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Reinventing State of Charge, Average Usage, and Remaining Time Estimations

For decades, a quick glance at a fuel gauge provided a clear answer to a crucial question: how much longer can we drive before needing a refill? Today, as battery-powered devices proliferate—from laptops and smartphones to medical equipment, industrial drones, and automobiles—the challenge has shifted to accurately predicting remaining runtime.

Unlike the trusty gas gauge, traditional battery indicators often leave users guessing. An empty bar might mean anything from minutes to hours of remaining operation. This whitepaper delves into the critical need for precise state-of-charge (SOC) measurement across various battery-powered applications. We will explore the limitations of current methods and introduce innovative solutions that empower users with a clear and dependable understanding of their battery's remaining capacity, translated into estimated runtime or operational range, depending on the specific device.

Consider relying on your laptop for a crucial presentation, only to have the battery indicator provide a wildly inaccurate estimate of remaining runtime. This all-too-common scenario goes beyond brand-new laptops; as batteries age, their life displays become notoriously unreliable, often exaggerating the remaining time. The result? A stressful scramble for a charger at the worst possible moment—a situation many laptop users are all too familiar with.

By addressing the need for accurate SOC measurement, we can prevent such disruptions and improve user experience across a range of battery-powered devices. This white paper aims to shed light on the advances in battery management technology that promise to make such disruptions a thing of the past.

What Makes Battery Gauging So Different and Complicated Compared to Traditional Gas Gauges?

The difference between battery gauging and traditional gas gauging is significant and profound. Traditional gas gauges typically use a float actuator that clearly indicates the level of gas in the tank. Given the fixed shape and size of the tank, this indication is nearly 100% reliable and repeatable. Although gas volume may change slightly with temperature fluctuations, these changes are too minor to significantly affect our estimation of how far we can drive with the remaining gas.

In contrast, battery gauging is far more complex. Battery state-of-charge (SOC) estimation is influenced by a variety of factors, including the battery's age, temperature, charge and discharge rates, and the specific chemistry of the battery cells. Unlike a gas tank, a battery's capacity and performance can degrade over time, and these changes are not always linear or predictable. Additionally, the state of charge is not directly visible or measurable. The closest analogy to the level of fuel in a tank is the battery voltage, but this is too variable to be useful on its own. Most modern systems infer the remaining charge from a combination of voltage, current, and other parameters, often requiring sophisticated algorithms to estimate accurately.

In newer cars, while there is an option to view the remaining mileage, many drivers still rely on their senses and judgment to determine if they have enough gas to reach their destination. This human factor, combined with the reliable nature of gas gauging, makes it relatively straightforward compared to the technical and variable-laden process of battery gauging.

Coulomb counting is a well-known method for charge estimation, measuring the coulombs (or electrons) entering and leaving the battery. However, for years, we have been told that this measurement alone is insufficient to accurately determine the remaining charge. To improve reliability, numerous algorithms have been developed, incorporating additional factors such as battery voltage, voltage profile over state of charge, temperature, and age. These fine-tuning adjustments provide the necessary guardrails to compensate for the inaccuracies of coulomb counting and ensure the estimations remain within acceptable limits.

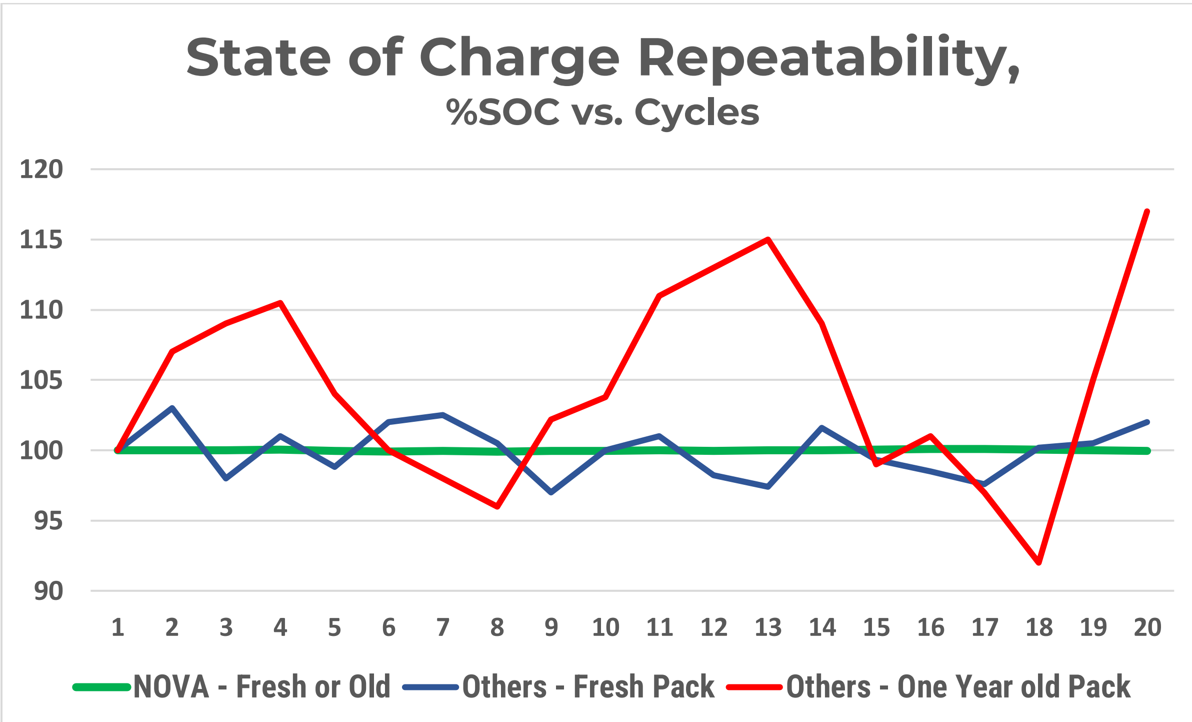
This all sounds good and can occasionally provide a somewhat reliable estimation. The major problem is that all the modeling and fine-tuning of these parameters remain valid for only a short period. As soon as the battery starts to age or its chemistry shifts, these corrections and guardrails become ineffective, leading to notoriously inaccurate estimations. Moreover, modeling the battery is a painstaking task that often takes weeks to perfect, but its accuracy is short-lived. Once the battery's characteristics change, the estimations quickly lose their reliability.

Why Accurate Coulomb Counting is So Difficult?

The industry has made significant advancements in creating highly accurate analog-to-digital converters (ADCs) with very high resolution. So, why can't we leverage these technologies to achieve precise coulomb counting? Here are a few reasons why simply using a high-resolution ADC to digitize the current signal does not lead to the necessary accuracy:

1. **Dynamic Range**: Depending on the system, there can be a vast difference between the peak or working current and the standby current. Most system integrators work hard to minimize standby power usage, reducing its usage to a few microamperes, while the working current could be tens or even hundreds of amperes. This enormous dynamic range makes achieving the required resolution extremely challenging, especially at a reasonable cost. For example, a system that needs to measure from 1 microampere up to 100 amperes requires a dynamic range of approximately 100,000,000 or 160dB. Experts in ADC specifications know that this is not feasible with current technologies. But why is measuring down to microamperes necessary? Depending on the system, a device can remain in standby mode for extended periods, such as weeks or months. If we cannot measure low currents accurately, the accumulation of these charges can become significant over time, leading to inaccuracies in the state of charge estimation.
2. **Current Variability**: Unlike steady DC currents, discharge currents can vary significantly, introducing current noise that can disrupt sampling systems. Charge currents, while typically less noisy, are also not perfectly clean DC current. ADCs typically require a constant input during conversion, which can be challenging given the lengthy conversion times required for high-resolution sampling. To accurately capture a variable input signal, continuous, high-speed, and back-to-back conversions are necessary to ensure all charges are accounted for. However, balancing high-speed and high-resolution systems is inherently complex and often results in increased power consumption beyond practical limits.
3. **Precision and Linearity**: To accurately measure all charges at any level, the ADC must have near zero offset and near-perfect linearity, which is a significant challenge at such high resolutions. Traditional ADCs require extensive final testing to either trim for linearity and offset or verify the necessary accuracy. This testing process is not only time-consuming but also potentially expensive, adding another layer of complexity and cost to achieving precise coulomb counting.

In contrast, Nova's coulomb counting engine is purpose-built to overcome these limitations, offering near-perfect coulomb measurement elegantly, even at low current and low cost.



The results speak volumes. The green line, nearly a perfect straight line, represents Nova's coulomb counting engine in action, with no additional corrections or guardrails. By eliminating dependencies on battery models, chemical shifts, temperature, and other variables, our approach provides highly accurate and repeatable state-of-charge readings.

We can think of a battery as a water tank. Knowing the water level doesn't require knowledge of fluctuations in tank volume due to external factors like temperature. Similarly, by accurately measuring the inflow and outflow of charge, we can precisely assess the remaining charge in the battery. Once this fundamental measurement is established, further refinements can be made, such as accounting for self-discharge and heat losses during charge and discharge, and verifying data integrity by keeping an eye on the voltage. These refinements are second order to the primary coulomb measurement, as demonstrated by the remarkable improvement over conventional methods shown in the graph above.

Average usage: Once we accurately determine the state of charge, the next task is to estimate the remaining time or usage range. Nova's coulomb counting engine precisely measuring the charge, allowing it to also measure usage charge over extended periods. This results in a near-perfect ratio of remaining charge to usage rate, offering far more accurate estimations of time and usage range than previously possible. Additionally, tracking new reading of the total capacity of any battery becomes straightforward. With reliable coulomb measurements, assessing the charge needed to reach a specific point, such as full charge, becomes a simple task.

Summary: Nova's BMS technology introduces numerous advancements and a few firsts to the battery management space, creating a paradigm shift in how BMS functions should be performed. Our system features high precision in cell voltage measurement, simultaneous measurement of all cells and current, and full flexibility in various functions, including cell balancing and impedance measurement. However, the best of all and a true game-changer is our accurate coulomb counting and state-of-charge (SOC) estimation, which will revolutionize all future battery-operated systems.

With the extensive use of earth resources and environmentally unfriendly materials in Li-Ion batteries, minimizing battery waste is crucial. Over the past few years, we have reverse-engineered many notebook computer battery packs deemed dead by their systems. We found that these batteries often still have 70-80% of their life remaining and can be revived and reconditioned. Given that most notebook batteries are no longer easily removable, it is concerning to consider how many notebooks are falsely reported as dead and subsequently recycled. This issue is prevalent across various end equipment, collectively causing a significant global environmental impact.

Such waste and environmental harm are unnecessary and can be mitigated by performing BMS functions correctly and accurately. Nova is proud to lead this effort and make a positive impact on our environment. We are committed to bringing state-of-the-art BMS solutions to all possible end equipment, ensuring optimal battery performance and longevity:

Saving our planet, one battery pack at a time!

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