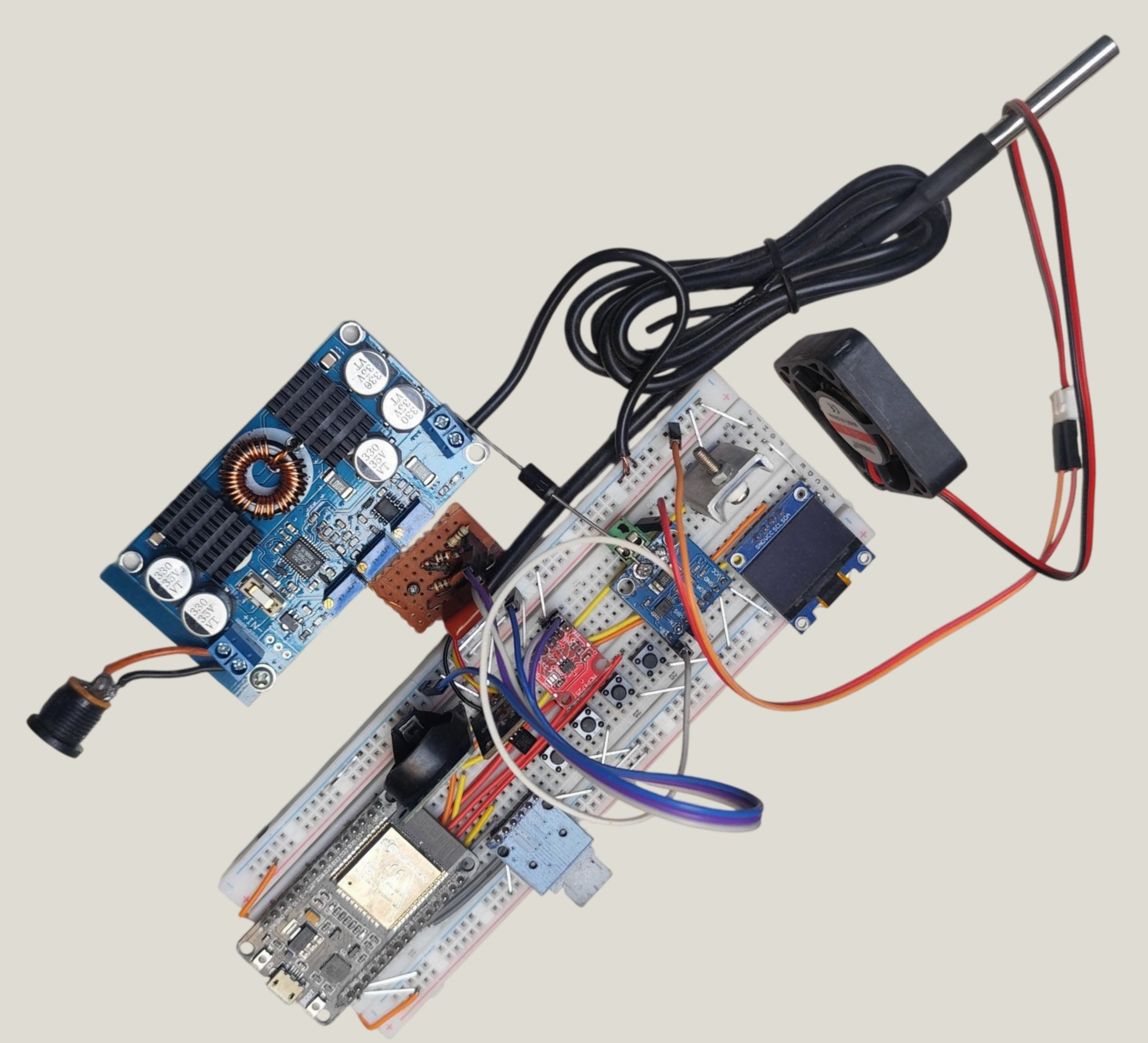


Design and Implementation of an Adaptive Smart Battery Charging and Testing Platform with PI-Controlled Regulation

“Traditional chargers follow fixed rules. Our system adapts to battery condition in real time. From static charging to intelligent battery-aware power management.”



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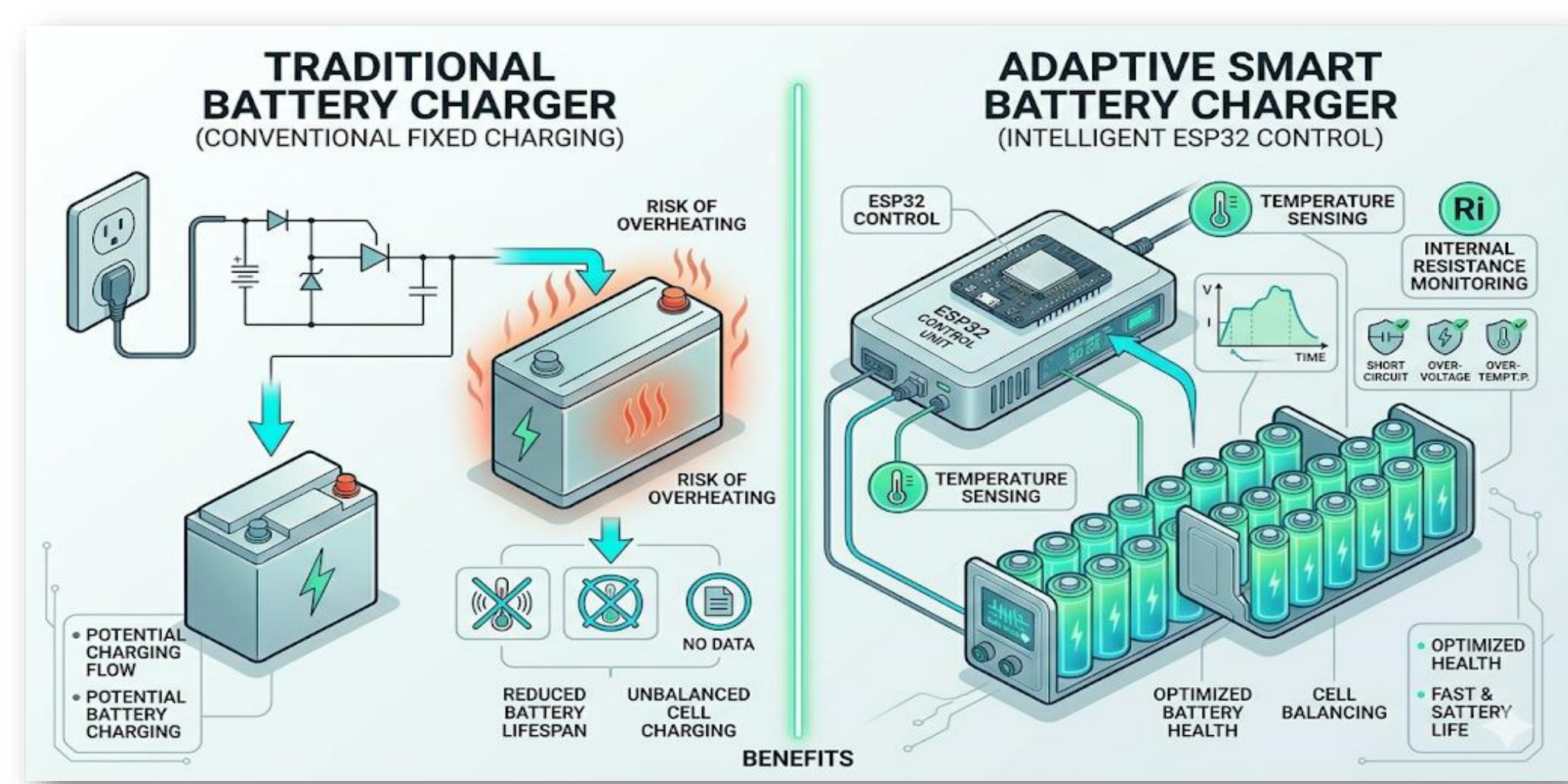
AFFILIATIONS

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INTRODUCTION

Modern batteries require safe and optimized charging to improve performance and lifespan. However, most conventional chargers use fixed charging methods without considering battery condition, temperature, or health status.

This project presents an adaptive smart battery charging and testing platform that monitors battery behavior in real time and adjusts charging conditions automatically using PI-controlled voltage regulation.



Problem Statement

Different battery chemistries and battery conditions require different charging behavior. Fixed charging methods may reduce battery lifespan, increase heat generation, and create safety risks.

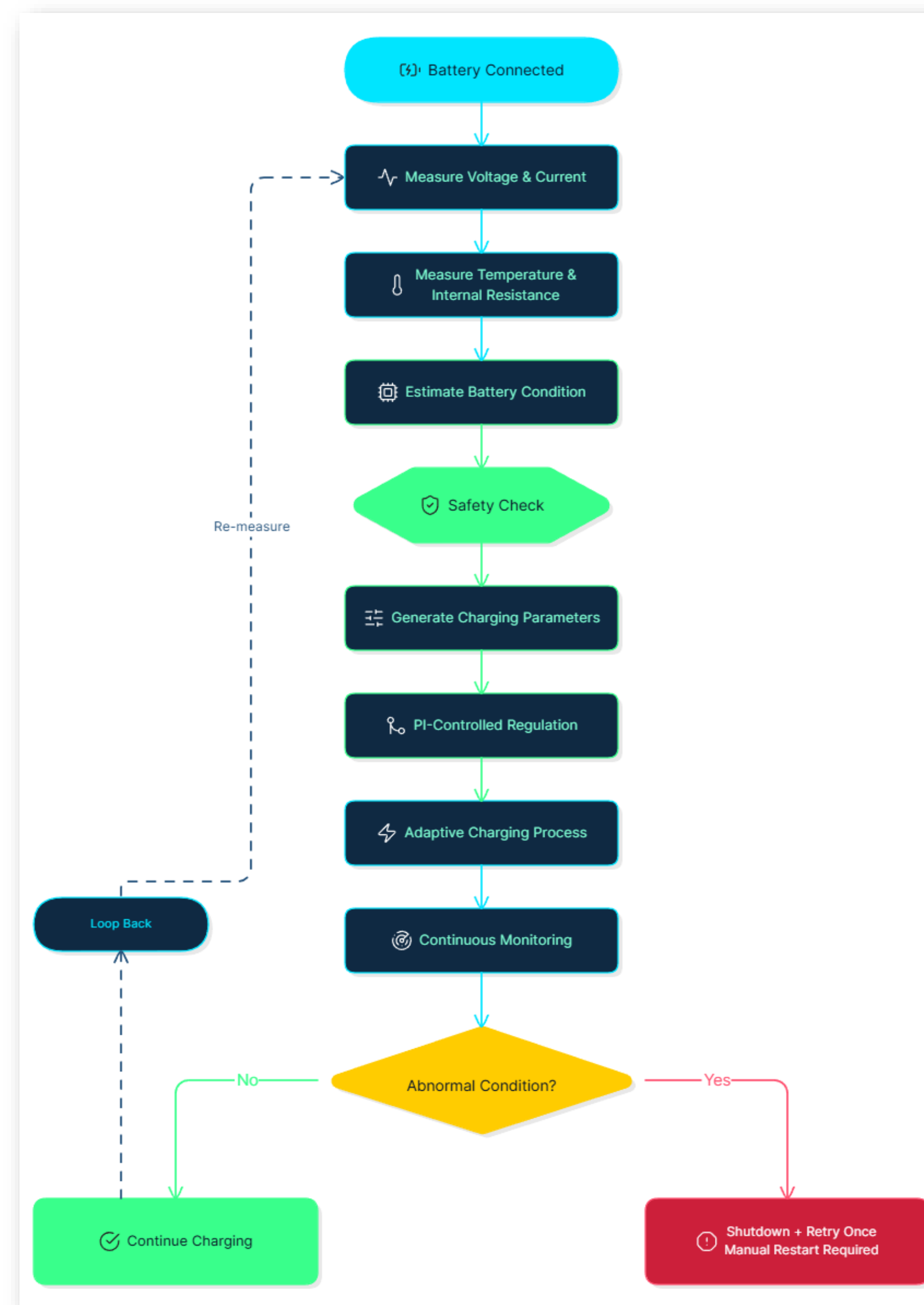
A charging system is needed that can monitor battery condition continuously and adapt charging behavior automatically.

OBJECTIVE

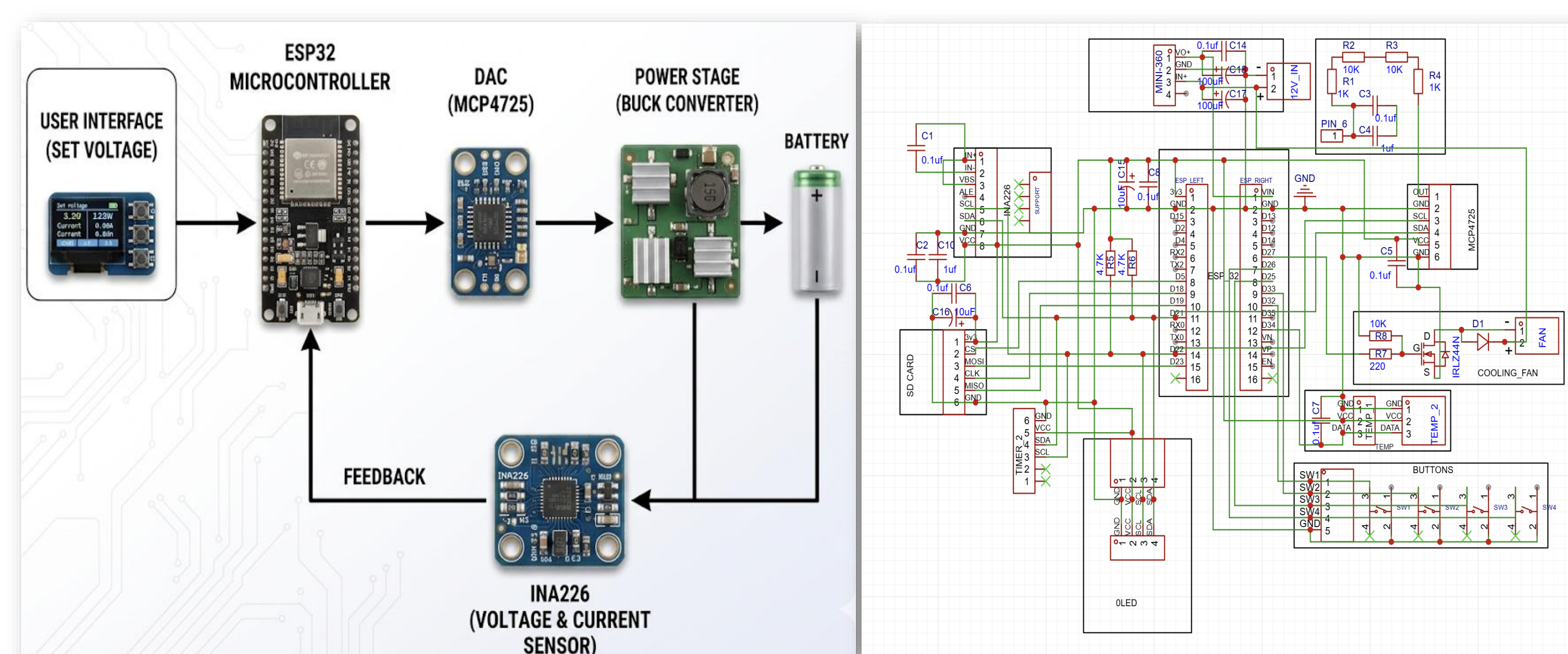
- ✓ Develop a universal smart charging platform for 1.3V–24V batteries
- ✓ Implement stable PI-controlled voltage regulation
- ✓ Monitor voltage, current, temperature, and internal resistance in real time
- ✓ Apply adaptive charging based on battery condition
- ✓ Improve charging safety using multi-layer protection logic
- ✓ Create a platform for future ML-based charging optimization

METHODOLOGY

The system continuously monitors voltage, current, temperature, and internal resistance using real-time sensor feedback. Based on battery condition, the ESP32 adjusts the charging parameters dynamically through PI-controlled regulation and adaptive decision logic.



Circuit Diagram



PI-Controlled Voltage Regulation

The charging voltage is controlled using a closed-loop PI controller. The ESP32 continuously measures output voltage through the INA226 sensor and adjusts the DAC output to maintain stable charging voltage under different operating conditions.

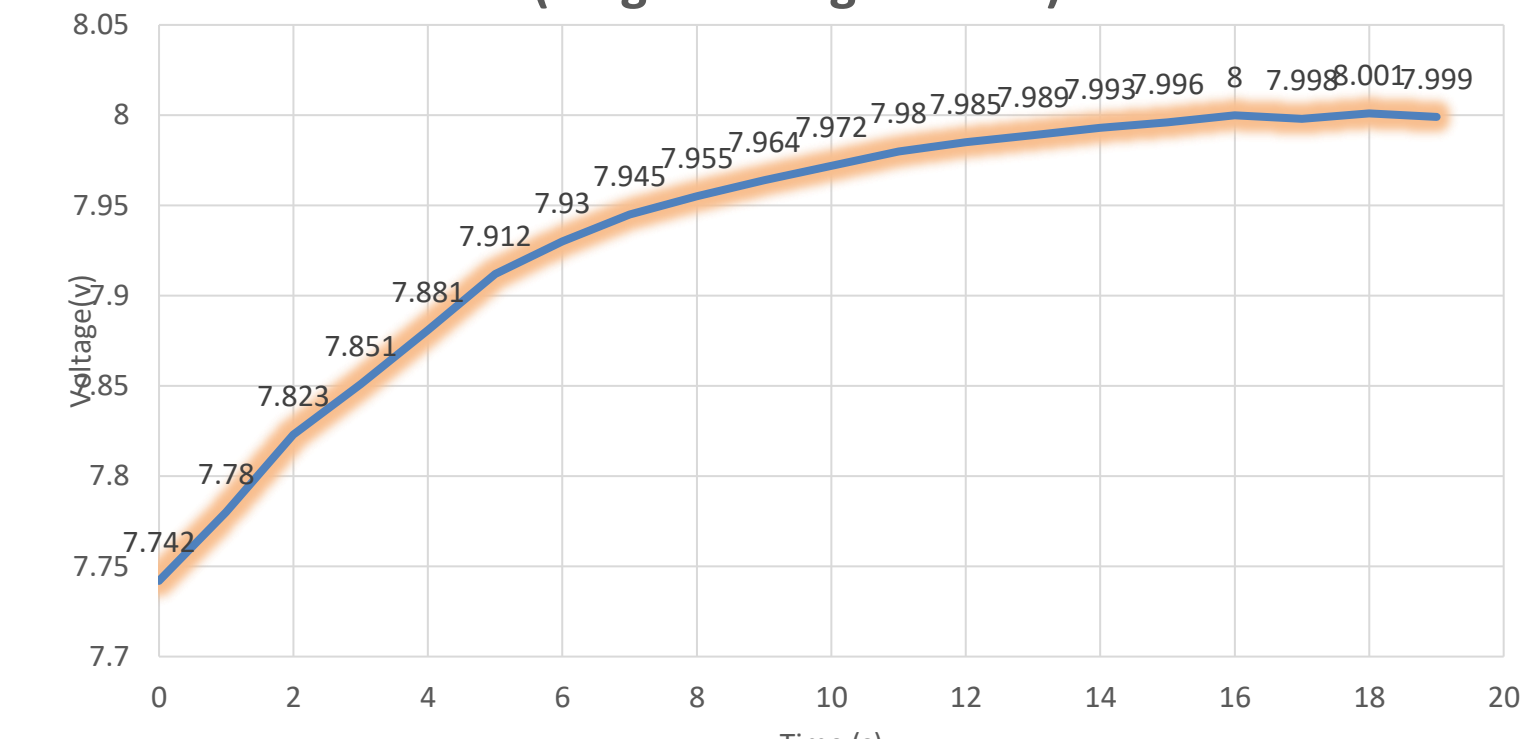
$$u(t) = k_p e(t) + k_i \int e(t) dt$$

PARAMETER TABLE

Parameter	Value
K _P	2.0
K _I	0.03
Deadband	10mV
DAC Range	295–2595
Max Voltage	24V
Max Current	5A

Result

Closed-Loop Voltage Stabilization Response (Target Voltage = 8.0V)

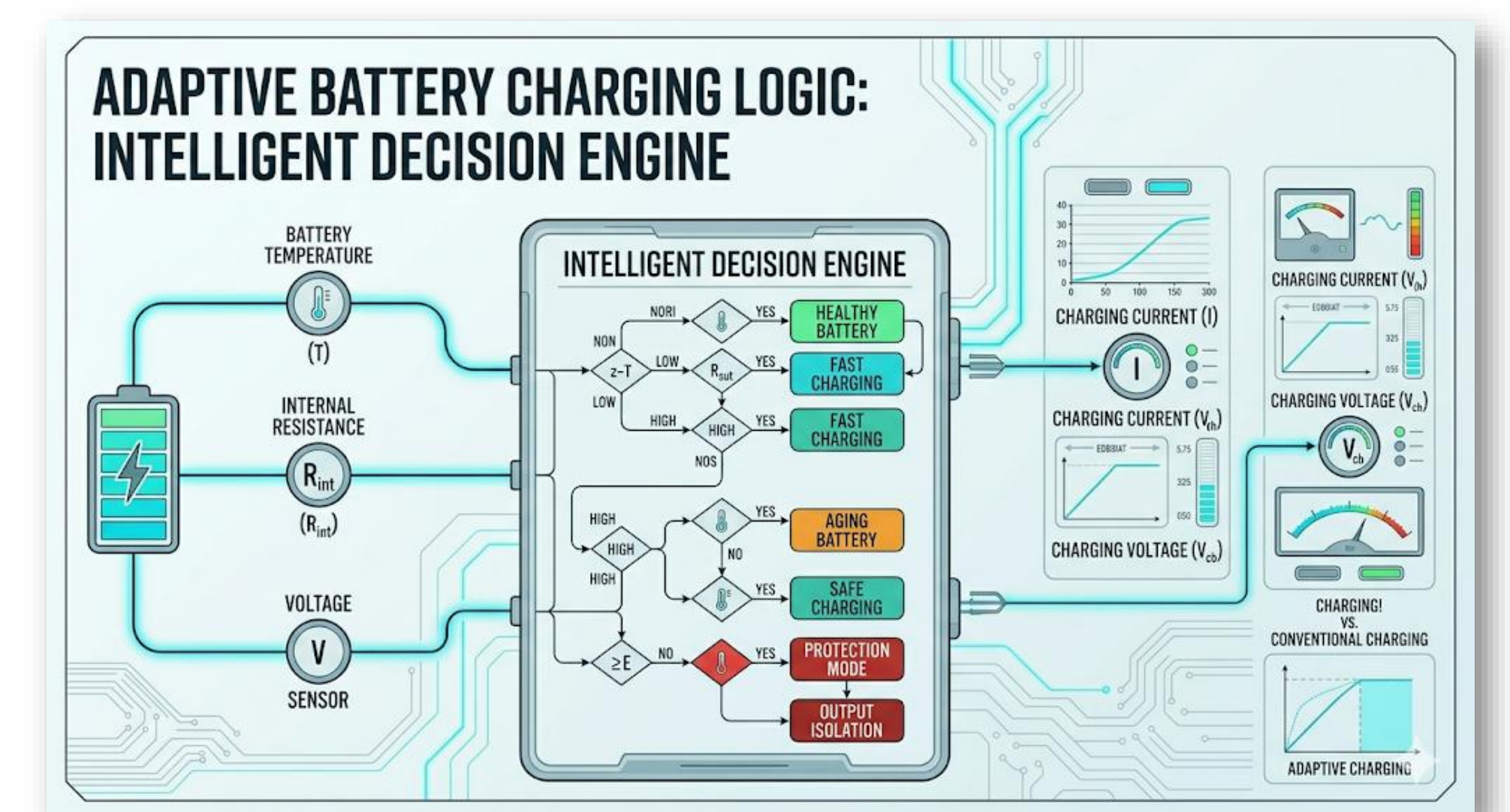


Metric	Value
Rise Time	0.11s
Overshoot	0mV
Settling Time	16.02s
SS Error	22mV

Adaptive Charging Logic

The system continuously monitors battery voltage, temperature, and internal resistance to determine suitable charging conditions.

Batteries with higher temperature or higher internal resistance receive reduced charging stress, while healthy batteries can safely receive faster charging.



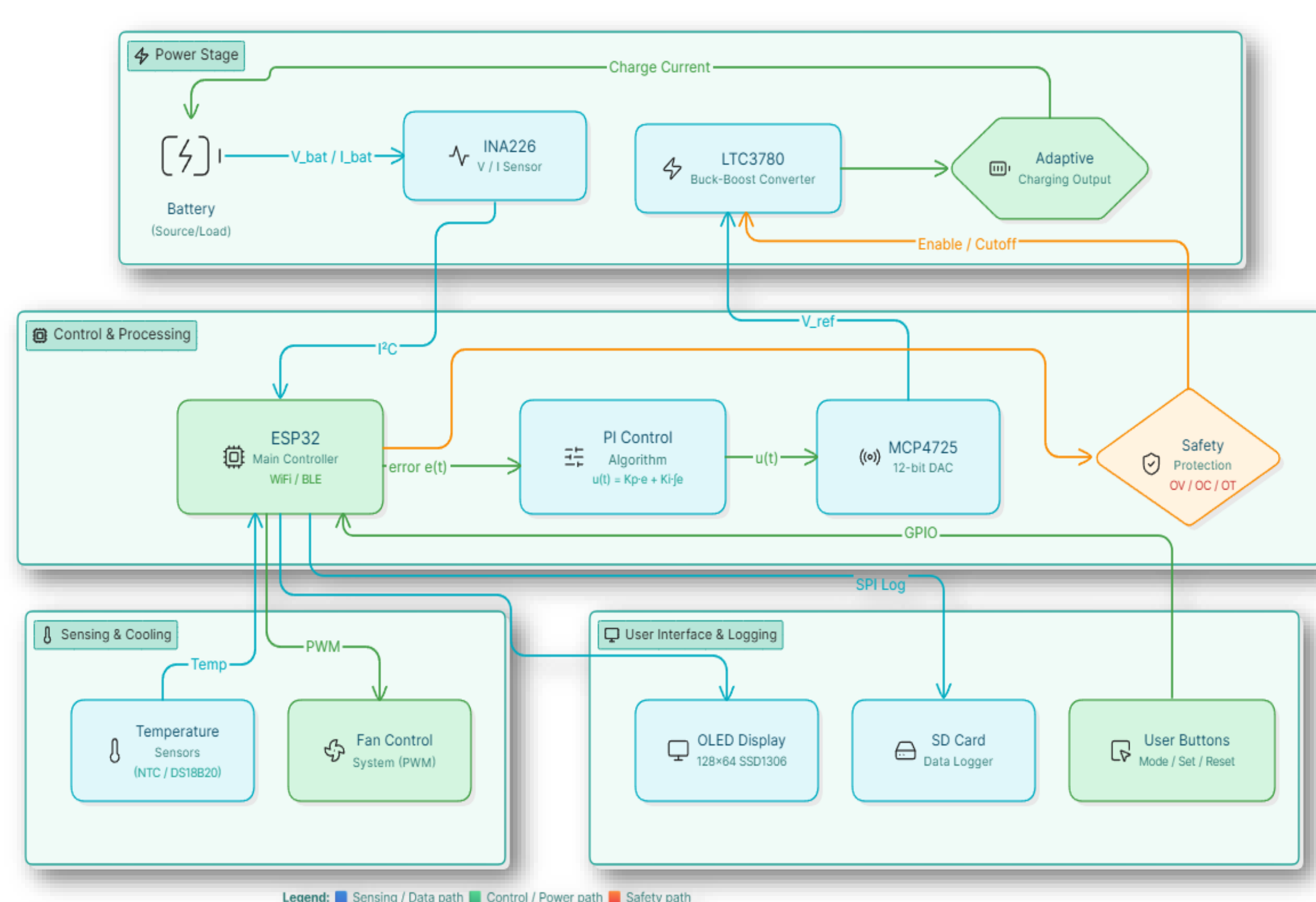
SAFETY FEATURES

- Overvoltage Protection
- Overcurrent Protection
- Temperature Cutoff
- Reverse Polarity Detection
- Fault Shutdown Logic
- Retry-Once Recovery System

Real-World Applications

- Smart charging systems for consumer electronics
- Adaptive charging stations for electric vehicles
- Battery testing and diagnostic platforms
- Renewable energy storage systems
- Research and educational battery laboratories
- Intelligent industrial battery maintenance systems

SYSTEM ARCHITECTURE



Future Scope

- ML-based charging optimization
- Predictive battery health analysis
- Higher power charging support
- Cloud-based charging data logging
- Multi-battery profile learning

Conclusion

The proposed adaptive charging platform successfully demonstrated stable PI-controlled voltage regulation and real-time battery monitoring. The system provides safer and smarter charging by adapting charging behavior according to battery condition and operating feedback.

RELATED LITERATURE

- [1] Texas Instruments, "INA226 Current/Power Monitor Datasheet," 2024.
- [2] Analog Devices, "LTC3780 High Efficiency Buck-Boost Controller Datasheet," 2024.
- [3] Microchip Technology, "MCP4725 12-Bit DAC Datasheet," 2023.
- [4] K. Ogata, Modern Control Engineering, 5th ed. Pearson, 2010.
- [5] M. H. Rashid, Power Electronics: Circuits, Devices and Applications, 4th ed. Pearson, 2014.
- [6] J. Larrimie and J. Lowry, Electric Vehicle Technology Explained, 2nd ed. Wiley, 2012.
- [7] Battery University, "Charging Lithium-Ion Batteries," [Online].