Design of an Intelligent Connected Electric Bicycle Charging Platform

Jiaxin Chen [1, a], Yuyang Hu [1, b], Zengjia Huang [1, c], and Man Wang [1, d, *]

[1] Wuhan Business University, MA 430056, China;

[a] 2826785928@qq.com, [b] 349151882@qq.com, [c] 1551727098@qq.com, [d] 309470466@qq.com

Abstract. To address safety hazards such as overcharging, overheating, electrical faults, and smoke leakage during electric bicycle charging, this study designs an STM32-based electric bicycle intelligent charging platform. The system integrates high-precision sensors and BeiDou/GPS dual-mode positioning, utilizes FreeRTOS for millisecond-level anomaly detection and power-off protection, and supports remote monitoring via a mobile app. The platform supports remote monitoring via an app, offering high stability and intelligence, providing a reliable solution for charging safety and sustainable urban mobility in smart cities.

Keywords: Electric bicycle charging safety; STM32; high-precision sensors; BeiDou/GPS dual-mode positioning; remote monitoring.

1. Introduction

In recent years, electric bicycles have become a vital tool for urban short-distance travel due to their affordability and convenience. According to data from China's Ministry of Industry and Information Technology, the number of electric bicycles in China exceeded 300 million by the end of 2022, with a compound annual growth rate of 15.2% over the past three years[1]. However, with their widespread adoption, charging safety concerns have intensified. Statistics from the Fire and Rescue Bureau of the Ministry of Emergency Management indicate that over 14,000 electric bicycle fire incidents occurred in 2021, with more than 80% related to charging processes[2]. Existing charging infrastructure suffers from significant technical limitations. At the perception layer, 78% of charging piles still rely on single electrical parameter monitoring, lacking multi-sensor fusion capabilities[3]. At the control layer, traditional polling detection mechanisms struggle to respond to millisecond-level short-circuit faults[4]. At the application level, only 12% of systems possess IoT-based remote management capabilities, with fault handling largely relying on manual intervention[5].

To address the aforementioned challenges, this study develops an IoT-based smart charging safety system. Its innovations include: integration of voltage, current, temperature, and smoke sensors to enable data fusion and improve detection accuracy; the control layer uses the STM32F103C8T6 microcontroller with the FreeRTOS real-time operating system to enhance fault handling efficiency; the application layer leverages the Alibaba Cloud IoT platform to build a big data analytics system, coupled with a user app to establish an intelligent maintenance network for charging stations, boosting remote fault handling efficiency by over 80%. This system provides reliable charging safety assurance and offers an efficient, intelligent charging solution for electric bicycle users.

2. System hardware design

The hardware architecture centers on the STM32F103C8T6 microcontroller, adopting a modular design that integrates sensors, communication units, power supplies, and actuators, as illustrated in Figure 1.

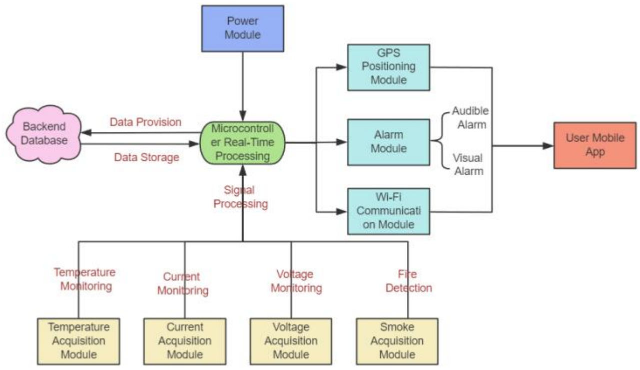

Fig. 1 System Framework

2.1 Sensor Module

The sensor module is the core component of the intelligent charging platform, responsible for real-time monitoring of critical parameters to ensure charging safety and efficiency.

To address overheating risks during charging, the system employs the DS18B20 digital temperature sensor[6], which operates within a range of -55° C to 125° C with an accuracy of ±0.5° C. Its direct digital output eliminates analog-to-digital conversion, simplifying data processing. When temperatures exceed preset thresholds, the system automatically triggers a power cutoff to prevent equipment damage or fire hazards.

To ensure stable voltage and current during the charging process, the system utilizes the IM1281B module for voltage and current measurement. This module offers high-precision measurement capabilities, with voltage accuracy of ±0.1% and current accuracy of ±0.2%. The IM1281B can simultaneously detect multiple voltage and current signals and is highly resistant to interference[7]. Using this module, the system can continuously monitor the charging station's output current and the voltage at the power input, converting these values into digital signals for the control system, thereby enabling efficient, safe, and intelligent charging services.

To prevent fire accidents, the MQ-2 semiconductor gas sensor is integrated for smoke detection. It detects combustible gases within a range of 100 – 10,000 ppm and outputs digital signals via a comparator circuit. When smoke concentrations exceed thresholds, the system immediately triggers alarms and emergency protocols.

The collaborative operation of these sensors ensures comprehensive monitoring of charging parameters, enhancing both safety and stability.

2.2 Positioning and Communication Module

The system integrates GPS positioning and WiFi communication technologies to establish an efficient remote management network. The GPS module enables precise location identification for user navigation and geofencing via the app. The ESP8266 WiFi module, configured in STA mode, transmits sensor data to the Alibaba Cloud IoT platform using the MQTT protocol, ensuring stable interaction between charging piles, cloud servers, and users.

2.3 Alarm and Execution Unit

The system employs a multi-level safety protection mechanism, integrating audible and visual alarms with power control to ensure a rapid response in the event of anomalies.The alarm module includes a buzzer and LED lights to alert users during anomalies. The power control unit uses a high-reliability relay circuit to cut off power within 50 ms when critical thresholds are breached, effectively mitigating risks.

$$c_2 = a_2 + b_2. \quad (1)$$

3. System software design

The software architecture comprises embedded control programs and a user app, designed with a layered structure.

3.1 Embedded Control Program

The embedded control program, developed on FreeRTOS (Free Real-Time Operating System), manages data acquisition, processing, and communication through multi-task scheduling[8]. Key tasks include periodic collection of temperature, current, voltage, smoke concentration, and GPS data; data filtering and threshold comparison; and immediate power cutoff and alarm triggering upon anomaly detection. Data is uploaded to the cloud via MQTT in JSON format, as shown in Figure 2.

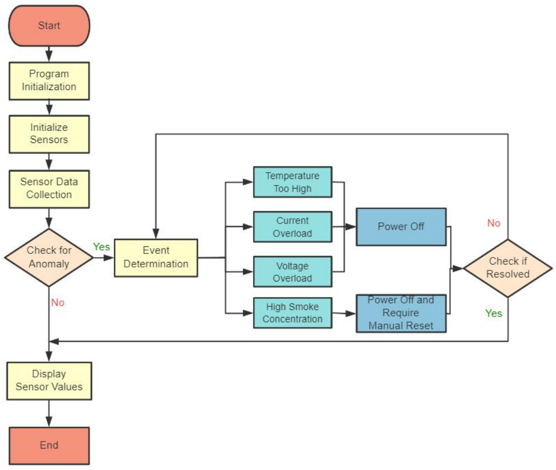

Fig. 2 Software Workflow

3.2 User App Development

The app, developed using Android Studio (backend: Spring Boot + MySQL), provides real-time charging status monitoring, parameter threshold customization, and GPS-based navigation. Users can remotely control charging piles and receive alerts via the app interface, illustrated in Figure 3.

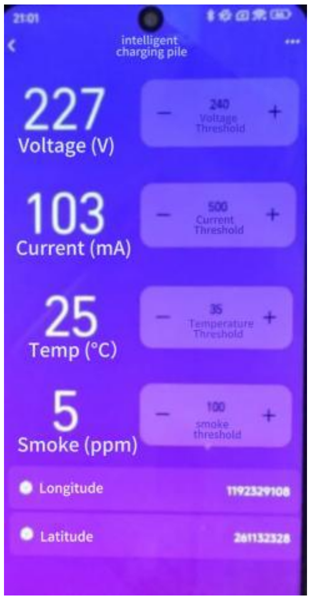

Fig. 3 App Interface

4. Testing and analysis

To validate the functionality, reliability, and safety of the public electric bicycle charging platform, the system was tested to ensure it can effectively monitor various parameters during the charging process and take appropriate protective measures in the event of anomalies. The tests assess the system's measurement accuracy, response time, and fault handling capabilities, ensuring it meets user needs and guarantees the safety of the charging process.

The hardware setup was powered and tested, showing normal operation and accurate sensor data. The monitoring interface is shown in Figure 4.

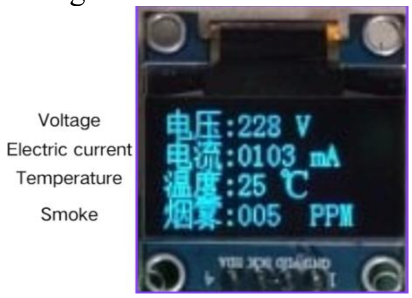

Fig. 4 Monitoring data

First, functionality testing was conducted to verify the power cutoff and alarm mechanisms under abnormal conditions. The thresholds were set as follows: voltage threshold = 240V, current threshold = 120mA, temperature threshold = 35° C, and smoke concentration threshold = 100PPM. After configuring the thresholds, the power supply was activated. Figure 5 shows the charging pile operating normally, with the LED next to the relay illuminated.

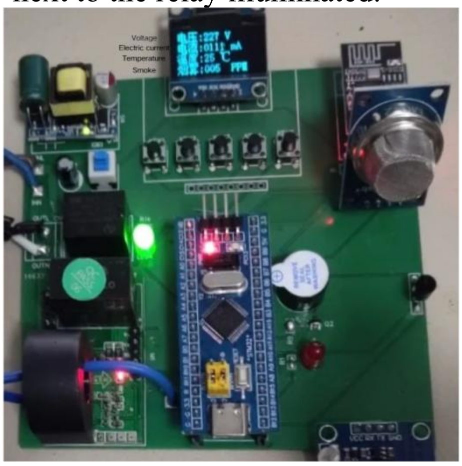

Fig. 5 Normal Operation

When an abnormal state occurred, the system cut off power via the relay to ensure safety. Figure 6 illustrates the charging pile during a temperature anomaly (54 ℃ > 35 ℃), where the relay disconnects power and the LED extinguishes.

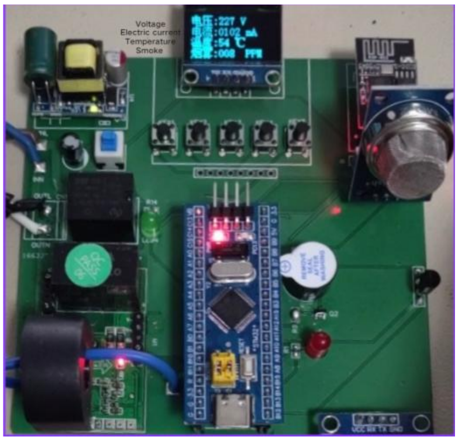

Fig. 6 Temperature Anomaly

Next, data accuracy testing was performed for the smart charging pile. Sensor values were recorded every minute, as shown in Table 1.

Table 1. Sensor value acquisition table

Test Number	Voltage (V)	Current (mA)	Temperature (℃)	Smoke concentration（ppm）
1	228	103	25	5
2	227	102	21	8
3	227	105	26	7
4	230	106	28	5
5	225	101	24	6
6	230	110	27	5
7	229	108	29	4
8	231	107	30	7
9	232	109	26	6
10	233	111	28	4

Taking voltage as an example, let the single measurement values be U1, U2,... Un, where U is the average of n measurements, and σ is the mean absolute deviation[9].

$$\sigma = {\sum |U_i - U|} \Big/ {\sum_{i=1}^{n} U_i} \tag{1}$$

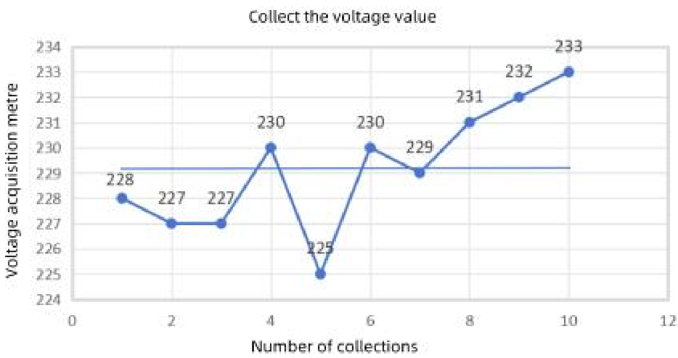

Fig. 7 Voltage Error Analysis Results

Analysis of Table 1 and Figure 7 shows that the average voltage measured was 229.2V, with a relative error of 0.873%. The current, temperature, and smoke concentration exhibited relative errors of 0.2637%, 0.819%, and 0.521‰, respectively. Traditional systems typically have error ranges of ±1% to ±5%[10]. This demonstrates the high stability and precision of the electric bicycle public charging platform.

The testing confirmed that the platform excels in functionality, measurement accuracy, and anomaly-handling. It enables real-time monitoring of charging parameters to ensure safety, providing a reliable solution for electric bicycle charging management.

5. Summary

This system integrates multiple sensor modules with IoT technology, successfully building an efficient, intelligent, and secure charging platform for electric vehicle charging stations. Real-time monitoring, remote app control, and rapid anomaly response significantly enhance user experience and safety. The platform's high precision and stability provide a reliable solution for electric bicycle charging management. Future advancements will further expand its role in promoting green mobility and smart city development[11].

Acknowledgment

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