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AN INTRODUCE ON SMART AND INTELLIGENT BATTERIES

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Abstract: - Most batteries for laptops and similar devices are “smart,” meaning that some communication occurs between the battery, the equipment and the user. The definition of “smart” varies among manufacturers and regulatory authorities. Some call their batteries smart by simply adding a chip that sets the charger to the correct charge algorithm. The Smart Battery System (SBS) forum states that a smart battery must provide State of Charge (SoC) indications.

An increasing number of rechargeable batteries are made smart. Smart means that the battery pack includes some level of intelligence. Equipped with a microchip, these batteries talk to the charger and inform the user of its status, such as indicating state-of-charge.

What then makes a battery 'smart'? Definitions still vary among organizations and manufacturers. The SBS forum states that a 'smart' battery must be able to provide SoC indications. This article introduces smart and intellbatt; a novel design of a multi cell battery. Intellbatt exploits the cell Characteristics to enhance battery lifetime.

Keywords*:* Multicell battery, cell switching circuit, intelligent battery, smart battery

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1. Introduction

Smart battery is more than just a collection of cells. The most commonplace additions in a smart battery are safety circuits. More advanced smart batteries have controller circuitry that controls the charging or discharging of the battery and optionally have a communication interface, such as SMBus or I^2C, for Communication with the device using the battery. Most of today’s battery packs used in laptops and portable electronics are smart batteries. Intellbatt takes smart batteries a step ahead by saving more energy and making them safer than other batteries [3].

Intellbatt differs from traditional smart batteries in the way it manages cells. Instead of simple connection and monitoring, it actively schedules cells to optimize capacity and charge delivery [2]. The predominance of battery operated, wireless handheld devices motivates the efficient and robust use of a limited energy supply.

Managing battery life and safety of the system are critical design constraints for portable systems. Battery Aware Task Scheduling (BATS) techniques have been used to ensure longer usage of a battery, while considering discharge/recharge characteristics. Smart batteries to manage the safety of battery packs have been deployed to manage concerns about high temperature, over discharge, and overcharge.

A paradigm shift to these traditional approaches would involve deploying a smarter battery into the system. Such an intelligent battery would manage the discharge or recharge of the cells while ensuring battery lifetime.

Battery safety is also managed to ensure robustness and reliability. Using an IBCA organization provides the following distinct benefits: (1) closely monitors cell status; (2) dynamically selects cells to match the device requirement, reducing loss in DC to DC converters or similar voltage and/or power regulators; (3) exploits charge recovery effect in cells, thereby giving advantages over monolithic batteries; and (4) provides the possibility of preprogramming the discharge pattern if the current profile is stable and known a priori. IntellBatt assumes no knowledge of the device as such and hence is applicable for any battery operated portable consumer electronics equipment. IntellBatt can operate in either a standalone fashion or can be combined with BATS techniques for maximum advantage [1].

In this article we introduce and compare two novel battery model named smart batteries and intelligent batteries. To this end, the second section will present the smart battery, section 3 introduce intelligent battery, in which the summery will present in the last subtitle of each section. And at last the future works is given.

2. Smart battery

2.1 Inner Workings of a Smart Battery

A speaker at a battery conference said, “The battery is a wild animal and artificial intelligence domesticates it.” Domesticating requires knowing the temperament of a battery, because an ordinary or “dumb” battery has an uncommunicative manner. Weight, color and size do not reveal its state-of-charge (SoC) and state-of-health (SoH). The user is at the mercy of the battery, and simply charging a battery does not guarantee the expected runtime.

Most batteries for laptops and similar devices are “smart,” meaning that some communication occurs between the battery, the equipment and the user. The definition of “smart” varies among manufacturers and regulatory authorities. Some call their batteries smart by simply adding a chip that sets the charger to the correct charge algorithm. The Smart Battery System (SBS) forum states that a smart battery must provide state-of-charge (SoC) indications.

An increasing number of rechargeable batteries are made smart. Smart means that the battery pack includes some level of intelligence. Equipped with a microchip, these batteries talk to the charger and inform the user of its status, such as indicating state-of-charge. Most smart batteries work on the principle of coulomb counting, a theory that goes back 250 years when Charles-Augustin de Coulomb first established the “Coulomb Rule.” Figure 1 illustrates a fuel gauge that measures the in-and-out flowing energies; the stored energy represents state-of-charge.

In 1990, Benchmarq was the first company to commercialize the concept by offering fuel gauge technology. Today, several manufacturers produce such chips. They range from the single wire system, to the two-wire system to the System Management Bus (SMBus). Let's first look at the single wire system.

There are several types of smart batteries, each offering different complexities and cost variants. The most basic smart battery may contain nothing more than a chip that sets the charger to the correct charge algorithm. In the eyes of the Smart Battery System (SBS) forum, these batteries cannot be called smart. What then makes a battery intelligent?

A circuit measures the in-and-out flowing energy; the stored energy represents state-of-charge. Definitions vary among organizations and manufacturers. The SBS forum states that a smart battery must provide SoC indications, and in 1990, Benchmarq was the first company to offer fuel-gauge technology. Today, several manufacturers offer integrated circuit (IC) chips in ***single-wire*** and ***two-wire*** systems, also known as System Management Bus (SMBus).

2.2 Single-wire Bus

The single-wire system delivers communications through one wire. A closer look reveals, however, that the battery still uses three wires. They consist of the data line that also provides the clock information, and the positive and negative battery terminals. For safety reasons, most battery manufacturers also run a separate wire for temperature sensing. Figure 2 shows the layout of a single-wire system (A single wire provides data communication). For safety reasons, most batteries also feature a separate wire for temperature sensing

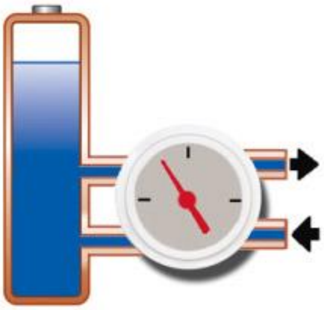

Figure 1: Principle of and fuel gauge based on coulomb counting

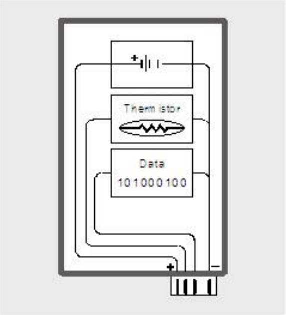

Figure 2: Single-wire system of a "smart" battery

The single-wire system stores the battery code and tracks battery readings that typically include voltage, current, temperature and state-of-charge information. Because of the relatively low hardware cost, the single-wire system is used for less complex and more price-sensitive products such as two-way radios, cameras and portable computing devices.

Most single-wire systems do not use a common form factor and this makes standardized state-of-health measurements impossible. Deviating from a set standard poses a further problem with attempting to charge diverse batteries with a universal charger. The Benchmarq single-wire solution, for example, cannot measure the current directly; this information must be extracted from a change in capacity over time. In addition, the single-wire bus only allows battery SoH measurement when "marrying" the host to a designated battery pack, and this requires a designated battery. Any deviation from the original battery will make the system unreliable or incompatible.

2.3 System Management Bus

The System Management Bus (SMBus) represents a concerted effort from the electronics industry to standardize on one communications protocol and one set of data. The Duracell/Intel smart battery system in use today was standardized in 1993 and consists of two separate lines for data and clock. Figure 3 shows the layout of the two-wire SMBus system with using a standardized communications protocol. This system lends itself to standardized state-of-charge and state-of-health measurements.

An SMBus battery contains permanent and temporary data. The manufacturer programs the permanent data into the battery, which includes battery ID, battery type, manufacturer's name, serial number and date of manufacture. The temporary data is being added during use and consists of cycle count, user pattern and maintenance requirements. Some of the information is kept for record, while other data is being renewed throughout the life of the battery.

The SMBus is divided into Level 1, 2 and 3. Level 1 has been discontinued because it does not provide chemistry-independent charging. It supported only one chemistry. Level 2 works with in-circuit charging, and a laptop servicing the battery is a typical example. Another application is a battery containing the charging circuit within the pack. Battery and support circuit in Level 2 are married to each other. Level 3 supports external SMBus chargers.

Most external SMBus chargers are Level 3 and are expensive to manufacture. Some lower-cost chargers have emerged that accommodate SMBus batteries, but they may not be fully SBS compliant. Manufacturers of SMBus batteries do not completely endorse this shortcut because of safety concerns, but pricing dictates the purchase decisions. Applications such as biomedical instruments, data collection devices and survey equipment lean towards Level 3 chargers with full-fledged charge protocols.

The original design philosophy behind the SMBus battery was to remove the charge control from the charger and assign it to the battery. With a true SMBus system, the battery becomes the master and the charger serves as slave that follows the dictates of the battery. This is done out of concerns over charger quality and compatibility with new battery chemistries in applying the correct charge and managing full-charge detection. Such a system makes charging fully transparent to the user, regardless of what chemistry is used.

Offering a charger in which the command is embedded in the battery makes sense because the universal charger can charge all compatible batteries. Algorithms of future battery chemistries convert the charger to the correct settings and the charger will never be obsolete. During the 1990s, several SMBus battery packs emerged, including the 35 and 202 (Figure 4).

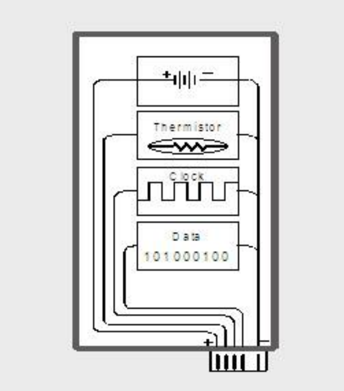

Figure 3: Two-wire SMBus system

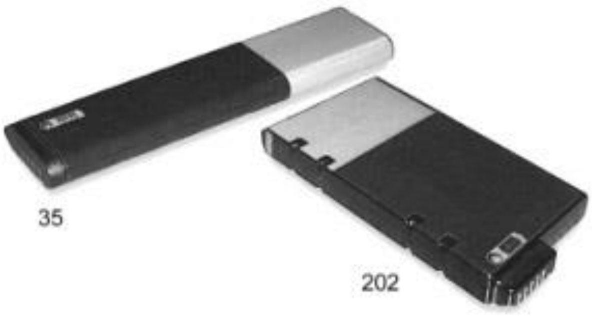

Figure 4: 35 and 202 series batteries featuring SMBus

They are available in nickel- and lithium-based chemistries, these batteries power laptops, biomedical instruments and survey equipment. Non-SMBus (dumb) versions with the same footprint are also available. Manufactured by Sony, Hitachi, GP Batteries and others, these batteries work (or should work) in all portable equipment designed for this system.

The idea was good but the desired standardization did not take hold and most manufacturers went their own way by offering proprietary packs. The reasons are to optimize the form factor and to ensure performance and safety, which can only be guaranteed with the manufacturers' own battery brands. This makes good sense, but the leading motive behind this may be pricing policies. In the absence of competition, the batteries can be sold at a premium price. To assure sole ownership, many manufacturers protect the battery with a code that is difficult to break.

2.4 Limitations

Twenty years after introducing the smart battery, the battery industry has still not solved key battery problems and this keeps haunting the users. I asked a hospital technician in the USA about the use of smart batteries and he provided me with his frank opinion. Let's examine why the smart battery does not fulfill all the promises made in the 1990s.

There is a notion that a battery indicating 100 percent SoC is good. This is not always the case because the user has no knowledge of the capacity level. The readout can be deceiving because the actual runtime is a product of capacity and SoC. Technicians also fret over the lack of standardization between manufactures, and there is little compatibility among packs. Other issues with SMBus batteries are logic problems, memory errors and glitches on low-voltage recovery. Custom-designed systems are said to be the most reliable.

Compliance among SMBus batteries and chargers is not improving. Unlike other tightly regulated standard formats, such as the long-play record introduced in the late 1950s, the audiocassette of the 1960s, the VCR of the 1970s, ISDN and GSM of the 1980s, or USB and MP3 in the 1990s, the SMBus protocol permits variations that include adding check bids to halt service if the circuit crashes, counting the number of discharges to advise on calibration and disallowing a charge if a certain fault condition occurs. While these additions are good by themselves, they cause compatibility problems with some chargers.

Ironically, the more features that are added to the SMBus battery and charger, the higher the likelihood of incompatibilities. Before implementing a system, SMBus batteries and chargers should be checked for proper function. The need to approve the marriage between battery and charger is unfortunate, given the assurance that SMBus technology would simplify life and not make it more complex.

Can this be the reason why the smart battery has not received the acceptance battery manufacturers had hoped for? When the SMBus battery was conceived in the early 1990s, cost was not as critical as it is now. Today, customers want products that are economically priced. Adding high-level intelligence to the battery may simply be too expensive for the purpose it serves. Some engineers go so far as to say that the SMBus battery is a “misguided principle.”

A SMBus battery costs about 25 percent more than the “dumb” equivalent, and this is also reflected in the charger. Instead of simplification, a full-fledged Level 3 charger must work as a hybrid by providing full charging function when charging “dumb” batteries and becoming a slave to obey the dictates of the battery on a SMBus-controlled charge. A large part of the cost is making the two systems compatible, and progress is being made in standardizing.

Besides electrical compliance, battery shape also varies and nowhere is this diversity more visible than with laptop packs. The efforts made in the 1990s to standardize on battery size did not materialize as expected and today each device comes with its own unique pack. Large-scale batteries for the electric powertrains also have their own batteries. This may one day change by making batteries with a common form factor available. For more information we presented the advantages and limitation of smart batteries in table below. The smart battery has not enjoyed the same success as with other standards, and this may have to do with lack of enforced standards [18].

2.5 Negatives of the 'smart' battery

The 'smart' battery has some notable downsides, one of which is price. An SMBus battery costs about 25% more than the 'dumb' equivalent. In addition, the 'smart' battery was intended to simplify the charger but a full-fledged Level 3 charger costs substantially more than a regular model.

Advantages	Provides state-of-charge status Records battery history such as cycle count, user pattern, maintenance requirements, etc. Reminds user of periodic service Protects battery from unauthorized use
Limitations	Adds 25% to the cost of a battery Complicates charger; most chargers for intelligent battery are hybrid and also service non-intelligent batteries Requires periodic calibration Readout only shows state-of-charge and not actual runtime

Table 1: Advantages and limitations of the smart battery.

A more serious drawback is the requirements for periodic calibration or capacity re-learning. The Engineering Manager of Moli Energy, a manufacturer of lithium-ion cell commented, "With lithium-ion we have eliminated the memory effect; but is the SMBus battery introducing digital memory?" Why is calibration needed? The calibration corrects the tracking errors that occur between the battery and the digital sensing circuit while charging and discharging.

The most ideal battery application, as far as fuel-gauge accuracy is concerned, would be a full charge followed by a full discharge at a constant current. In such a case, the tracking error would be less than 1% per cycle. In real life, however, a battery may be discharged for only a few minutes and the load pulses may be very short. Long storage also contributes to errors because the circuit cannot accurately compensate for self-discharge. Eventually, the true capacity of the battery no longer synchronizes with the fuel gauge and a full charge and discharge is needed to 're-learn' the battery.

How often is calibration needed? The answer lies in the battery application. For practical purposes, a calibration is recommended once every three months or after every 40 short cycles. Many batteries undergo periodic full discharges as part of regular use. If the portable device allows a deep enough discharge to reset the battery and this is done regularly, no additional calibration is needed. However, if no discharge reset has occurred for a few months, a deliberate full discharge is needed. This can be done on a charger with discharge function or a battery analyzer. What happens if the battery is not calibrated regularly? Can such a battery be used in confidence? Most 'smart' battery chargers obey the dictates of the chemical cells rather than the electronic circuit. In this case, the battery will fully charge regardless of the fuel gauge setting and function normally, but the digital readout will become inaccurate. If not corrected, the fuel gauge simply becomes a nuisance.

An addition problem with the SMBus battery is non-compliance. Unlike other tightly regulated standards, the SMBus protocol allows some variations. This may cause problems with existing chargers and the SMBus battery should be checked for compatibility before use. The need to test and approve the marriage between a specific battery and charger is unfortunate, given the assurance that the SMBus battery is intended to be universal. Ironically, the more features offered on the SMBus charger and the battery, the higher the likelihood of incompatibilities.

2.6 summery

SMBus battery technology is predominantly used for higher-level industrial applications. Improvements in the ‘smart’ battery system, such as higher accuracies and self-calibration and will likely increase the appeal of the ‘smart’ battery. Endorsement by large software manufacturers such as Microsoft will entice PC manufacturers to make full use of these powerful features.

‘Smart’ battery technology has not received the widespread acceptance that battery manufacturers had hoped. Some engineers go so far as to suggest that the SMBus battery is a ‘misguided principal’. Design engineers may not have fully understood the complexity of charging batteries in the incubation period of the ‘smart’ battery. Manufacturers of SMBus chargers are left to clean up the mess.

One main drawback of the ‘smart; battery is high price. In the early 1990s when the SMBus battery was conceived, price many not have been as critical as it is today. Now, buyers want scaled down products that are economically priced and perform the function intended. In the competitive mobile phone market, for example, the features offered by the SMBus would be considered overkill.

In spite teething problems and relative high costs, the ‘smart’ battery will continue to fill a critical market segment. Unless innovative improvements are made and manufacturing costs are drastically reduced, this market will be reserved for high-level industrial applications only.

3. INTELLBATT

IntellBatt is composed of three different components: cells, cell switching circuit (CSA), and battery cell array manager. Detailed information on their function and operation is presented in later parts of this section.

3.1 BATTERY CELL ARRAY STRUCTURE

The IBCA consists of three components. Figure 5 illustrates the envisioned system. The cells in IntellBatt are organized into banks of cells that are connected to the main terminals of the IntellBatt via a CSA. The IBCA manager manages the cells and determines their interconnection based on the required system load current. The SMBus interface7 between IntellBatt and the system will provide for information exchange between the two entities. For simplicity, the SMBus implementation is ignored for the purpose of this research. The following sub sections detail the structure and operation of the IBCA components.

3.2 INTELLBATT CELLS

The cells are organized as a collection of banks connected in series among themselves. Inside each of the banks there can be one or more cells connected in parallel to provide the required current rating from a selected bank. If the device has a rated voltage requirement Vdev and each cell has voltage Vcell, then the number of banks required is V_{dev}/V_{cell}. For applications like laptop computers, with standard Vdev = 10.8V ~ 11.1V and standard lithium (Li) cells with Vcell = 3.6V ~ 3.7V, there is a need for three banks of cells. For smaller devices like a portable DVD player or wireless media players with Vdev = 7.2V ~ 7.4V, the number of banks that would be needed is two. Typical battery packs uses 3 to 12 cells organized in a series or parallel combination as required. These cells provide the required load current for the target battery operated system via the CSA.

3.3 CELL SWITCHING CIRCUIT (CSC)

The CSC connects cells to deliver the required current to the target system in which IntellBatt is installed. CSC configuration is performed by the IBCA manager with a code word. The CSC has to be designed to ensure the following for the IntellBatt:

- ✓ Connect cells in banks, specified via a code word from the IBCA manager to the output terminals of IntellBatt;
- ✓ Provide rapid switch reconfiguration (order of picoseconds); and
- ✓ Support the current drawn by the system without incurring significant losses in the switch.

Figure 6 shows the detail structure of the cell switching circuit. It is a matrix of two power transistor switches that can be turned on and off by a control signal. Any cell can be connected to any bank by activating the switch at the intersection of the bank and the cell.

3.4 IBCA MANAGER

The IBCA manager is the core of the IntellBatt system. It provides the following functionalities: monitors cell status, schedules cells for load current delivery, and ensures the safety of the IBCA.

3.4.1 MONITORING

The monitoring logic in the IBCA manager keeps track of the following parameters for each cell: delivery voltage, delivery current and operating temperature. These values are used to ensure safety and to make scheduling decisions. High speed and ultra low power sensing circuits9, 10 are available so that they do not increase the load on IntellBatt.

3.4.2 CELL SCHEDULING

IBCA Manager performs cell scheduling based on two aspects of rechargeable cells: discharge cycle length and total battery life. Discharge cycle length refers to the duration for which the fully charged cell can deliver the required current. This parameter is important for handheld and portable devices because the ability to run longer in a single charge cycle is desirable. Battery life refers to the number of discharge cycles achievable before the battery becomes unusable.

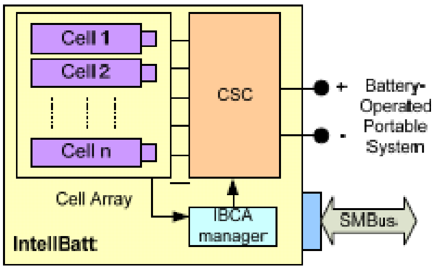

FIGURE 5: INTELLBATT STRUCTURE

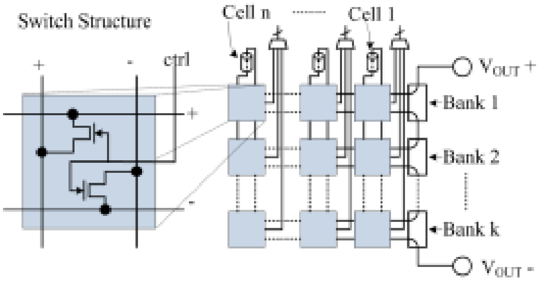

FIGURE 6: CELL SWITCHING CIRCUIT

The main properties of Li ion cells that affect the lifetime and performance of the cell are discharge current, discharge condition such as temperature, variation in the discharge current, and charge recovery effect. In general, the higher the discharge current, the lower the charge delivery capability of the cell. The optimum discharge current is a property of the cell's composition. Environmental conditions like high (> 45 °C) or low temperature (< 10 °C) have been found to reduce the capacity of the cell. If the discharge reaction is slower than the optimum rate (dependent on cell geometry), it results in substance buildup, which can clear if the cell is idle for a while. This effect is known as charge recovery and is exploited in IntellBatt.

3.4.3 SAFETY

The IBCA manager continuously monitors cell parameters like voltage level, temperature, and current. Unlike traditional smart batteries, which need to disconnect the power supply, the IBCA manager can shuffle the cells to control heat, current, etc. Thus, it provides right voltage and current, ensuring safe and non interrupt operations1.

3.5 INTELLBATT OVERHEAD

The overhead of a battery cell array based design is determined in terms of area, power, and delay. Area is not a concern since the IBCA manager and the CSC are implemented on the board level. Power and delay overheads due to the CSC are compensated by the overall benefits of the IntellBatt. The power consumed in the IBCA manager is orders of magnitude less than that of the CSC, which is of the order of microwatts.

3.6 INTELLBATT AND FUEL CELLS

Fuel cell technology is fast developing as the next generation energy source. In this section, the applicability of IntellBatt like designs to manage fuel cell batteries is examined. Fuel cell Li ion cell analogy: Figure 7 shows the key similarity points of Li ion cells and fuel cells. Similar to the charge recovery characteristic of Li ion cells, fuel cells respond to cell temperature. The chemical reaction in a typical fuel cell is exothermic; hence, the temperature of the cell increases with usage. With increased temperature, the efficiency of the cell goes down after a certain optimum point. In addition, smaller and less capacity cells are easier to manufacture and are cheaper. A larger number of smaller cells can perform better than one large cell [4].

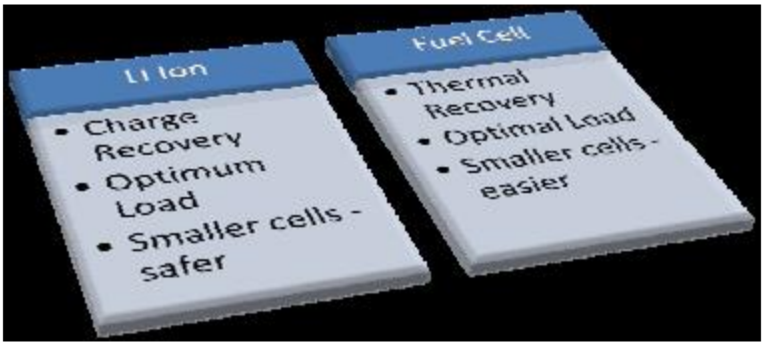

FIGURE 7: FUEL CELL VS. LI ION CELL

3.7 SUMMARY

In this part of article, IntellBatt, a novel Intelligent Battery Cell Array design has been proposed to offload battery management responsibilities from the system onto the battery. By using multiple cells and an intelligent battery cell array manager, IntellBatt exploits the charge recovery effect of cells combined with a cell scheduling scheme to deliver the required load to the system while enhancing battery lifetime. Besides this support, IntellBatt also addresses safety concerns due to the use of multi cell battery packs. IntellBatt can either be used standalone or can be combined with traditional battery aware task scheduling approaches to further enhance battery life for a portable battery operated system. Our research demonstrated the benefit of using multiple cells and cell scheduling schemes.

4. FUTURE WORKS

Future research activities in this direction will focus on a hardware prototype of IntellBatt to further validate functionality.
The temperature effect can be made more sensitive to temperature response by introducing a band gap energy modeling for CdTe solar cell as the band gap is not completely constant with the temperature.
Since today battery is the most usual energy source, managing the battery usage is up to date problem. Using battery in battery security systems and even in wireless networks is very common. These systems need to small, light and programmable batteries to the future works. These types of batteries required algorithms which can schedule tasks in battery lifetime.
Scheduling is meaningless for one battery, but when we have a network of sensors, each sensors battery can consider as one cell and the proposed algorithm can use in it. Mostly, in these networks, there are routers which their duty is to transmitting collection of data, from Sensor nod To date Sink.
To save more energy in all sensors, battery aware Routing for transmitting data must be done. Switching from one direction to other Direction Lead to charge Recovery and so it changes to battery scheduling problem.
Other thing that makes this more attractive is rechargeable batteries. In This Case not only charge recovery affects the charge of battery, but also the charge is increasing in the unit of time. In this case correct pattern for using battery makes the battery lifetime increase.

Using appropriate algorithms for battery scheduling leads batteries to become smaller, lighter and portable. Efficient Management of Enter loads To Systems, has the required Potential to Decrease battery Weight extremely. This is more Important and favorable between the soldiers that forced carrying Furniture, by their Organizations, Contains Batteries.

As we know that the number of cell is important, analyses can be made for the question "how many cell is better for smart and intellbatt?"

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