IOT-Based Smart Battery Charging and Swapping Station for Electric Two-Wheelers

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Abstract—Electric two-wheelers are spreading quickly, but plug-in charging keeps a vehicle idle for a long time and leaves riders unsure whether a charged battery will be available when they reach a station. This paper describes the design and ongoing prototype development of an Internet-of-Things (IoT) enabled battery swapping station in which a discharged battery is exchanged for a charged one rather than recharged in the vehicle. An ESP32 microcontroller supervises the station, reading battery voltage, current and state of charge, identifying users through an RFID reader and a keypad, and driving servo-operated locking mechanisms. Station data are synchronized through Firebase and shown to riders in a ReactJS web application that displays live battery availability and lets a rider reserve a charged battery before arriving. The prototype uses an 11.2 V, 2200 mAh lithium-polymer pack with a battery-management module and a DC-DC converter. This paper reports the architecture, component selection, operating workflow and hardware and software progress achieved so far; quantitative test results will follow once integration testing is complete.

Keywords—battery swapping, electric vehicle, Internet of Things, ESP32, Firebase, RFID, battery management, battery reservation.

I. INTRODUCTION

Electrified road transport is gaining ground in India, and electric two-wheelers lead that growth because they are affordable to run and well suited to short urban trips. The weak point is energy replenishment. Recharging a traction battery from a socket takes hours, so a vehicle that needs to be on the road must either wait or be left plugged in for a long period. For delivery riders and shared-mobility operators, where every idle hour costs money, this delay is a serious obstacle.

Battery swapping addresses the problem differently. Instead of charging the battery inside the vehicle, the rider hands over a depleted pack and receives a charged one, so the exchange takes about as long as buying fuel. The depleted pack is then charged at the station, away from the rider, at whatever pace suits the battery and the electricity supply. Because ownership of the battery can be separated from ownership of the vehicle, swapping also lowers the purchase price of the vehicle; this idea is the basis of the draft national framework published by NITI Aayog for two- and three-wheelers [5].

A swapping station is only convenient if riders can trust it. They need to know which batteries are ready, how healthy they are, and whether one can be held for them; the operator needs to know who has taken which battery and to prevent unauthorized removal. These requirements are information problems as much as electrical ones, which makes IoT technology a natural fit. This paper presents a station that joins the electrical side (charging, protection, locking) with the information side (monitoring, cloud synchronization, reservation and access control) in a low-cost prototype aimed at two-wheelers.

II. RELATED WORK

Research on swapping stations has so far concentrated on operation and planning. Cui et al. reviewed the mathematical optimization methods used to run swapping and charging stations, grouping them by objective, constraint and ownership model, and pointed to dynamic pricing, battery-to-grid scheduling and user-behaviour scheduling as areas that remain open [1]. Kumbhar and Kalkhambkar surveyed coordinated operation of swapping and charging facilities

and listed siting, station coordination, grid integration, battery ownership and battery management among the main challenges standing in the way of wider deployment [2].

Work that links swapping stations with identification and information technology is less common. Xue et al. described an RFID and context-awareness based management system for charging and swapping stations that supports appointment booking, entry and exit control, allocation of service positions and resource dispatch, and reported gains in operating efficiency and automation [3]. On the battery side, Insia et al. built an IoT-based battery management and monitoring system for electric vehicles that warns users in real time about battery condition, motivated by the shortened life and fire risk that follow from overcharging lithium-ion cells [4].

Earlier reviews fill in the wider picture. Ahmad et al. compared swapping with conventional charging, described station infrastructure and operating techniques, and set out the main obstacles to deployment [6]. Zhan et al. examined where stations should be placed and how large they should be, how they should be scheduled and whether they are economically worthwhile, and stressed the need to coordinate station decisions with grid conditions and vehicle routing [7]. On the operating side, Mahoor et al. formulated a least-cost scheduling model for a station that faces random requests for charged batteries, using the stored battery inventory to shift load and sell energy back while accounting for battery wear [8].

Two further strands support the sensing and communication parts of this project. Reviews of lithium-ion battery management emphasize that state of charge indicates the energy remaining in a battery and that its accurate estimation underpins safe charging strategies and long battery life, although the electrochemical complexity of the cells still limits accuracy [9]. For the cloud link, Hasib and Akib showed that an ESP32 working with the Firebase Realtime Database can keep sensor readings and remote commands synchronized with web clients at low cost, which supports using the same combination for station monitoring [10].

At policy level, the draft Indian framework promotes a battery-as-a-service model, calls for published technical and operational characteristics so that batteries from different makers can be interchanged, and proposes a unique identification number so that each battery can be tracked through its life [5]. These provisions make per-battery identification and monitoring, as implemented in the present work, directly relevant.

III. RESEARCH GAP AND OBJECTIVES

A. Research gap

The studies above show that station-level optimization, battery monitoring and RFID-based management have each been addressed, but usually separately. A compact system that, in one design, measures the state of every stored battery, makes that information visible to riders as live availability, allows a charged battery to be reserved in advance, and secures the physical exchange with authentication and electronic locking is not commonly reported, particularly at a cost and scale appropriate for two-wheelers. The present work targets that combination.

B. Objectives

- Build an IoT-based battery swapping station that shortens the time needed to put an electric two-wheeler back on the road.
- Monitor battery voltage, current, charging status and availability in real time.
- Develop a ReactJS web application that shows live battery availability to riders.
- Provide RFID-secured access together with advance reservation of a charged battery.

IV. SYSTEM ARCHITECTURE

A. Overview

Figure 1 shows the block diagram of the station. The ESP32 microcontroller sits at the center and acts as the swap controller. Its inputs are the RFID scanner and keypad (user identification), the fuel-gauge module (battery state of charge) and the voltage and current sensors. Its outputs are the 16×2 LCD (status and instructions), the buzzer (audible alerts) and the servo motors that operate the gate and slot locks. The controller also logs each swap and exchanges data with the cloud over its built-in Wi-Fi link. Depleted batteries are placed in slot units that are connected to the charging section, which charges them under the protection of a battery-management system (BMS).

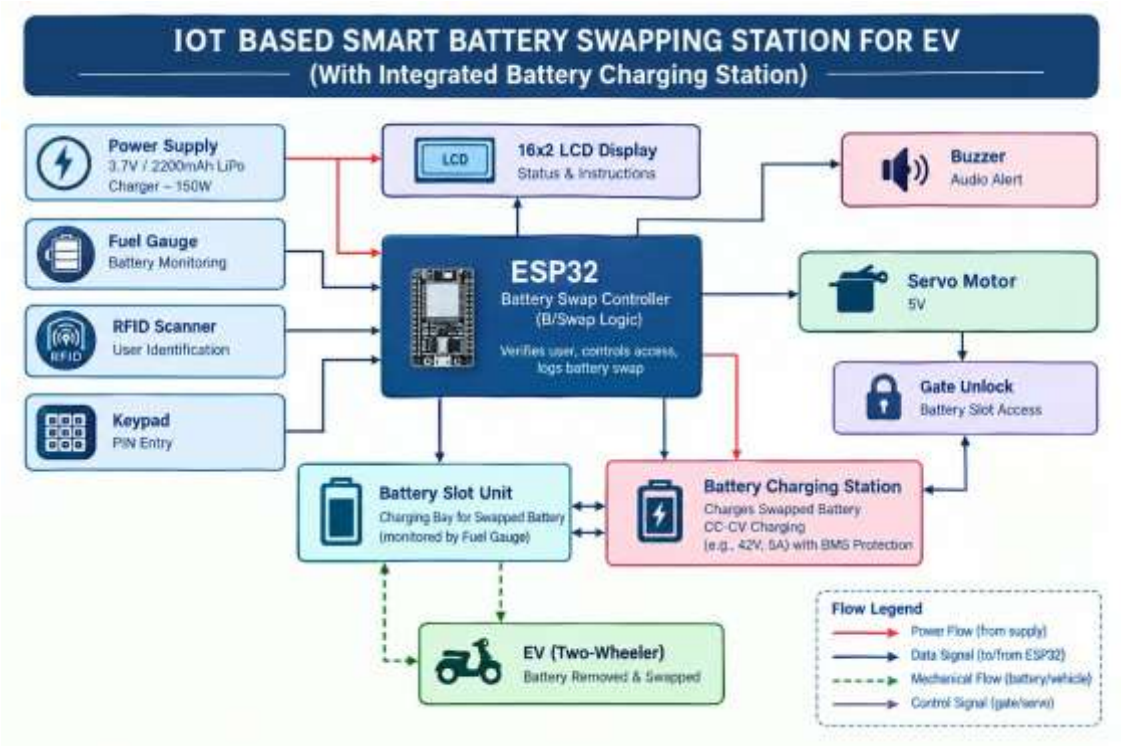


Fig. 1. Block diagram of the proposed IoT-based battery swapping station with integrated charging.

B. Hardware

The components chosen for the prototype and their roles are listed in Table I. The ratings are those specified for the selected parts. The energy source is an 11.2 V, 2200 mAh lithium-polymer battery; a BMS board and a DC-DC buck converter are fitted to the pack, and a relay module switches the charging path.

TABLE I. COMPONENTS OF THE PROTOTYPE

No.	Component	Function	Rating
1	ESP32	Main controller with Wi-Fi and Bluetooth	3.3 V logic
2	Li-Po battery	Rechargeable energy storage	11.2 V, 2200 mAh
3	RFID reader (RC522)	User identification and authentication	13.56 MHz, 3.3 V
4	Voltage sensor	Measures battery voltage	5 A
5	Current sensor (ACS712)	Measures charging and discharging current	20 A
6	Fuel gauge	Battery state-of-charge monitoring	5 V
7	16×2 LCD	Displays battery and station status	5 V
8	Servo motor (SG90)	Operates the locking mechanism	5 V
9	Electronic lock	Secures battery access	12 V
10	4×4 keypad	User input (PIN entry)	3 V
11	Buzzer	Audible indication and alerts	3 V
12	Power supply	Supplies the station	230 V (mains)
13	BMS module, DC-DC buck converter, relay module	Cell protection, voltage conversion and charge-path switching (seen in the assembled prototype)	As per module

C. Software and cloud

The ESP32 firmware reads the sensors, applies the access and swap logic, and writes battery and slot data to Firebase, whose real-time database keeps every connected client synchronized without polling. Each slot is represented by a record holding its RFID tag, charge percentage, PIN and a booking flag, where 0 indicates that the battery is available and 1 indicates that it is reserved. The rider-facing application is written in ReactJS and subscribes to these records, so

a change at the station appears on the rider's screen almost immediately [10]. State of charge is read from the fuel-gauge module, because it decides when a returned battery may be offered again [9].

V. METHODOLOGY AND OPERATING WORKFLOW

The method followed in the project, from the rider's first look at the application to the return of a battery to the pool of available packs, is shown as a flowchart in Fig. 2 and described step by step below.

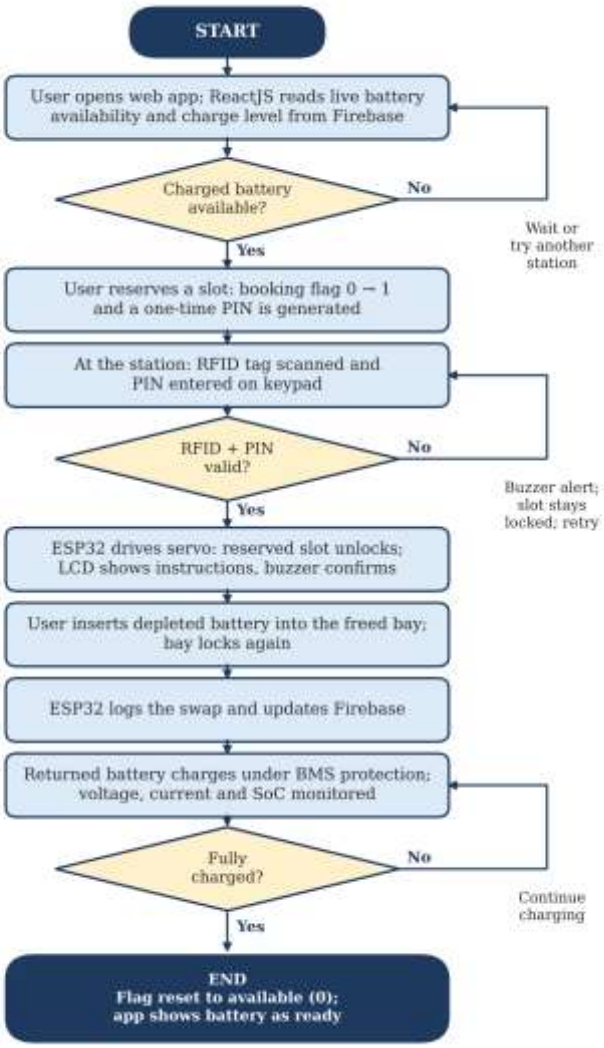


Fig. 2. Flowchart of the methodology: reservation, authentication, swapping and recharging.

The intended sequence of a swap is as follows.

- The rider opens the web application and sees which slots hold a battery that is ready, together with its charge level.
- The rider reserves a charged battery. The booking flag of that slot is set and a one-time PIN is generated for the rider.
- At the station the rider identifies themselves with the RFID tag and enters the PIN on the keypad. The ESP32 checks both against the stored record.
- When the check succeeds, the servo-driven lock opens the reserved slot, the LCD shows instructions and the buzzer confirms the action. A failed check keeps the slot locked and raises an alert.
- The rider inserts the depleted battery into the freed bay. The bay locks again, the swap is logged, and the returned battery is charged under BMS protection until it is full, after which its flag returns to available.

Locking a returned battery until it has been recharged prevents a partly charged pack from being offered to the next rider and keeps the availability shown in the application trustworthy.

VI. IMPLEMENTATION PROGRESS

Since the first project seminar the work has moved from design to a physical prototype. The overall system architecture and station layout have been completed, components have been selected, and the monitoring scheme for voltage, current, charge state and availability has been defined. A working mechanical assembly has been built with a main control board, relay module, power-supply section, LCD, three servo-driven locking arms and a battery-swapping mechanism (Fig. 3). A battery pack fitted with a BMS module, battery connector and DC-DC buck converter has also been assembled.

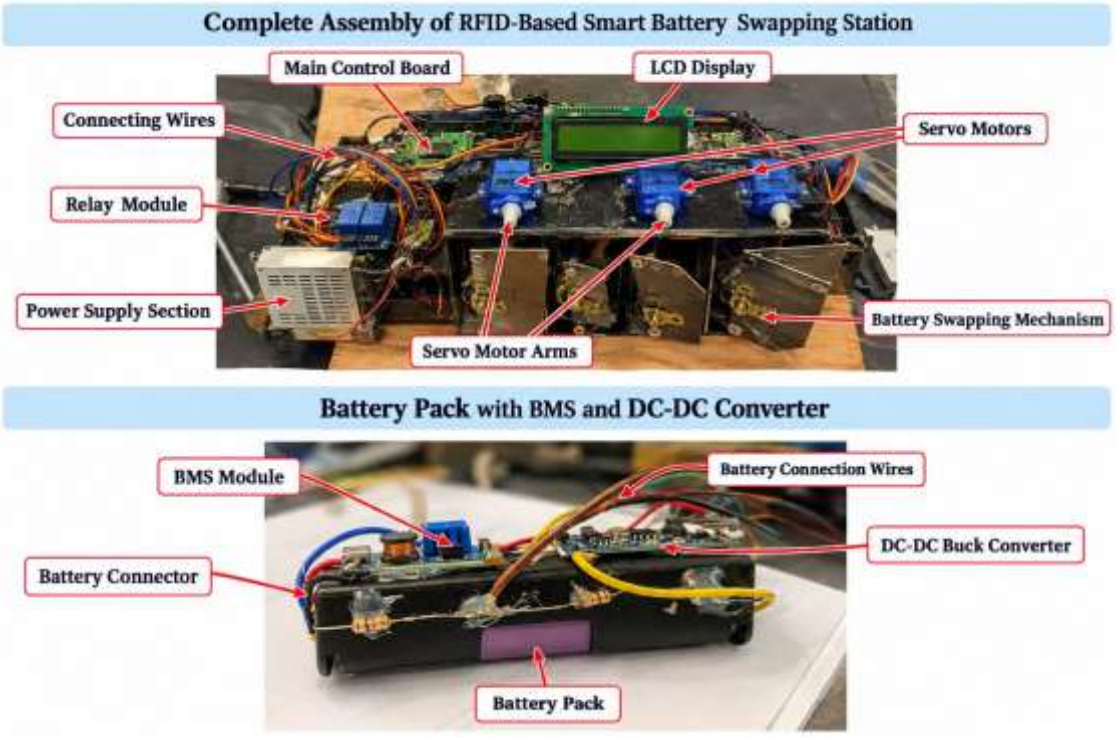


Fig. 3. Assembled RFID-based swapping station prototype (top) and battery pack with BMS module and DC-DC converter (bottom).

On the software side, the ReactJS web application has been developed with a station view showing the battery bays, charge level and booking state, a slot-booking function that issues a PIN, an on-site code-entry terminal that verifies the PIN to release a battery, and a map of stations (Fig. 4). The interface values visible in Fig. 4 are demonstration data used while developing the screens and should not be read as measurements from the hardware. Integration of the hardware with the cloud and application, and prototype testing, are currently in progress.

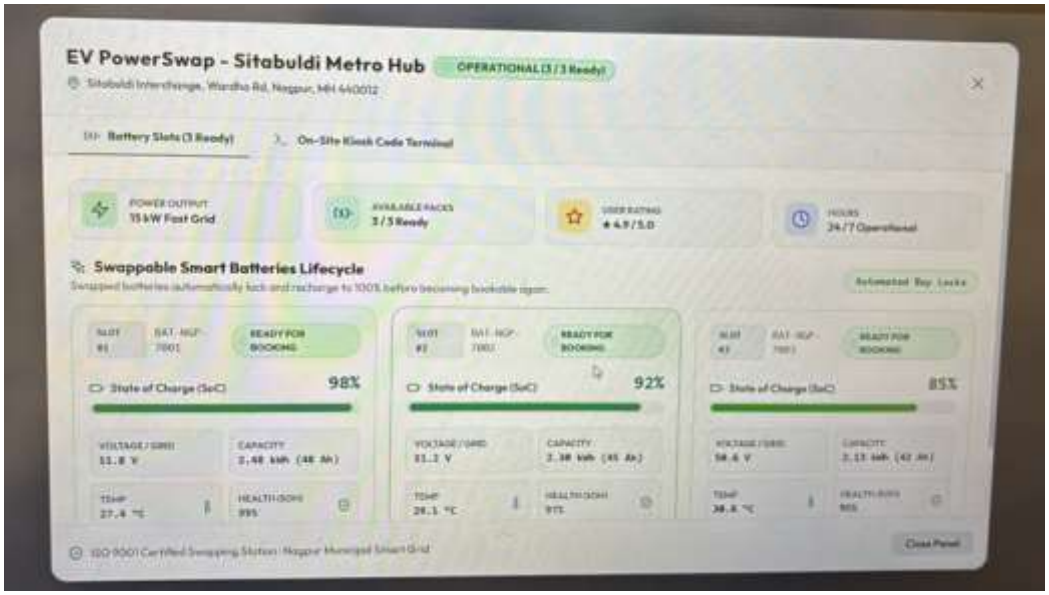


Fig. 4. Station screen of the web application, showing battery slots with charge level and booking status (demonstration data).

VII. EXPECTED BENEFITS AND APPLICATIONS

A. Expected benefits

- Shorter waiting time, because a charged battery replaces the depleted one instead of the rider waiting for a recharge.
- Real-time visibility of battery voltage, current, charge state and availability.
- Advance reservation, so a rider can secure a charged battery before reaching the station.
- Secured access through RFID, PIN verification and electronic locking.
- A low-cost, scalable design suited to electric two-wheelers, with better utilization of the stored batteries.

B. Applications

The concept applies wherever vehicle downtime must be kept small: electric scooters and motorcycles in cities, delivery and logistics fleets, e-rickshaws and shared-mobility services, commercial fleets, dedicated swapping facilities in parking areas or at fuel-station-style sites, and smart-city charging infrastructure that combines monitoring with reservation.

VIII. CONCLUSION AND FUTURE WORK

This paper has presented an IoT-based battery charging and swapping station that unites battery monitoring, cloud synchronization, a web application with live availability and reservation, and RFID and PIN-based secured access around a single ESP32 controller. A hardware prototype and the web application have been built, and system integration and testing are under way. No performance figures are claimed here; the planned tests will measure swap time, accuracy of the voltage, current and charge-state readings, reservation and unlocking reliability, and charging behaviour under BMS protection, and these results will be reported when testing is complete. Further work could extend the station to more slots, add battery-health estimation and demand forecasting, and align the battery identification with the interoperability and tracking provisions of the national framework [5].

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