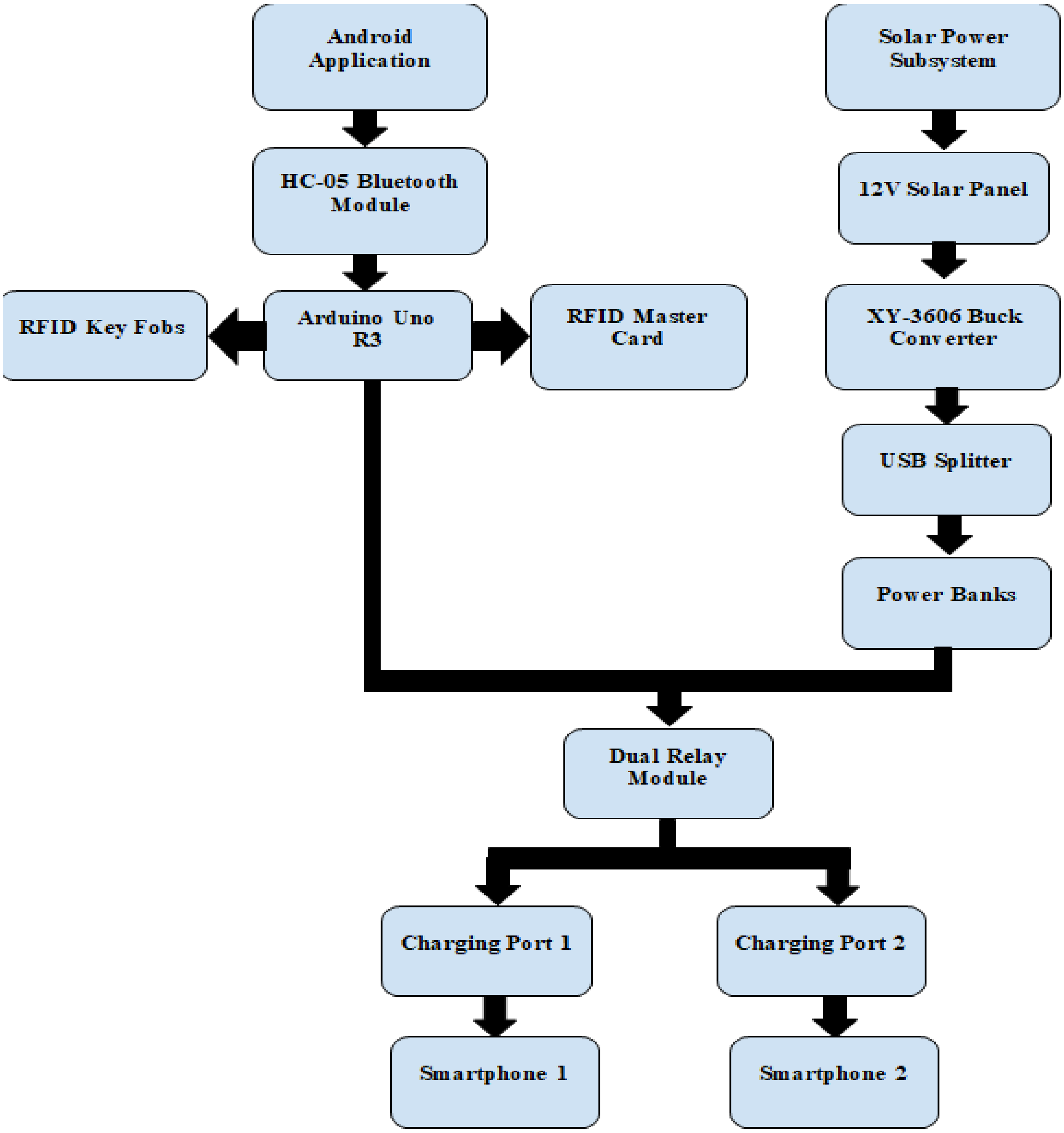


Figure 2. System Block Diagram of the RFID-Based Solar-Powered Portable Phone Charging Station Showing Hardware Components, Bluetooth Communication, and Android Application Interaction

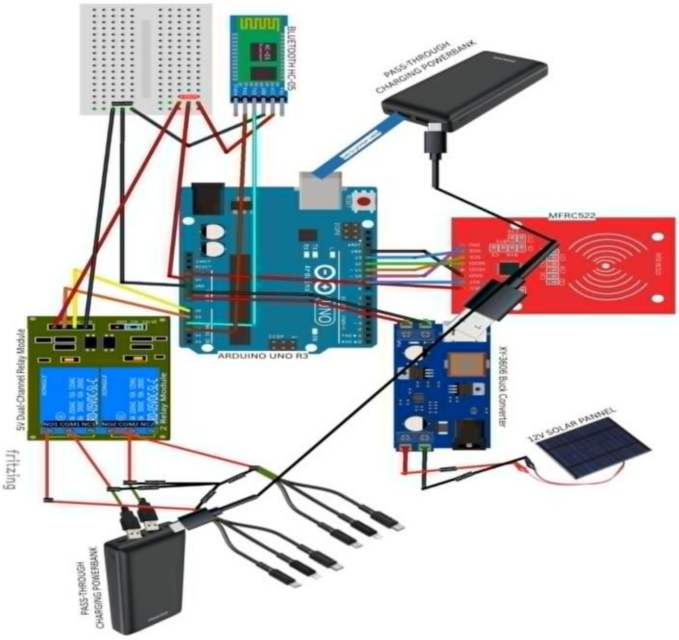


Figure 3. Schematic Diagram of the RFID-Based Solar-Powered Portable Phone Charging Station Showing the Electrical Connections Between the Arduino Uno R3, MFRC522 RFID Reader, HC-05 Bluetooth Module, Relay Module, Buck Converter, Solar Panel, and Charging Outputs.

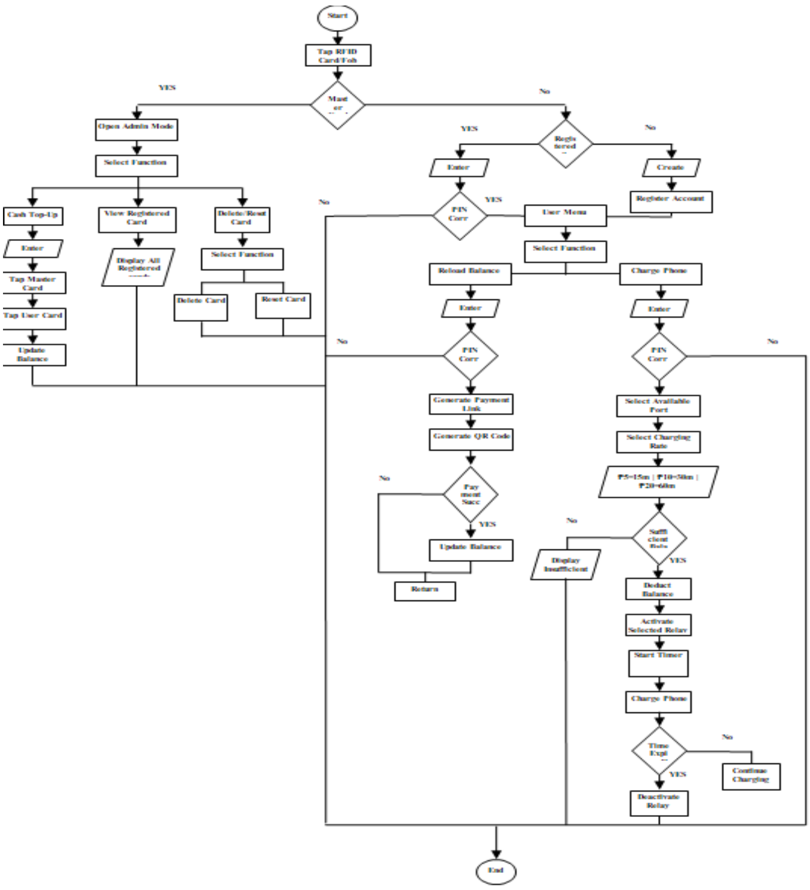


Figure 4. Flowchart of the RFID-Based Solar-Powered Portable Phone Charging Station Showing User Registration, RFID Authentication, Admin Functions, Balance Management, Digital Payment Processing, and Charging Operations Through the Android Application.

Prototype development procedure

The development of the RFID-Based Solar-Powered Portable Phone Charging Station began with the assembly of the hardware components. The Arduino Uno R3 was configured as the main controller and integrated with the MFRC522 RFID reader, HC-05 Bluetooth module, dual-channel relay module, EEPROM storage, XY-3606 buck converter, solar panel, power banks, a USB splitter, and two 3-in-1 USB charging cables. Specifically, the 12V solar panel was connected to the XY-3606 buck converter, which reduced the voltage to a regulated 5V output. The converter output was connected to a 1-female-to-2-male USB splitter, enabling the simultaneous charging of two power banks used for energy storage and system operation. Electrical connections were established in accordance with the system design to enable RFID authentication, wireless communication, power regulation, charging control, and simultaneous charging.

The Arduino was programmed using the Arduino IDE to perform RFID identification, balance verification, Bluetooth communication, timer management, relay activation, relay deactivation, and automated charging termination. A hybrid storage architecture was implemented in the system. The Android application stores user accounts, RFID data, PINs, and balance records in a local database, while the Arduino EEPROM stores RFID identifiers for hardware-level persistence. Temporary charging session information and PIN verification data were managed in the Arduino's SRAM during active charging operations. The dual-channel relay module was programmed to independently control the two charging ports through its two relay channels, allowing multiple users to charge their mobile devices simultaneously while maintaining separate charging sessions and timers.

An Android application was developed in Android Studio to serve as the system's primary user interface. The application was designed to provide user registration, PIN authentication, balance monitoring, balance reloading, charging rate and duration selection, charging port selection, charging control, port status monitoring, and transaction management. Bluetooth communication between the Android application and the Arduino was established via the HC-05 module, enabling wireless transmission of commands and system status information.

To support account reloading through digital payments, the Android application was integrated with the PayMongo payment gateway. The system generates QR code payment transactions that can be completed via supported electronic payment platforms. Upon successful payment confirmation, the corresponding account balance is updated and synchronized with the RFID-based account management system.

Administrative functions were incorporated through the RFID master card. Once authenticated, administrators can load balance offline, view registered RFID cards, monitor registered user information, and reset or delete user cards as needed. These functions provide effective management and maintenance of the prepaid charging system.

After the hardware and software components were integrated, RFID key fobs were registered in the system database and linked to user accounts. Charging rates and charging durations were configured within the Android application according to the prepaid charging scheme. Functional testing was then conducted to verify RFID authentication, Bluetooth communication, account registration, balance management, payment processing, charging port selection, simultaneous charging capability, timer operation, charging control, and overall system performance.

The completed prototype was evaluated to determine whether all hardware and software components functioned correctly and whether the system successfully provided secure, portable, sustainable, and controlled phone-charging services for multiple users.

Table 2. Presents the charging rates implemented in the system.

Amount (₱)	**Charging Duration**
₱ 5	15 minutes
₱ 10	30 minutes
₱ 20	60 minutes

Testing and evaluation

Functional testing was conducted to evaluate the performance, reliability, and effectiveness of the developed RFID-Based Solar-Powered Portable Phone Charging Station with Bluetooth-Enabled Android Application and Prepaid Credit Management. The evaluation focused on the system's major hardware and software functions, including RFID authentication, Bluetooth communication, account registration, balance management, payment processing, charging port selection, charging control, timer operation, and simultaneous charging capability. The XY-3606 buck converter was also tested to verify stable voltage regulation from the power subsystem to the Arduino controller and charging outputs.

Registered and unregistered RFID key fobs were used to assess the effectiveness of the authentication and registration processes. Additional tests were performed to verify successful communication between the Android application and the Arduino microcontroller through the HC-05 Bluetooth module. The functionality of PIN authentication, balance loading, QR code payment processing, balance synchronization, and account management was also evaluated.

The charging subsystem was tested to verify charging port status monitoring, charging port selection, relay operation, timer accuracy, automatic charging termination, and mobile device charging capability. Simultaneous charging tests were conducted using two mobile devices connected to separate charging ports to determine whether independent charging sessions could operate concurrently without affecting system performance.

Offline charging functionality was also evaluated to determine whether users could continue accessing charging services without an internet connection, provided that sufficient account balance was available. The observed results were recorded and compared with the expected system behavior to assess the prototype's overall functionality, reliability, and suitability as a portable, sustainable, and multi-user charging solution.

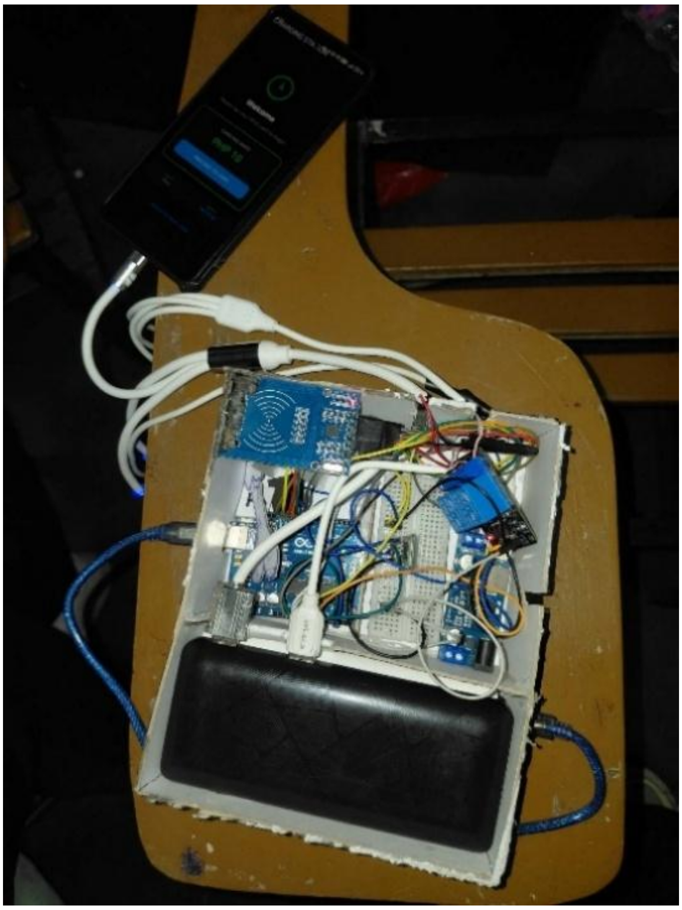


Figure 5. Functional Testing of the Developed Prototype Evaluating RFID Authentication, Account Registration, Balance Management, Payment Processing, Charging Port Selection, and Charging Control.

RESULTS AND DISCUSSION

This section presents the results of the functional testing conducted on the RFID-based Portable Phone Charging Station. The evaluation focused on the performance of the RFID authentication system, balance management features, timed charging mechanism, and overall charging functionality.

Testing procedure

Functional testing was conducted from May 15–20, 2026, at the Computer Engineering Laboratory of Eulogio "AMANG" Rodriguez Institute of Science and Technology (EARIST). The testing involved five researchers who performed repeated trials on the prototype using multiple Android smartphones equipped with Bluetooth connectivity. Each major function of the system was tested between 20 and 30 times under normal operating conditions.

The evaluation focused on RFID authentication, account registration, PIN verification, balance loading, QR payment generation, Bluetooth communication, charging control, timer operation, relay activation, and simultaneous charging capability. A trial was considered successful when the function produced the expected output without errors, delays, or system interruptions.

Functional testing results

A series of tests was conducted to determine whether the prototype operated as intended. The tests included RFID authentication, Balance Loading Using RFID Master Card, PIN authentication, account registration, balance management, payment processing, charging port selection, charging control, and simultaneous charging.

Success rates for each tested function were computed using the following formula:

Success Rate (%) = (Number of Successful Trials ÷ Total Number of Trials) × 100

This formula was used to determine the reliability of each system function during testing. A trial was considered successful when the tested feature produced the expected output without errors, delays, or interruptions. The calculated success rates were used to evaluate the effectiveness and operational performance of the developed RFID-Based Solar-Powered Portable Phone Charging Station.

Table 3. Functional Testing Results

Test Conducted	Number of Trials	Successful Trials	Success Rate (%)	Average Response Time (s)	Remarks
RFID Key Fob Registration	20	20	100%	Immediate	Successfully registered new RFID key fobs
RFID Authentication	30	30	100%	Immediate	Authorized users are recognized correctly
Bluetooth Communication	30	29	96.7%	1.0 s	One trial required reconnection
PIN authentication	30	29	96.7%	0.9 s	One incorrect PIN entry detected
Balance Viewing	30	30	100%	Immediate	Correct balance displayed in application

Master Card Balance Loading	20	20	100%	Immediate	Balance updated successfully
QR Code Payment Generation	20	20	100%	2.2 s	QR codes generated correctly
Digital Payment Processing	20	19	95.0%	8.4 s	One transaction was delayed due to a network issue
Balance Synchronization	20	20	100%	Immediate	Balance updated correctly after payment
Charging Port Status Display	30	30	100%	0.5 s	Port availability is displayed correctly
Charging Port Selection	30	30	100%	0.8 s	Users successfully selected available ports
Charging Duration Selection	30	30	100%	Immediate	Selected charging package accepted
Automatic Balance Deduction	30	30	100%	Immediate	Correct amount deducted from the account
Offline Charging Operation	30	30	100%	Immediate	Charging is available without an internet connection
Buck Converter Voltage Regulation	20	20	100%	Immediate	Stable 5V output maintained during operation
Relay 1 Operation	30	30	100%	0.2 s	Charging output activated and terminated correctly
Relay 2 Operation	30	30	100%	0.2 s	Charging output activated and terminated correctly
Independent Timer Operation	30	30	100%	±1 second accuracy	Timers operated independently for each charging port
Simultaneous Dual-Port Charging	30	30	100%	Immediate	Two devices are charged simultaneously without interruption
Phone Charging Functionality	30	30	100%	Immediate	Mobile devices charged successfully
Overall System Functionality	20	20	100%	2.0 s	The entire charging process was completed

					successfully

The results presented in Table 3 indicate that the developed system achieved a high level of functionality and reliability across all tested features. Most system functions recorded a 100% success rate, demonstrating consistent performance during repeated trials. Minor failures were observed only in Bluetooth communication, PIN authentication, and digital payment processing, which were primarily attributed to temporary connectivity issues and intentionally incorrect user inputs during testing.

Overall, the prototype achieved an average success rate of 99.2%, confirming that the RFID authentication system, Android application, prepaid credit management, charging control mechanism, and solar-powered charging subsystem operated as intended. These findings suggest that the developed system can provide a dependable and user-friendly charging service for public and educational environments.

Table 4. Summarizes the measured performance metrics of the developed system.

Category	**Metric**	**Measured Value**
RFID Performance	RFID Detection Range	2-4 cm
RFID Performance	Authentication Time	<1 s
Bluetooth Communication	Connection Time	1-3 s
Bluetooth Communication	Command Transmission Time	<1 s
Balance Management	Balance Synchronization Time	1-2 s
Payment Processing	Payment Confirmation Time	5-10 s
Charging Control	Number of Charging Ports	2
Charging Control	Simultaneous Users Supported	2 Users
Charging Control	Independent Timer Support	Yes
Charging Control	Relay Response Time	0.2 s
Charging Control	Timer Accuracy	±1 s
Charging Control	Port Status Monitoring	Available/Occupied
Charging Output	USB Output Voltage	5.0 V
Charging Output	Maximum Charging Current per Port	1-2 A
Charging Output	Charging Interface	3-in-1 USB Cable
Power System	Solar Panel Output Voltage	12 V
Power System	Power Source Configuration	Solar Panel + 2 Power Banks
Power Regulation	Buck Converter Input Voltage	12 V
Power Regulation	Buck Converter Output Voltage	5 V
Power Regulation	Voltage Regulation Accuracy	Stable Output

Table 4 summarizes the measured performance characteristics of the developed charging station. The results show that the RFID subsystem provided fast user authentication with an average response time of less than one second, while Bluetooth communication maintained stable command transmission between the Android application and the Arduino controller. Payment confirmation and balance synchronization were also completed within acceptable response times for practical operation.

Furthermore, the charging subsystem successfully supported two simultaneous users through independently controlled charging ports while maintaining accurate timer operation and stable power delivery. The measured output voltage of 5.0 V and charging current of 1–2 A demonstrate that the system provides adequate charging performance for commonly used mobile devices.

Figure 6. The Android application interface during (a) RFID authentication and (b) Rate Selection

DISCUSSION

The functional testing results demonstrated that the developed RFID-Based Solar-Powered Portable Phone Charging Station successfully performed its intended functions. The prototype achieved reliable RFID authentication, Bluetooth communication, account registration, balance management, payment processing, charging control, and phone charging operations. Most system functions achieved 100% success, while Bluetooth communication and digital payment processing recorded success rates above 95%, indicating a high level of reliability during testing.

The RFID subsystem effectively identified registered RFID key fobs, detected unregistered RFID key fobs for new user registration, and recognized the RFID master card for administrative operations. The average authentication time remained below one second, allowing users to access charging services quickly and conveniently. The registration process successfully enabled new users to create PIN-protected accounts linked to their RFID identifiers.

The Android application significantly improved user interaction by providing a centralized interface for account registration, PIN authentication, balance viewing, balance reloading, charging rate selection, charging control, and administrative functions. Bluetooth communication between the Android application and the Arduino microcontroller remained stable across most testing scenarios, with only minor reconnection issues observed in a few trials.

The prepaid credit management system successfully supported both online and offline balance loading methods. Online balance reloading was accomplished via PayMongo-generated QR codes, while offline reloading was performed via administrator authorization using the RFID master card. Balance synchronization and account updates were completed successfully during testing, ensuring accurate account management and transaction processing.

The charging subsystem effectively implemented the predefined charging packages of 15, 30, and 60 minutes. Automatic balance deduction was correctly applied to all successful charging transactions, and both relay channels reliably activated and deactivated their corresponding charging outputs based on the selected charging duration. Timer operation remained accurate within an acceptable tolerance of approximately one second.

The findings of the present study are consistent with the work of Praveena et al. (2018), who demonstrated the feasibility of an RFID-based mobile charging system utilizing Arduino-based control and solar power integration. Similar to their findings, the developed prototype successfully implemented RFID authentication and controlled charging operations. However, the present study extends the functionality of previous systems by integrating a Bluetooth-enabled Android application, PIN-based user authentication, prepaid credit management, QR-based digital payment processing, and dual charging ports with independent timer control. These additional features improve user convenience, account security, and charging accessibility while supporting multiple users simultaneously.

Furthermore, the results support the observations of Munoz-Ausecha et al. (2021), who emphasized the reliability and effectiveness of RFID technology in authentication and access-control applications. The 100% RFID authentication success rate obtained during testing indicates that RFID technology remains a suitable solution for secure user identification in prepaid charging systems. The successful implementation of Bluetooth communication between the Android application and the Arduino controller also aligns with previous studies that highlight the effectiveness of wireless communication technologies in embedded and Internet of Things (IoT) applications.

The system also demonstrated effective offline charging capability. Since user account information and balance records were primarily maintained in the Android application's local database and synchronized with the Arduino controller, users could access charging services without an active internet connection, provided they had sufficient account balance. This feature improved system accessibility and reliability in areas with limited network connectivity.

The solar-assisted power system contributed to the prototype's sustainability by using a 12V solar panel, power banks, and an XY-3606 buck converter to support system operation. The integration of renewable energy components enhanced portability while maintaining stable power delivery for both the control circuitry and charging outputs.

Overall, the results indicate that the developed prototype successfully achieved its objectives of providing a portable, secure, sustainable, and user-friendly charging station. The integration of RFID authentication, Bluetooth-enabled Android application control, prepaid credit management, online and offline balance loading, dual charging ports, and simultaneous charging capability demonstrates the system's effectiveness as a practical charging solution for schools, transportation terminals, public facilities, and other community environments.

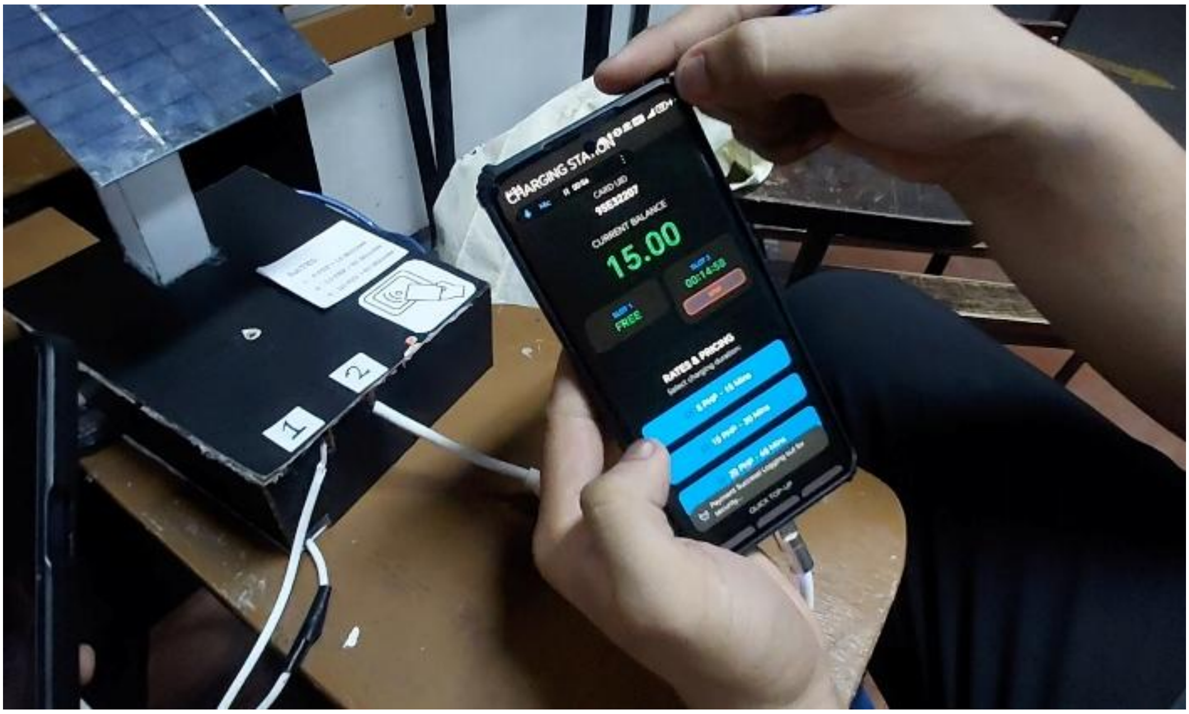


Figure 3. Active Charging Session Showing Independent Timer Operation and Relay-Controlled Power Delivery Through the Selected Charging Port.

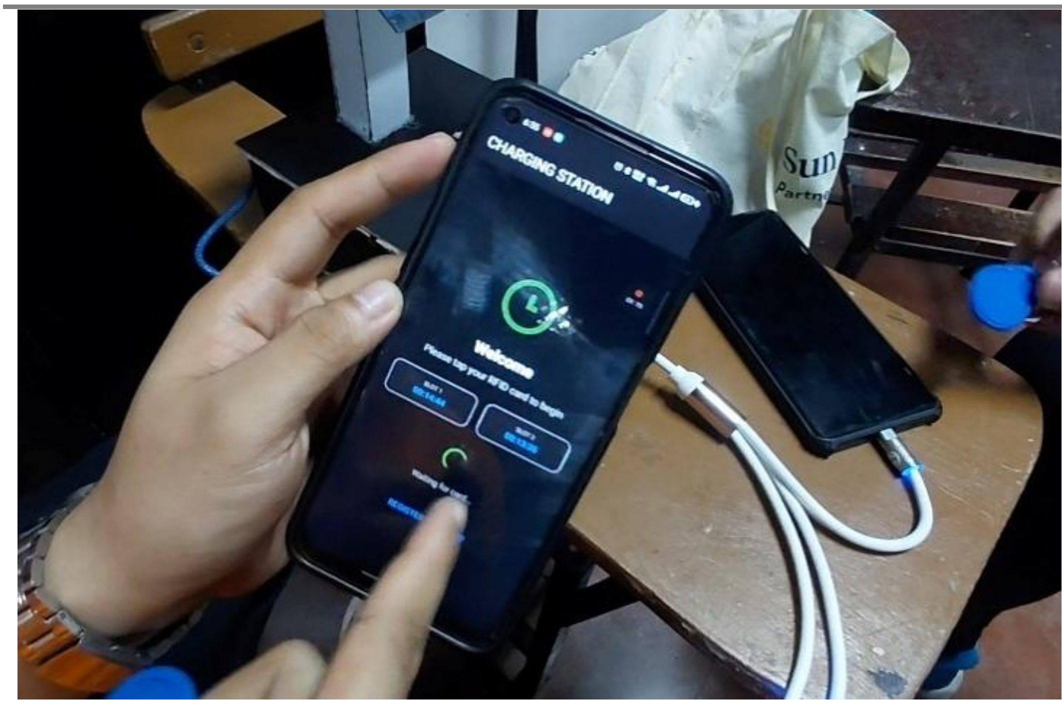


Figure 4. Final Prototype Demonstrating Simultaneous Charging Operation Through Two Independently Controlled Charging Ports.

Limitations of the study

The developed prototype was evaluated primarily through functional testing under controlled laboratory conditions. Long-term field testing in public environments was not conducted. User acceptance, customer satisfaction, and economic feasibility were not evaluated and may be investigated in future studies. The system's charging capacity was limited by the available power bank storage and the solar panel's output. Charging performance may vary depending on solar irradiance and weather conditions, which affect the charging rate of the power banks. Additionally, the study evaluated only two simultaneous charging ports, which may not represent larger-scale deployment scenarios.

CONCLUSION AND RECOMMENDATIONS

This study successfully developed an RFID-Based Solar-Powered Portable Phone Charging Station with Bluetooth-Enabled Android Application and prepaid credit management. The system integrated an Arduino Uno R3 microcontroller, an MFRC522 RFID reader, RFID key fobs, an RFID master card, an HC-05 Bluetooth module, a dual-channel relay module, EEPROM storage, an XY-3606 buck converter, a solar panel, two power banks, a 1-female-to-2-male USB splitter, and two 3-in-1 USB charging cables to provide a portable and controlled phone-charging solution.

The developed prototype successfully implemented RFID-based user authentication, account registration, PIN verification, prepaid credit management, online and offline balance loading, Bluetooth communication, charging port selection, and automated charging control. The Android application served as the primary user interface, allowing users to manage charging transactions, account balances, and payment operations without requiring direct interaction with hardware controls.

Functional testing demonstrated that the system reliably performed its intended operations, including RFID authentication, balance management, digital payment processing, charging control, and phone charging functionality. The implementation of dual charging ports enabled two users to charge their mobile devices simultaneously while maintaining independent charging sessions and timer operations. The system also supported offline charging using previously stored balances and used a solar-assisted power subsystem to improve portability.

Based on the test results, the developed prototype met its objectives and demonstrated its potential as a secure, user-friendly, sustainable, and practical charging solution for schools, transportation terminals, public facilities, and other community environments that require controlled charging services.

Recommendations

Based on the study's findings, several improvements may be considered for the system's future development. Additional charging ports may be incorporated to accommodate more users simultaneously and further improve service availability. The power subsystem may also be enhanced by using higher-capacity energy storage and solar components to support longer operating periods.

Additional security and account management features may be implemented, such as transaction history, user activity logs, and cloud-based data synchronization. Future versions of the Android application may also include real-time monitoring, notification features, and enhanced reporting functions for administrators.

Future researchers may further improve the system by integrating additional electronic payment platforms, expanding compatibility with other mobile devices, and evaluating the system in larger public environments to assess its long-term performance, scalability, and user acceptance.

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