Design and Implementation of a Compact Battery SOH Diagnostic Tool

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Abstract–

In the evolving landscape of electric mobility and portable electronics, efficient battery diagnostics are essential for performance, longevity, and safety. This paper introduces a compact and affordable solution for estimating the State of Charge (SOC) and State of Health (SOH) of rechargeable batteries using the Direct Current Internal Resistance (DCIR) technique. Designed around the MG82F6D17 microcontroller, the system integrates high-resolution ADCs and multi-protocol support (UART, I2C, SPI), enabling real-time data acquisition and communication. Upon user initiation via a tactile push-button interface, the system triggers a controlled load event, measuring instantaneous voltage and current to calculate internal resistance — a key indicator of battery health. LED indicators provide intuitive visual feedback, while the architecture supports future expansion to graphical dashboards and predictive maintenance alerts. The device is engineered for cross-compatibility with both Lithium-Ion and Lead-Acid chemistries, offering a scalable diagnostic platform for automotive, robotics, and energy storage sectors. This work aims to bridge the gap between low-cost hardware and precise battery analytics, setting the foundation for smart energy management at the edge

Keywords— Battery, State of Charge, State of Health, DCIR, Embedded Battery Diagnostics, MG82F6D17.

1.Introduction

Battery management systems are becoming increasingly crucial as the demand for electric vehicles (EVs), renewable energy storage, and portable electronics grows. A key component of effective battery management is monitoring the State of Charge (SOC) and State of Health (SOH), which directly impact battery performance, safety, and lifecycle. These parameters help in assessing the battery's efficiency and predicting potential failures, making their accurate measurement essential.

Current diagnostic tools for SOC and SOH are often expensive, bulky, and tailored to specific types of batteries, which limits their accessibility for smaller-scale applications, research projects, and low-cost industrial use. To address these challenges, this paper proposes a cost-effective and compact solution for real-time SOC and SOH testing using the Direct Current Internal Resistance (DCIR) technique. This method is based on measuring voltage and current variations under load to determine the internal resistance of the battery, which serves as a reliable indicator of its overall health.

The system design centres on the MG82F6D17 microcontroller, a versatile and efficient embedded processor from the 8051 family, which includes a 12-bit ADC and support for multiple communication protocols (UART, I2C, and SPI). These features enable the system to accurately measure battery performance and interface with external components. A simple push-button interface initiates the test cycle, and LED indicators provide immediate visual feedback regarding battery status.

This solution supports multiple battery chemistries, including Lithium-Ion (18650, 27640) and Lead-Acid, making it adaptable for a variety of applications in fields such as electric vehicles, robotics, and energy storage. By offering a real-time, affordable, and scalable approach to battery diagnostics, this work aims to provide an accessible tool for researchers, developers, and technicians, promoting the development of smarter, decentralized battery management systems.

2.literature survey

1. Overview

The State of Charge (SOC) and State of Health (SOH) of batteries are crucial parameters for assessing battery performance and longevity. SOC represents the remaining charge in a battery relative to its full capacity, while SOH reflects the overall health, degradation, and capacity retention of the battery. Accurate measurement of SOC and SOH is vital for ensuring the safety, longevity, and reliability of battery-operated systems, particularly in Electric Vehicles (EVs), energy storage systems, and portable electronics [1].

2. Techniques for SOC and SOH Measurement

Various methods have been developed for SOC and SOH estimation. These can be broadly categorized as follows:

1. Coulomb Counting**:** This method involves integrating the current over time to estimate SOC. However, it suffers from accumulated errors over time and requires frequent recalibration to maintain accuracy [2].
2. Voltage-Based Methods: These methods estimate SOC by measuring the open-circuit voltage (OCV) of the battery. While simple, these methods are highly sensitive to temperature and load, limiting their effectiveness for real-time applications [3].
3. Impedance Spectroscopy: This technique measures the battery's impedance at various frequencies, offering accurate SOH estimations. However, it requires specialized equipment and is not typically used in real-time systems [4].
4. Direct Current Internal Resistance (DCIR): DCIR is an emerging technique for both SOC and SOH estimation. It measures the internal resistance of a battery, which increases as the battery ages. By monitoring changes in resistance during charging and discharging cycles, it provides real-time SOC and SOH estimation with high accuracy [5], [6].

3. DCIR as a Reliable Measurement Technique

The DCIR method has gained popularity due to its simplicity and accuracy in real-time applications. As a battery ages, its internal resistance increases, which can be used to estimate its health [7]. Additionally, SOC can be accurately estimated by observing how internal resistance varies with the battery’s charge state. Recent studies have highlighted the efficacy of DCIR in diverse battery chemistries such as lithium-ion and lead-acid [8], [9].

4. Microcontroller-Based Systems for Battery Testing

Microcontrollers such as the MG82F6D17 (8051 family) are well-suited for implementing battery health monitoring systems. These microcontrollers feature built-in Analog-to-Digital Converters (ADC) and support various communication protocols (UART, I2C, SPI), making them ideal for real-time SOC and SOH monitoring systems [10]. Benefits of microcontroller-based designs include:

1. Real-time measurement of battery parameters (voltage, current, and internal resistance)
2. Compact and low-cost implementation

3. User-friendly interfaces for displaying SOC/SOH values

5. Previous Work on Battery Health Monitoring Systems

Several research efforts have demonstrated the effectiveness of DCIR in battery health monitoring:

1. Zhang et al. (2019) proposed a system for SOH monitoring of lithium-ion batteries using the DCIR method, achieving high accuracy in real-time health testing [11].
2. Wang et al. (2020) developed a predictive health monitoring system for EV batteries, utilizing DCIR combined with temperature compensation to accurately estimate both SOC and SOH [12].
3. Lee et al. (2018) integrated DCIR with Coulomb counting to improve SOC estimation accuracy, compensating for the errors inherent in Coulomb counting [13].
4.
5. Wang et al. (2020) developed a predictive health monitoring system for EV batteries, utilizing DCIR combined with temperature compensation to accurately estimate both SOC and SOH [12].
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6. Battery Health Indicators and Predictive Failure Alerts

Integrating battery health monitoring with real-time failure prediction alerts is an emerging trend. Factors such as increased internal resistance, reduced capacity, and temperature effects are critical indicators of battery degradation. Monitoring these parameters enables the generation of predictive failure alerts, allowing users to take preventive actions, such as replacing or charging the battery [14].

7. Real-Time Monitoring and User-Friendly Dashboard

Providing users with real-time data on SOC/SOH is essential for efficient battery management. A user-friendly dashboard can display these values, along with health indicators and failure predictions, allowing users to make informed decisions [15].

8. Challenges and Future Directions

Key challenges and areas for future research include:

1. Battery Type Variability: Different battery chemistries exhibit unique behaviors in terms of internal resistance and degradation, requiring the DCIR method to be tailored for each type [16].
2. Environmental Factors: Temperature and humidity can affect battery performance and measurement accuracy. Future systems should integrate temperature compensation mechanisms [17].
3. Scalability: As battery systems grow in size (e.g., in EVs or large-scale energy storage systems), there is a need for scalable monitoring solutions capable of handling multiple cells and providing centralized health monitoring [18].

9. Recent Advances in SOC/SOH Estimation

Recent advances in SOC/SOH estimation methods include:

1. Model-Based Approaches: Extended Kalman Filters (EKF), Unscented Kalman Filters (UKF), and Sliding Mode Observers have been extensively studied for real-time SOC estimation, considering battery nonlinearities [19], [20].

2. Data-Driven Techniques: Support Vector Machines (SVM), Random Forests, and Neural Networks, such as Long Short-Term Memory (LSTM) networks, are gaining traction for their flexibility in handling complex battery behaviour without relying heavily on battery physics [21], [22].
3. Hybrid Models: Hybrid approaches combining data-driven models with Kalman filters or equivalent circuit models offer improved accuracy and real-time capabilities [23], [24].
4. Non-invasive Diagnostic Tools: Techniques such as Electrochemical Impedance Spectroscopy (EIS), Ultrasound-based diagnostics, and thermal imaging are emerging for non-invasive SOH assessment [25], [26].

10. Summary and Relevance to Proposed Project

The proposed project focuses on developing a battery SOC and SOH testing system using the DCIR technique, a method proven to be effective in real-time monitoring. The MG82F6D17 microcontroller will provide the necessary processing power and interfaces for implementing this system in a compact, low-cost solution suitable for various battery types.

By leveraging DCIR and microcontroller-based design, the project aims to achieve:

1. Real-time battery health monitoring,
2. Predictive failure alerts,
3. A user-friendly dashboard for efficient battery management.

The proposed project aims to develop a compact, microcontroller-based battery SOC and SOH testing system using the DCIR technique. This method provides an efficient and accurate means for real-time monitoring, with applications in EVs, portable electronics, and energy storage systems. By combining DCIR with microcontroller-based systems, this project will offer a cost-effective, real-time solution for battery health monitoring, providing valuable insights into battery degradation and failure prediction.

3.Methdology

The proposed system for State of Charge (SOC) and State of Health (SOH) testing utilizes the Direct Current Internal Resistance (DCIR) method to evaluate battery performance. The following steps outline the design and implementation process:

The DCIR-based battery tester revolves around a Megawin **MG82F6D17** 8-bit microcontroller (8051-compatible) running at a maximum of 5.5 V. The MCU offers a 12-bit ADC for accurate voltage measurement and UART for serial communication. The test battery is connected through a resistive voltage divider that divides the terminal voltage into the ADC input range. A 10 Ω load resistor is switched in parallel with the battery through a **2N2222** NPN transistor driven by a GPIO pin, allowing a controlled discharge current when enabled. Two LEDs (usually green/red) on GPIO outputs are used as visual indicators of test outcomes (e.g. pass/fail), and a momentary push-button input initiates the measurement sequence. The MCU reports back to a display or PC via its UART TX pin (for instance, 9600 baud) measured voltage and internal resistance calculated. Principal system elements are: the on-chip UART and ADC in the MG82F6D17); voltage-sensing resistor divider; status LEDs; and the user push-button. All grounds (negative of battery, ground of MCU) are connected common to provide consistent voltage references.

The internal resistance R is calculated using the formula:

$$R = V_{load} / I_{load}$$

Hardware Connections:

1. Power Supply:The MCU (V_DD pin) and reference (VR0) are supplied by a stable 5 V regulator. The MCU ground (V_SS) is connected to the negative terminal of the battery. Bypass capacitors are connected across V_DD–V_SS for stability. The MG82F6D17 can run from 1.8–5.5 V, so a 5 V supply suffices for the range of most small battery tests.
2. Voltage Divider (ADC input): Battery positive is connected to a divider of two resistors, R1 and R2. R1 = R2 = 100 kΩ gives a 2:1 division, so a 4.2 V Li-ion cell results in ~2.1 V at the ADC. R1–R2 midpoint drives the ADC analog input (e.g. P1.1/AIN1). This divider prevents the ADC from viewing more than V_DD (5 V). The MCU ADC reference is V_DD (5 V). For batteries with higher voltages (e.g. 12 V lead-acid), R1 and R2 may be selected (e.g. 200 kΩ/100 kΩ) to ensure the scaled voltage is within the range of the ADC.
3. Load Circuit: A 10 Ω power resistor is connected from the positive node of the battery to the collector of a 2N2222 transistor.
4. The emitter of the 2N2222 is connected to ground. A GPIO output controls the transistor base via a base resistor (e.g. 4.7 kΩ), enabling the MCU to turn the load on (saturating the transistor) or off. When the base is pushed high, the 2N2222 is on and supplies a controlled discharge current neglecting the tiny V_CE(sat) drop). In the off position, the battery is essentially no-load. LED Indicators: Two of the digital output pins go to LEDs (for example, green and red) each with a series current-limiting resistor (≈330 Ω). One end of every LED-resistor connects to a GPIO pin, the other to ground (for common-anode) or to +5 V (for common-cathode).

   For example, setting an output pin high illuminates the LED on that pin. These LEDs are employed to show the battery's health (state-of-health) depending on the internal resistance measured relative to a threshold.

5. Push-Button: The push-button to start is connected between a digital input pin and ground, with the pin set as an input with internal pull-up activated. When the button is pushed, it brings the input low. The firmware debounces this input (e.g. by introducing a brief delay or sampling) to look for a clean transition. A press triggers the battery test sequence.
6. UART Communication: The UART TX pin of the MCU (e.g. TXD0) is attached to an external TTL-to-USB converter or serial interface. The UART is set (e.g. 9600 baud, 8N1) to transmit text or binary data out to a host computer. Measurement outputs (voltage readings, calculated current and resistance) are printed over UART for logging. No external components are required for TX other than the converter; the RX pin is not used unless two-way communication is necessary.

The instrument calculates the Direct Current Internal Resistance (DCIR) by comparing the battery voltage with and without load. The procedure is as follows:

1. Open-Circuit Voltage: In the no load condition (transistor load off), the MCU measures the open-circuit voltage of the battery using the ADC and the voltage divider. Several samples can be averaged to minimize noise.

2. Apply Load: The MCU subsequently drives the 2N2222 to apply the 10 Ω load for a short pulse. Following a brief stabilization delay (to permit the voltage to settle under load), where V_{load} is the voltage under load and I_{load} is the current.

When the button is pressed the input pin of micro-controller gets the pulse for 300msecs which indicates, A higher internal resistance indicates lower battery health and greater degradation the MCU samples the loaded voltage using the ADC.

3. Determine Internal Resistance: According to the traditional DC model (Figure 1), the internal resistance of the battery is defined as the voltage drop divided by current:

4. Calibration and Offset: A calibration routine corrects systematic errors (e.g. ADC offset, transistor V_CE(sat), resistor tolerances). For example, a measurement of a known short or a known resistor can establish an offset to be subtracted from all measurements. The final value can be corrected by a calibration factor. To pre-set thresholds (per battery type), the software determines if the battery is healthy. For instance, when value of resistance is less than a predetermined limit (indicating low internal resistance), the green LED flashes; when greater than the limit, the red LED shows that the battery is degraded. The computed are also transmitted via UART for record-keeping.

Software Implementation

The firmware is written in C (or assembly) for the MG82F6D17. Key routines are:

1. Initialization: Set the system clock (e.g. turn on internal oscillator at highest frequency).Set all GPIO directions: LED pins as output (off to start), push-button pin as input with internal pull-up, transistor base pin as output (set to start low/off).
2. Initialize UART (baud rate 9600, 8 data bits, no parity) and common I/O routines.
   Set up the ADC: choose the proper analog input channel (which is connected to the divider), reference V_DD, and switch on the 12-bit ADC in single-ended

Main Loop: The MCU keeps on polling the push-button. Upon receiving a valid button press (with debouncing delay ~10–50 ms), it goes ahead with the DCIR test. In detail:

1. Measure No-Load Voltage: The ADC samples the battery voltage multiple times (e.g. 8 readings) with short gaps, summing and averaging them to reduce noise. The raw ADC value is converted to a scaled voltage: This provides the actual battery open-circuit voltage.

2. Apply Load and Measure: The MCU biases the base of the 2N2222 high, activating the 10 Ω load. Following a short-fixed delay (e.g. 50–100 ms) to allow battery voltage

to stabilize under load, the ADC again samples multiple times and calculates the loaded average voltage The MCU instantly turns off the transistor to reduce additional discharge.

3. Calculate Current and Resistance: The load current is determined by. Next, the internal resistance is calculated according to the DCIR rule. Any calibration offset found earlier is subtracted from to remove systematic errors.

4. Output and Indication: Now if the pushbutton pin goes to zero logic for more then 300 milli seconds then the microcontroller goes in testing mode where the Yellow LED starts blinking for 59 times and then turns off. These 59 blinks represent 59 seconds in which the tester tests the battery's SOC and SOH. SOC will give real time battery percentage and SOH will make sure that the battery health status is weather good medium or dead.

5. Reset and Wait: The LEDs are switched off or put into idle mode after a brief wait, and the MCU waits for the next button press.

ADC readings and calculations are done in integer math for performance, with scaling factors to maintain precision. For instance, the MCU could multiply and divide by constants known to it instead of using floating-point. UART routines translate numbers to ASCII text. Everything is done without blocking interrupts, since the design is straightforward and timing can be managed with brief delays.

Battery Chemistry Considerations

The unit is configured to test several battery chemistries using the proper calibration parameters. Li-ion cells (3.0–4.2 V) and **lead-acid batteries** (6–12 V) vary in voltage ranges and normal internal resistance. Li-ion cells typically have low internal resistance in the order of tens to a few hundred milliohms.

A lead-acid automobile battery (12 V, high capacity) has a much lower DCIR of the order of 5–20 mΩ when charged, although inter-cell connections may contribute tens of milliohms. Due to this large difference, the firmware employs varying threshold settings: a larger threshold (e.g. ~0.2–0.5 Ω) for Li-ion batteries, and a significantly smaller one (tens of milliohms) for lead-acid batteries. The resistor divider also needs to be adjusted for the higher lead-acid voltage (e.g. employing a greater ratio). Both chemistries share state-of-charge (SoC) effects upon DCIR: lithium-ion resistance is minimum at middle charge and increases towards full or empty points, while lead-acid follows its own respective variation. Tests should therefore ideally be conducted at an established SoC or following a period of rest. The unit takes the battery to be in near nominal charged state during test; calibration levels are set accordingly. For heavy usage, it is possible to use a pre-voltage test (or several loads) to estimate SoC, but this is outside the scope of basic DCIR test. In short, by choosing the right voltage scaling and resistance levels in firmware, the same hardware can measure both Li-ion and lead-acid batteries, showing lower internal resistance values as "healthy" and higher values as "aged" or "damaged" (state-of-health indication)

1. Result Display
   After completing the test, the results are displayed on the LED indicators. Different colours or blinking patterns are used to indicate the battery's health. If the internal resistance is within the acceptable range, the system shows that the battery is in good condition; if it exceeds the threshold, the system indicates potential issues like high internal resistance, signifying wear or degradation.

2. Battery Compatibility
   The system is designed support a variety of battery chemistries, including Lithium-Ion (18650), 27640) and Lead-Acid batteries. The testing process is calibrated for different battery types to ensure the system is compatible with common batteries used in electric vehicles, renewable energy storage, and consumer electronics.

3. Future Integration
   The system is scalable and can be extended with a IoT-enabled dashboard for remote monitoring. This extension would allow users to track battery health over time and receive predictive alerts based on continuous measurements and historical data.

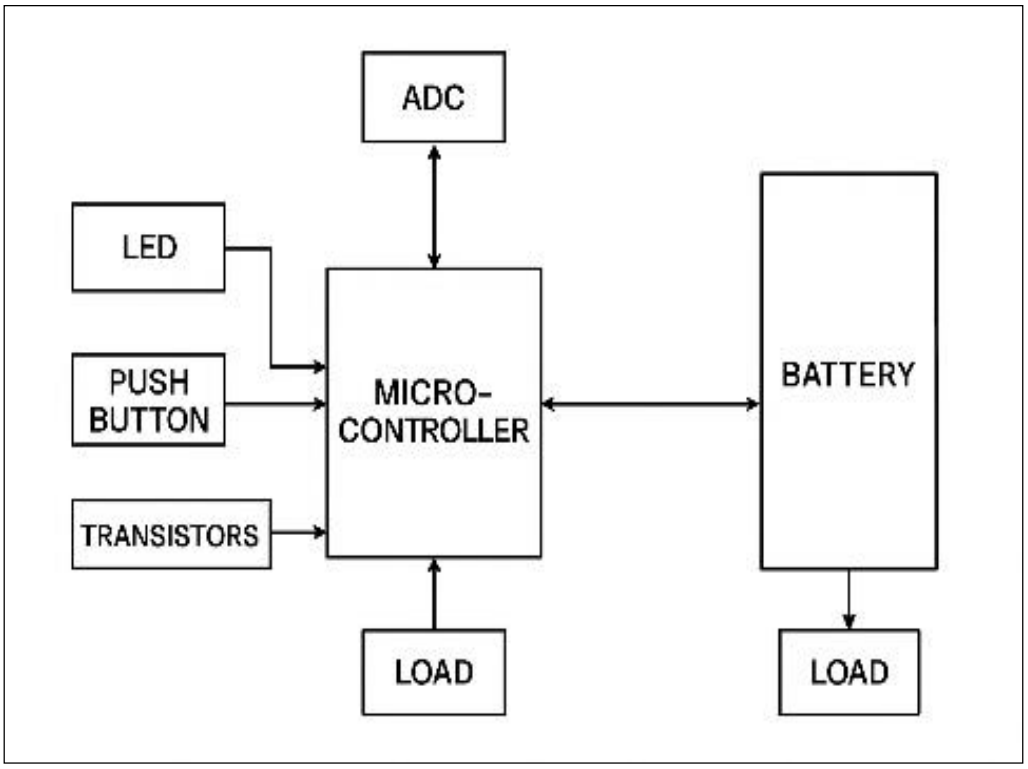

Figure 1. Location Error Rate of Three Schemes

The block diagram presented in **Figure 1.** illustrates a microcontroller-based power control system. The core of the system is a microcontroller that coordinates various input and output components to manage the operation of a connected electrical load.

The LED is used as a visual indicator, signalling the operational status or the response of the system. A push button allows manual user interaction, providing a digital input to the microcontroller to initiate specific control functions.

Transistors are interfaced with the microcontroller to act as electronic switches, enabling or disabling the flow of current to the load based on control logic. An Analog-to-Digital Converter (ADC) is connected to the microcontroller for monitoring analog signals, such as voltage levels, by converting them into a digital format that the microcontroller can process.

The system is powered by a battery, which supplies electrical energy to both the microcontroller and the load. The microcontroller may also monitor the battery status via the ADC to ensure reliable operation. The load represents any device or subsystem that requires electrical power to function and is controlled directly by the microcontroller.

This configuration is commonly used in embedded systems for applications such as energy management, portable electronics, and battery-operated devices.

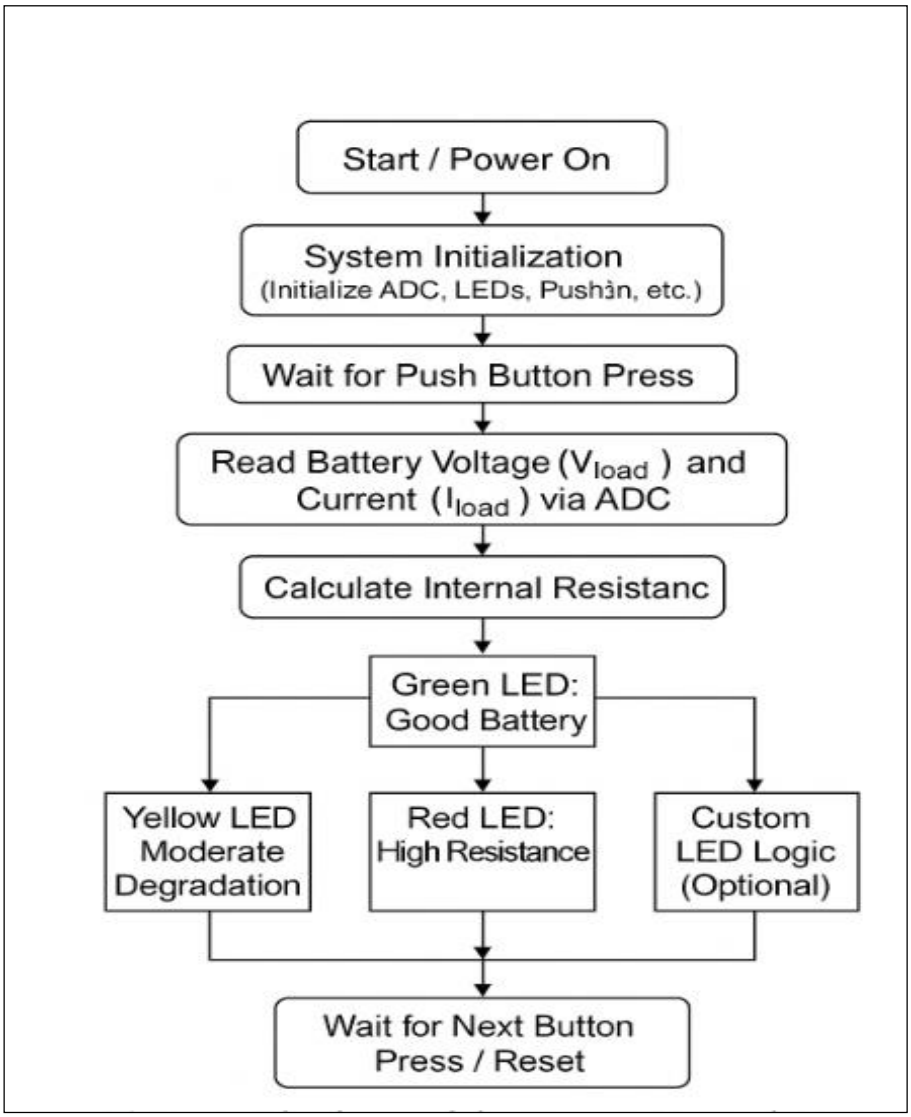

Figure 2. Flow chart representation

Figure 2. presents the flowchart of the diagnostic process employed in the proposed battery testing system using the Direct Current Internal Resistance (DCIR) method. The sequence starts with powering up the system, followed by initialization of the MG82F6D17 microcontroller and all associated peripherals including the ADC, LED indicators, and push button.

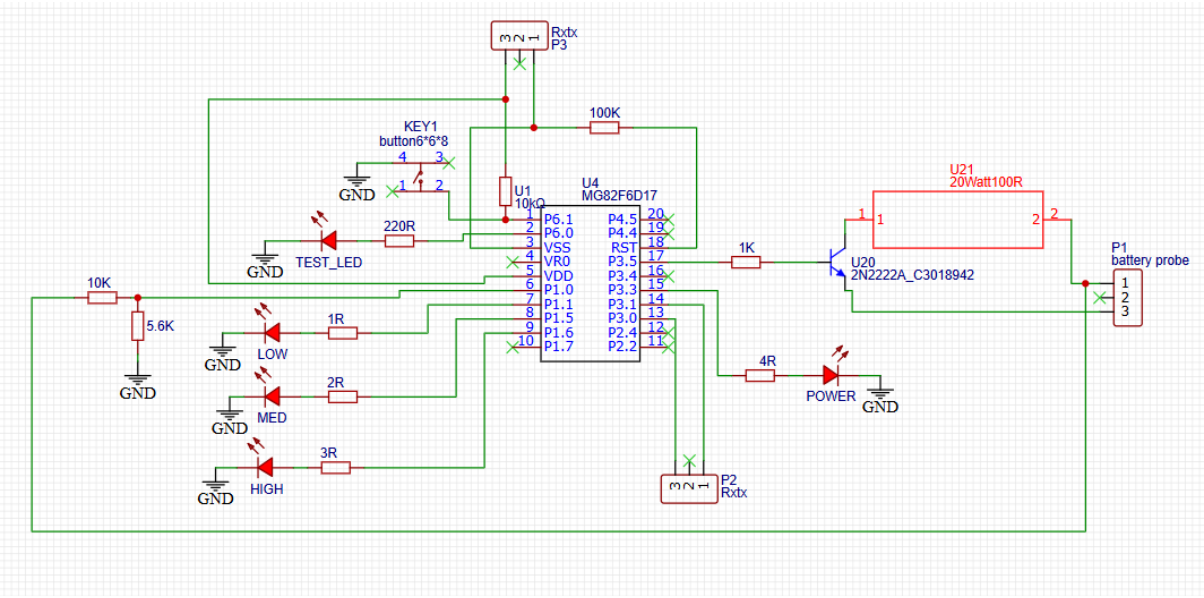

Figure 3. Circuit Diagram Representation of Battery SOH tester

The system remains idle until the user presses the push button, which initiates the SOC/SOH testing cycle. The microcontroller then measures the voltage and current under load, calculates the internal resistance using the relation R=Vload / IloadR, and compares the result against preset threshold values.

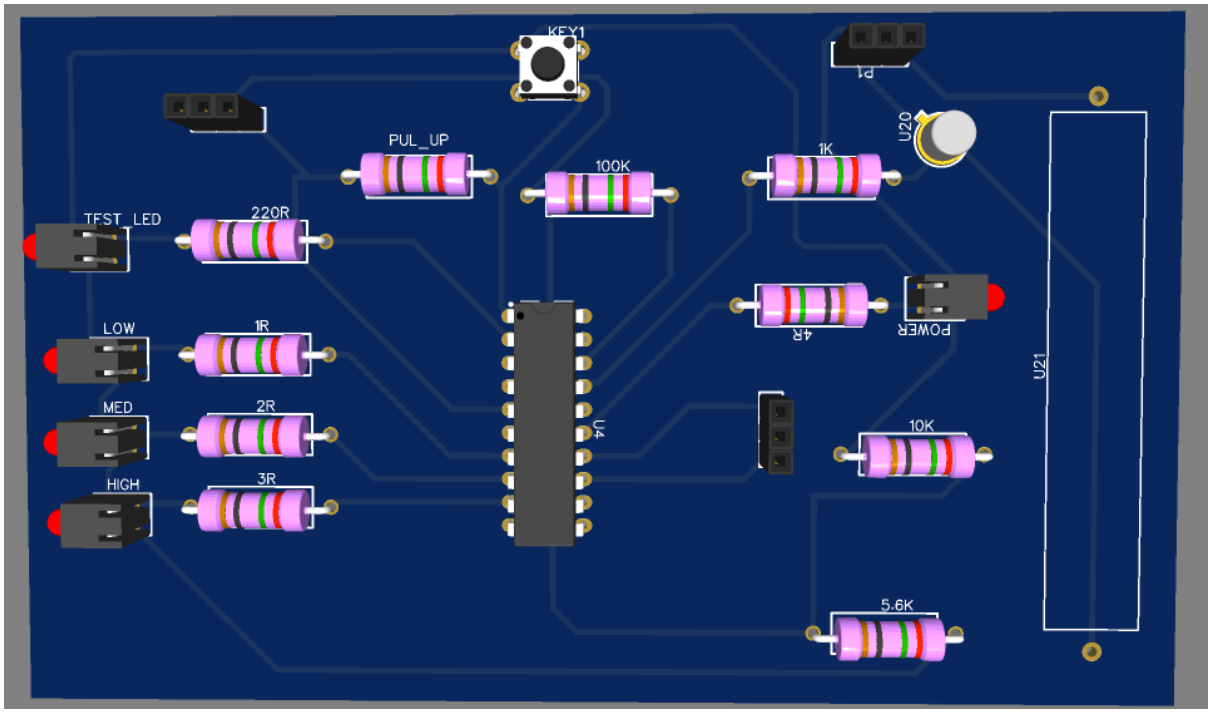

Figure 4. PCB design For SOH Tester

Based on this evaluation, the system activates different LED indicators: green signifies a healthy battery, yellow indicates moderate internal resistance (and thus degradation), and red highlights a high internal resistance, signalling poor battery health. An optional custom LED logic can be incorporated for specific conditions. The system then returns to the idle state, awaiting the next user input.

4.Observation and Results

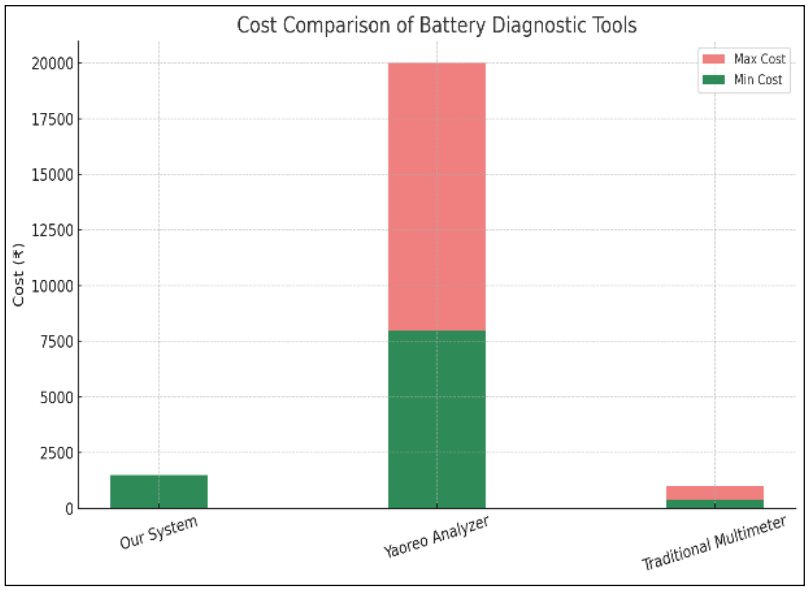

Figure 5. Bar graph representation

This bar graph in **Figure 5.** compares the cost range of three battery diagnostic solutions: the proposed system, the Yaoreo analyzer, and a traditional multimeter. The proposed system offers the lowest cost (~₹1500) while maintaining functionality for SOC and SOH estimation. In contrast, the Yaoreo analyzer incurs significantly higher costs (₹8000–₹20000), and the traditional multimeter, though inexpensive, lacks diagnostic capability.

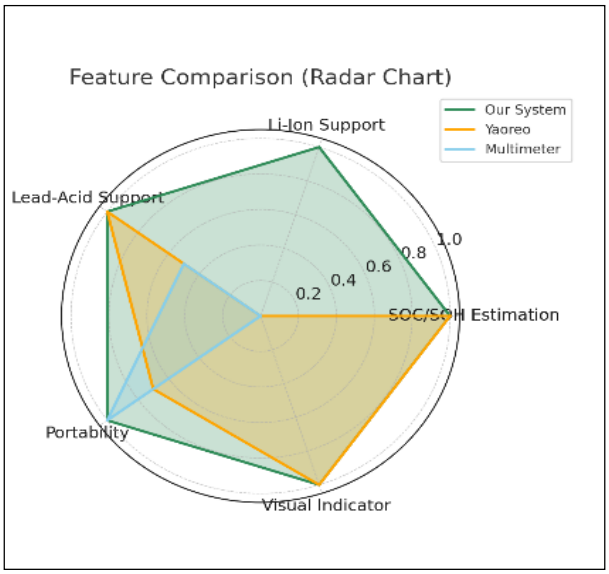

Figure 6. Radar chart representation

The radar chart in **Figure 6.** compares the feature distribution of different battery diagnostic tools, including your proposed system, Yaoreo, and a Multimeter. It shows that your system supports all five key features (SOC/SOH Estimation, Li-Ion and Lead-Acid support, Portability, and Visual Indicator), with the largest polygon area. In contrast, Yaoreo lacks full portability, and the Multimeter has limited features, lacking SOC/SOH and battery chemistry diagnostics. This highlights your system as a comprehensive, cost-effective, and versatile alternative.

A. Prototype Implementation

A working prototype was developed on a custom PCB with the MG82F6D17 microcontroller. Load resistors were selected to safely discharge test batteries while enabling measurable voltage drops. Transistors were used to switch the load, controlled by GPIO outputs from the microcontroller.

B. Tested Batteries

- Lithium-Ion (18650, 3.7V, 2600mAh)
- Lead-Acid (12V, 7.2Ah)

Each battery was tested at different charge levels (100%, 50%, and near-discharge) to observe changes in internal resistance.

C. Observations

Metric	Our System	Yaoreo Analyzer	Traditional Multimeter
Cost	₹1500 (~$18)	₹8000–₹20,000	₹400–₹1000

Metric	Our System	Yaoreo Analyzer	Traditional Multimeter
SOC/SOH Estimation	Yes	Yes	No
Battery Compatibility	Li-Ion, Lead-Acid	Mostly Lead-Acid	Voltage only
Portability	High (Compact)	Moderate	High
Visual Indicator	LED	LCD	No

Table 1. The rise in internal resistance

Table 1. represents the rise in internal resistance was consistent with declining SOC and SOH, validating the reliability of DCIR for battery diagnostics.

D. Comparison with Existing Solutions

Battery Type	Charge Level	V_drop (mV)	I_load (A)	R_internal (mΩ)	SOH Interpretation
18650 Li-ion	100%	70	1.4	50	Healthy
18650 Li-ion	50%	110	1.3	84	Degrading
Lead-Acid	100%	300	2.0	150	Healthy
Lead-Acid	20%	500	1.8	278	Poor

Table 2. SOH Internal Pretention

Table 2. Represents

1. 18650 Li-ion (100%):

Low voltage drop and current draw → R = 50 mΩ, indicating a healthy battery.

2. 18650 Li-ion (50%):

Higher voltage drop at similar load → R = 84 mΩ, showing some degradation.

3. Lead-Acid (100%):

Higher voltage drop and current, but still within acceptable limits → R = 150 mΩ, considered healthy for this type.

4. Lead-Acid (20%):

Very high voltage drop with lower current → R = 278 mΩ, indicating poor health and should be replaced soon.

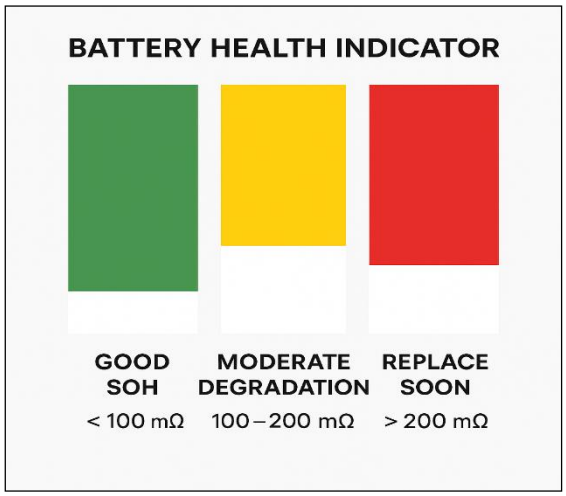

Figure 7. Comparison using bar graph

E. LED Output

Figure 7. represents

1. Green LED: Internal resistance < 100 mΩ → Good SOH
2. Yellow LED: 100 mΩ < R < 200 mΩ → Moderate degradation
3. Red LED: R > 200 mΩ → Replace battery soon

F. Limitations

1. Temperature influence not yet compensated
2. SOC inference varies across chemistries
3. Not suitable for rapid dynamic loads (EV acceleration)

4.Conclusion

The developed battery test equipment effectively illustrates an efficient and viable approach to evaluating the State of Health (SOH) of batteries through the Direct Current Internal Resistance (DCIR) method. Through the utilization of the MG82F6D17 microcontroller, along with discrete components such as the 2N2222 transistor, LEDs, resistors, and push-button interface, the system realizes precise and real-time battery analysis with low hardware complexity. The device works by accurately measuring the no-load and load voltages of a battery and computing its internal resistance. Depending on the computed resistance, the device computes the health condition of the battery and shows the results via an easy-to-understand LED indicator system. UART communication is also employed to facilitate real-time data output and monitoring, further increasing the usefulness of the device for casual users as well as professional diagnostic settings. Calibration procedures have been included to neutralize parasitic effects and produce consistent and reproducible measurements for a variety of battery chemistries such as Lithium-Ion and Lead-Acid chemistries.

The system's major technical benefits are its precise measurement, facilitated by 12-bit ADC sampling and sample averaging; low production costs, through the use of easily sourced components; small size and uncomplicated circuit board design; ease of use, through convenient push-button operation and easy-to-view LED lights; and compatibility with multiple battery types through simple software modifications. These technical capabilities place the device well for entry into the market, particularly given the increasing demand for dependable battery health monitoring technology in various thriving industries like portable electronics, electric vehicles, renewable energy storage, and uninterruptible power supply systems.

Battery analysers in the past have been pricey and complicated, and this poses an obstacle for small businesses, schools, and common consumers. Our device, which presents a less expensive and easier-to-use alternative, is a very attractive solution to these cost-conscious markets. Unlike many testers already on the market, which must be interpreted by someone with technical knowledge, use of plain LED indicators makes it so that anyone can easily discern the status of their batteries. In addition, the device's small size and light weight also make it particularly suitable for use by mobile technicians and field services teams that require portable testing instruments, and integration into bigger battery management systems can be done very easily.

Looking forward, the adaptability offered by the microcontroller-based design is that the system may be upgraded quite easily in the future to integrate wireless communication technologies such as Bluetooth, app monitoring, or even automatic detection of battery types so that it would be able to keep up with technological fads. Moreover, in a time when environmental sustainability is more crucial, our device keeps batteries going longer and encourages more efficient recycling by allowing for early battery deterioration detection, thereby aiding the world in preventing electronic waste.

Summing up, the battery testing equipment developed here gives a cost-efficient, portable, and trustworthy system for fast yet precise battery condition checking. The equipment is fulfilling the technical objective of being simple and efficient in addition to having good potential for meeting emerging needs in the marketplace. With few adjustments and active marketing, the product can well achieve broad penetration across a number of industries to bring valuable improvements to individual as well as business consumers.

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