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Battery Operation Time Enhancement Based On Alternating Battery Cell Discharge

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Abstract**—**This paper proposes an alternating discharge method of multiple battery cells to extend battery operation time. In the proposed method, two battery cells are periodically connected in turn to a mobile device and only one cell supply power while the other rests. Battery operation time of the connecting cell decreases due to rate-capacity effect, while that of the resting cell increases due to recovery effect. These two effects conflict each other, but recovery effect is generally larger than rate-capacity effect and battery lifetime is extended. It was found from the result that battery operation time increase about 7% by using alternating battery cell discharge.

Keywords**—**Battery, Recovery Effect, Rate-Capacity Effect, Low-Power, Alternating Battery Cell Discharge.

I. Introduction

POWER consumption becomes an important issue with the advent of modern mobile devices. Various low-power technologies have been developed to reduce the power consumption. They cover almost every aspects of system design, including device, circuit, architecture, system, algorithm, and operating system levels. They have successfully extended the battery operation time, but recently they almost seem to reach a deadlock. Modern mobile devices still need large batteries, and some different approaches are necessary to solve this problem.

Conventional low-power technologies are mainly focused on the power consumption of the device. They assume that the electrical energy stored in the battery is constant irrespective of discharge condition. However, the chemical reactions in the battery are quite sensitive to discharge conditions. Therefore, even if same amount of energy is initially stored in the battery, the energy that can be derived varies a lot under different discharge conditions such as voltage, current, and time [1]. This gives an important idea - battery operation time of a device can be extended if the discharge voltage, current, and time are optimally controlled.

Modern mobile devices often exploit multiple battery cells to increase operation time [2]. Usually, these cells are connected in parallel in the battery pack, and all cells supply power to the device continuously and equally. However, if only some cells supply power to the device in turn, other cells can rest in turn and all cells are intermittently discharged. In the intermittent discharge, more energy can be derived from the cells.

In this paper, we propose an alternating discharge method of battery cells to extend battery operation time. In the proposed method, two battery cells are periodically connected to the device in turn and only one cell supply power while the other rests.

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II. Rate-Capacity Effect and Recovery Effect

Two major effects on the battery operation time are rate-capacity effect [3], [4] and recovery effect [5], [6].

A. Rate-Capacity Effect

Ideally, battery voltage is constant during discharge, and it drops to 0 instantly when the battery is fully discharged. Yet in reality, battery voltage slowly decreases during discharge, as shown in Fig. 1. Battery operation time is defined as the accumulated discharge time until the battery voltage reaches the lower limit of system operation voltage. Effective battery capacity is defined as (battery discharge time× discharge current), and it is total energy derived from the battery.

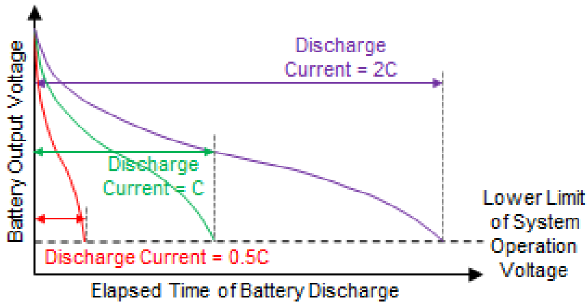

Fig. 1 Battery voltages with different discharge current (modified from [3])

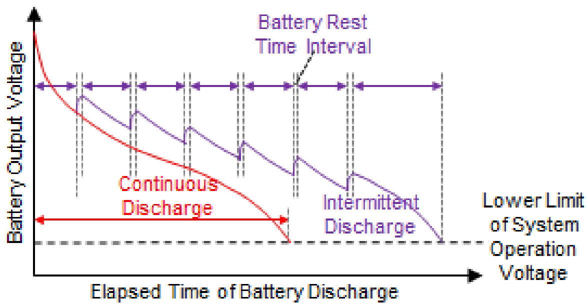

Fig. 2 Battery voltages of continuous and intermittent discharges (modified from [1] and [5])

As shown in Fig. 1, effective battery capacity decreases as discharge current increases. This is called as *rate-capacity* *effect* [3], [4]. Considering this effect, it is better to reduce discharge current to derive more energy from the battery.

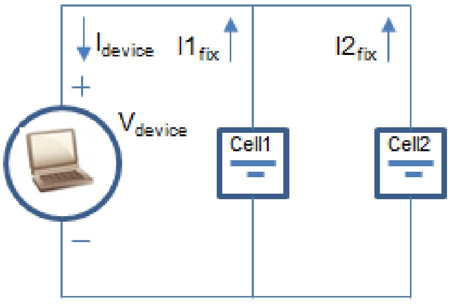

Fig. 3 Parallel connection of two battery cells

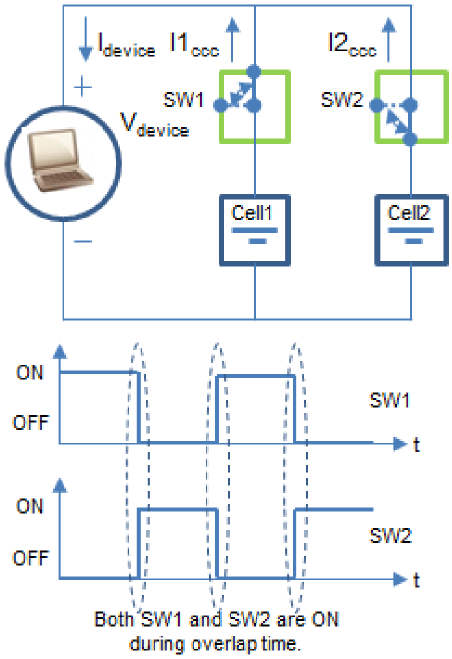

Fig. 4 Cell connection control of two battery cells

B. Recovery Effect

In general, battery operation times of continuous and intermittent discharges are quite different even if the stored energy and discharge current are same. Fig. 2 shows the battery voltages of continuous and intermittent discharges.

Battery voltage always decreases in the continuous discharge. However, when a battery rests in the intermittent discharge, the battery voltage is somewhat recovered and battery operation time increases, as shown in Fig. 2. This is called as *recovery effect* [5], [6]. This is because the electrolyte far from electrodes can deliver more electrons to the electrolyte near electrodes during battery rest time interval. Considering this effect, battery operation time can be extended when the battery cell rests.

III. Proposed Method

Assume two situations as shown in Figs. 3 and 4, where they represent the conventional and the proposed methods, respectively. In Fig. 3, the device is connected to two same battery cells in parallel. In Fig. 4, only one cell is connected to the device in turn. Note that there are some overlap time where both cells are connected, since system power should be supplied steadily during transition. In Fig. 3, $I1_{fix} = I2_{fix} = 1/2\ I_{device}$. However, in Fig. 4, $I1_{ccc} = I_{device}$ and $I2_{ccc} = 0$ for the first half period, and $I2_{ccc} = I_{device}$ and $I1_{ccc} = 0$ for the second half period. Here, subscript fix and ccc denote fixed connection and cell connection control, respectively.

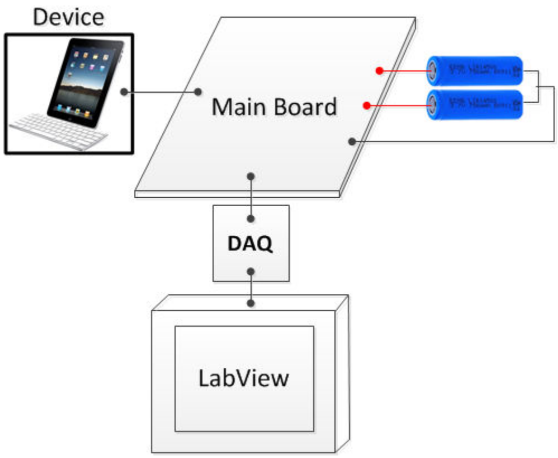

Fig. 5 Experimental setup

In Fig. 4, rate-capacity effect and recovery effect are conflicting with each other. Since $I1_{ccc}$ and $I2_{ccc}$ are larger than $I1_{fix}$ and $I2_{fix}$, effective cell capacity decreases in Fig. 4 due to the rate-capacity effect. However, there is battery rest time in Fig. 4, and the recovery effect increases battery operation time. So, the cell connection control in Fig. 4 increases system battery operation time if advantages from recovery effect defeats disadvantages from rate-capacity effect.

IV. Measurement Results

Experimental setup in this paper is shown in Fig. 5. Two 750mAh Li-ion batteries are connected to an iPad2™ via two discrete-device solid-state current switches on the main board. These switches are controlled by DAQ™ (data acquisition device). DAQ generates control signals of the switches. It also measures supply voltages, battery discharge voltages, and battery discharge currents. LabView™ is a software package controlling DAQ. It sends current switch control command to DAQ and acquires measured data from DAQ. By programming LabView, hardware is easily controlled in a software manner. LabView also determines the connection modes and records battery operation time.

Initial voltage of fully charged Li-ion battery is $V_{device,initial} = 4.2V$, and system malfunction occurs at $V_{LL} = 3.3V$. It was observed that $V_{PL} = 3.6V$ shows best performance. Voltage transition, battery operation time, and connection mode are shown in Figs. 6 and 7.

Table I shows the simulation results. Average battery operation times of the conventional and the proposed methods are 9733 and 10418 seconds, respectively. Power consumption overheads of current switches are considered and included in the results. Thus, the proposed method improves the battery operation time by 7%.

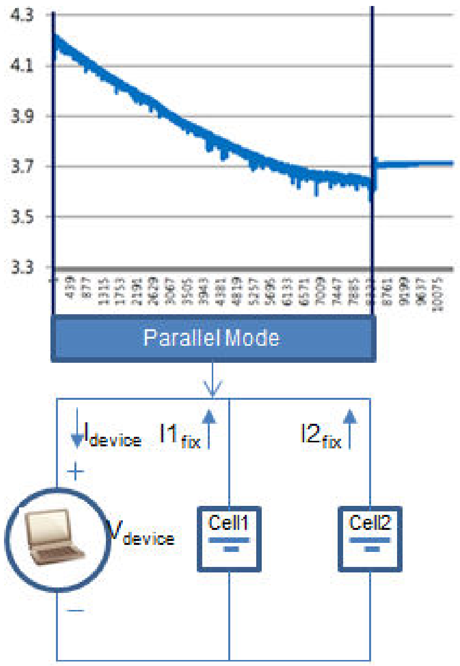

Fig. 6 Voltage transition and mode change in the conventional method

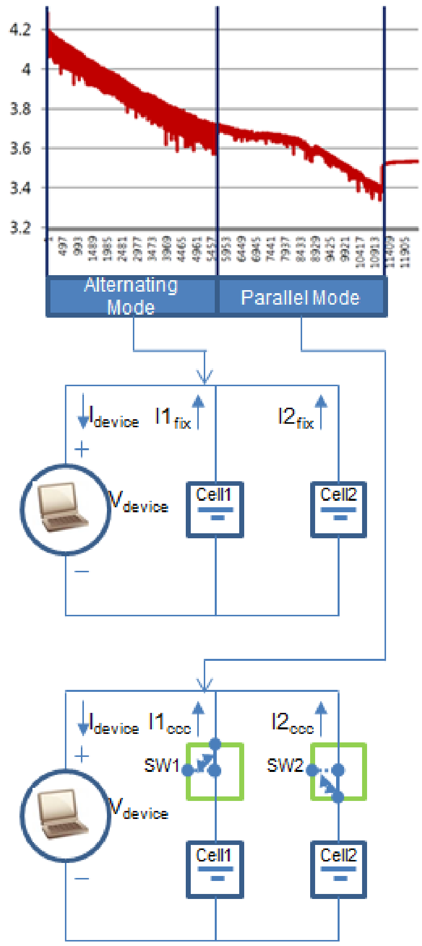

Fig. 7 Voltage transition and mode change in the proposed method

TABLE I
MEASUREMENT RESULT

Experiment	#1	#2	#3	#4	Average	Improvement
Conventional	9707s	9689s	9667s	9869s	9733s	-
Proposed	10179s	10367s	9935s	11194s	10418s	7.04%

V. CONCLUSION

In this paper, alternating battery cell discharge method was proposed to extend battery operation time of mobile devices. When switching the battery cells, rate-capacity effect shortens battery operation time, while recovery effect extends it. However, advantage of the latter is larger than disadvantage of the former, so battery operation time is finally improved. Simulation results show that the battery operation time increased by 7%.

This improvement can be achieved by only adding current switches and timing circuits in the battery pack, and the device does not need to consider the switching operation. This method is totally independent of other low-power technologies. So it can get additional battery operation time with no performance degradation even if the device was fully optimized in power consumption.

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REFERENCES

[1] Y. Jang, H. Yang, and S. Lee, “Battery-aware wireless video transmission based on battery recovery effect”, *Proceeding of IEEE Conference on Consumer Electronics*, pp. 418-419, 2012.
[2] J. Nam, J. Choi, J. Baek, and H. Hwang, “A study on cell equalizing of secondary battery”, *Proceeding of Power Electronics Annual Conference*, pp. 143-145, 2006. (in Korean)
[3] M. Doyle, and J. Newman, “Analysis of capacity-rate data for lithium batteries using simplified models of the discharge process”, *Journal of Applied Electrochemistry*, vol. 27, no. 7, pp. 846–856, Jul. 1997.

[4] F. Qin, M. Wahab, Y. Wang, and Y. Yang, "Battery recovery aware sensor networks", *Proceedings of Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks*, pp. 203-211, 2009.
[5] T. Martin, "Balancing batteries, power, and performance: system issues in CPU speed-setting for mobile computing", *PhD Thesis, Carnegie Mellon University*, 1999.
[6] V. Rao, G. Singhal, A. Kumar, and N. Navet, "Battery Model for Embedded Systems", *Proceeding of International Conference on VLSI Design*, pp. 105-110, 2005.

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