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EKF Based SOH State Estimation Algorithm for UAV Li-Po Battery Pack

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Abstract Ignorance of battery pack life could bring unexpected UAV crashes and so the SOH estimation became a next important factor to the SOC estimation. In contrast to the EV applications, the small UAV could not carry heavy and complex BMS and so it is required to apply a simple, light, cheap, but powerful BMS to prevent any accident. In this paper, we show two SOH estimation methods, using internal resistance and using SOC_I and SOC_V with CF. Results show that the SOH becomes about 92% after 30 number of discharging cycles.

• Key Words : CF, EKF, SOH, UAV

요 약 배터리 팩 수명에 대한 무지는 무인항공기의 추락을 야기할 수 있으며 이로 인해 잔존수명 예측이 잔존용량 예측에 있어서 중요 요소가 되었다. 전기자동차와는 달리, 소형 무인항공기는 무겁고 복잡한 배터리 관리 시스템을 운반 할 수 없기 때문에, 사고를 예방하기 위해서는 간단하고, 가볍고, 저렴하고, 강력한 배터리 관리 시스템을 적용하는 것이 필요하다. 본 논문에서는, 두 가지 잔존수명 예측 방법들을 보여주는데, 한 가지는 내부 저항을 이용하는 것이며 다른 한 가지는 상보필터를 이용한 SOC_I와 SOC_V를 사용하는 방법이다. 결과를 통해 30 방전 사이클 후의 잔존용량은 92%로 계산되었다.

• 주제어 : 상보필터, 확장칼만필터, 잔존수명, 무인항공기

1. Introduction

As the unmanned aerial vehicle (UAV) implementation increases in a variety of fields [1,2,3,4,5], knowing the exact state of health (SOH) of Li-Ion battery pack is highlighted to prevent possible collapses of UAVs. Ignorance of SOH brings failures to catch under voltage (UV) or over voltage (OV) limits and would eventually result in catastrophe accidents.

In contrast to the matured technologies to estimate state of charge (SOC), there are not enough proven trustworthy estimation methods for SOH [6,7,8,9]. This is due to the difficulty to collect aging data of Li-Ion

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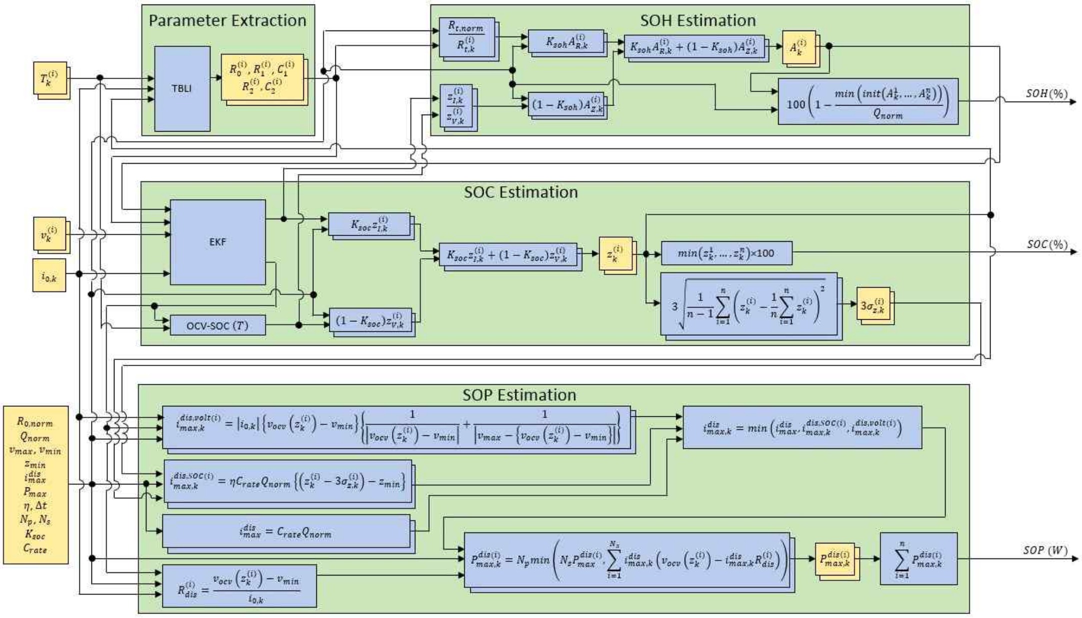
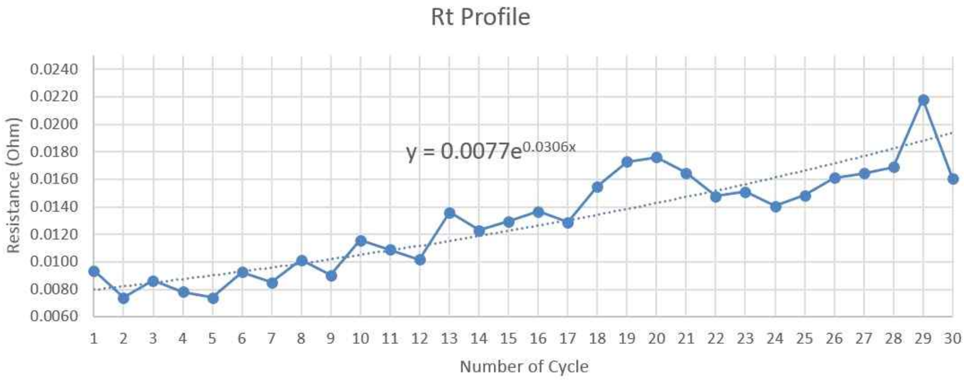


[Fig. 1] Overall battery state estimation logic



[Fig. 2] The R_t profile

or Li-Po cells since normal Li-Ion and LI-Po cell has several hundreds of cycle times. If some rest time, one or two hours, is applied at the beginning and the end of each charge-discharge cycle, the data collection time would even take longer.

In general, aging data collection of a particular cell takes several months depends on the cell type, application type, c-rate, and etc. and this is only with an assumption that there is no unexpected equipment failures, data collection failures, and etc. Due to the previously mentioned difficulty of collection aging data of a cell, there are not many research works showing the accuracy of the SOH, in particular, regarding the UAV application [10,11,12,13].

This paper explains a real-time SOH estimation method focusing on the UAV application. In contrast to the electric vehicle (EV) application, the UAV could not carry heavy payloads and even slightly increased payload results in drastically decreased flight time. So, it is highly recommended to apply a simple and light battery management system (BMS) for the UAV application and even cheap BMS for the small size radio-controlled (RC) UAVs.

The flow of this paper is as follows. In Section 2, SOH state estimation logic is explained. Section 3 explains test cases for the aging test. Section 4 and Section 5 shows experiment setup and corresponding results and Section 6 contains the conclusion of this paper.

2. SOH State Estimation Algorithm

Overall SOH state estimation logic is shown in [Fig. 1] where subscript k represents the present time index, superscript i denotes the i-th cell in a battery pack, and n denotes the total number of cells in a battery pack [14].

Here, please note that the extended Kalman filter (EKF) is applied to calculate SOC_I in the SOC estimation part which eventually affecting the SOH estimation.

The EKF is one of the most widely applied estimation method performing greatly with the Gaussian linear system model and its performance has been proven from many practical examples. However, it brings complex computations and requires decoupling of the state variables. Detailed derivations of the estimation vector and covariance vector propagation of the EKF algorithm are omitted in this paper since it is a general method [15].

The SOH estimation is calculated by integrating two separate calculations; 1) using varying R_t parameter value; 2) using varying slope values of z_I and z_V.

2.1 Using Internal Resistance Value

As the cell grows old, internal resistance values increase. Depends on ECMs, the internal resistance value would slightly differ and we would use R_t value as the sum of internal resistance with the chosen two ladder ECM model [16].

Here, the R_t is calculated by looking at the sharp voltage drop at the beginning of the open circuit voltage (OCV) discharging curve ([Fig. 4]) and by using the equation as,

$$R_{t,k}^{(i)} = \frac{v_k^{(i)}}{i_{0,k}} \tag{1}$$

where i_0 is the applied current (A) and v is the cell terminal voltage (V). The calculated R_t with the increasing number of cycles is drawn as shown in [Fig. 2].

The R_t value can be applied to calculate SOH as,

$$A_{R,k}^{(i)} = \frac{R_{t,norm}}{R_{t,k}^{(i)}} \tag{2}$$

where $R_{t,norm}$ is the initial resistance value (Ω), R_t is the internal resistance value (Ω), and A_R is the aging factor corresponding to the resistance (1).

2.2 Using SOC_I and SOC_V Values

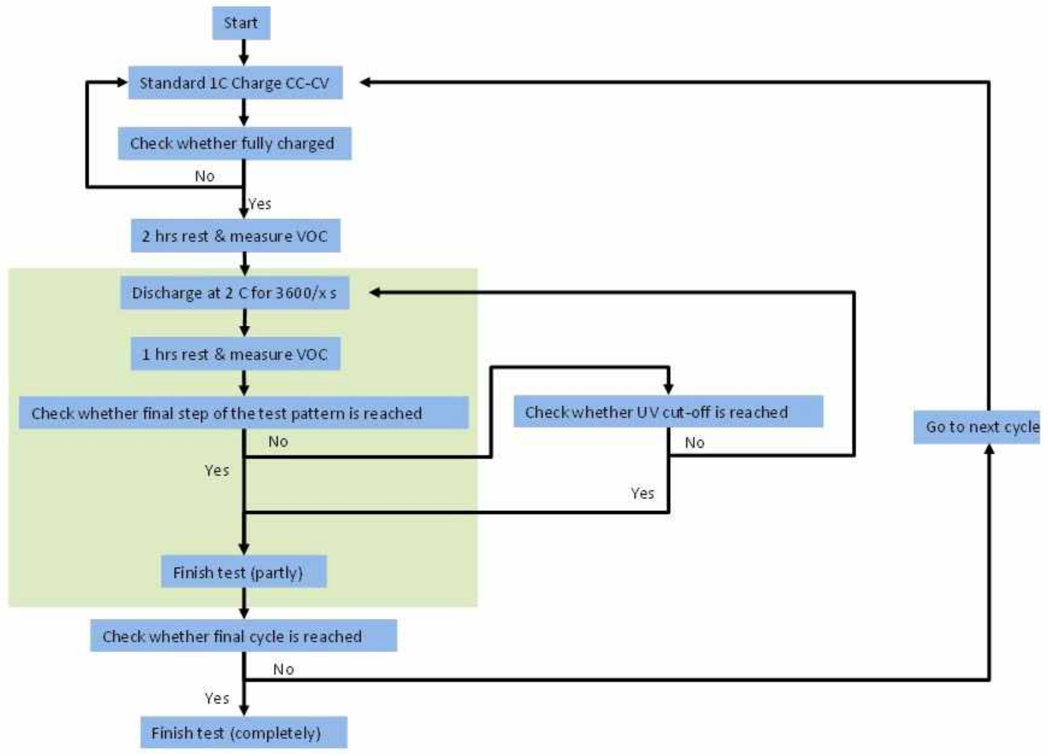
The amount of cell aging can also be quantified using SOC_I and SOC_V values where SOC_I is the SOC calculated by using the cumulative current integration method and SOC_V is the SOC calculated by referring OCV-SOC curve.

The SOC_I is accurate during a short period of time but it becomes vulnerable as time flows since errors are also integrated. On the contrary, the SOC_V is quite inaccurate during short period of time since it is estimated using OCV-SOC curve based linear interpolation method, but the SOC_V can be used as a reference value regardless of time. So, SOC_I and SOC_V values are complementary each other.

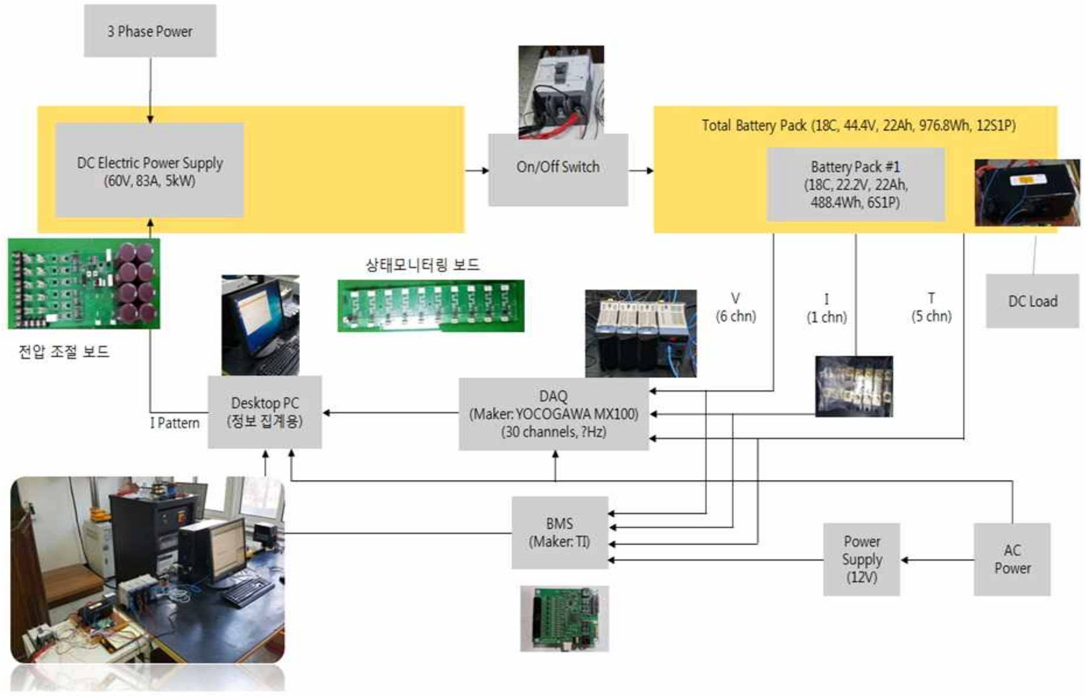
The SOC_I and SOC_V values can be used to calculate SOH as,

$$A_{Z,k} = \frac{z_{I,k}}{z_{V,k}} \tag{3}$$

where z_I is the SOC_I (%/100), z_V is the SOC_V (%/100), and A_Z is the aging factor corresponding to the SOC (1).



[Fig. 3] Aging test schedule



[Fig. 4] indoor test environment

2.3 Using CF

The previously calculated $A_{R,k}$ and $A_{Z,k}$ can be integrated by using the complementary filter (CF) as,

$$A_k = K_{soh} A_{R,k} + (1 - K_{soh}) A_{Z,k} \quad (4)$$

where K_{soh} is the CF coefficient and A is the final aging factor (1). Throughout this paper, we used $K_{soh} = 0.5$.

Since we need to consider the battery pack rather the individual cells, we calculate the SOH of the battery pack as,

$$SOH_{pack,k} = 100\left(1 - \frac{\min\left(init\left(A_k^1, \ldots, A_k^n\right)\right)}{Q_{norm}}\right) \quad (5)$$

where $SOH_{pack,k}$ is the SOH of the battery pack (%) and Q_{norm} is the initial capacity of the battery pack (Ah). Here, we use the minimum A value among n number of cells to conservatively estimate SOH value.

3. Test Case

Aging tests are performed to gather varying OCV data as cells grow old using the constant current discharge pattern as shown in [Fig. 3].

Tests are executed with a beginning of life (BOL) battery pack until it becomes about an middle of life (MOL) battery pack having 90% of initial capacity.

4. Experiment Setup

The indoor and outdoor test environments are shown in [Fig. 4] and [Fig. 5].

[Fig. 5] Outdoor test environment

5. Experiment Result

The OCV curves with total 30 times of discharging tests are shown in [Fig. 6]. Here, we can notice that the OCV curves shift as the number of cycles increases.

The varying SOH curve corresponding to the increasing number of cycles is finally obtained as shown in [Fig. 7] and <Table 1>. Here, we can notice that the SOH value decreases as the number of cycles increases. It means that the full charge capacity decreases as the number of cycles increases.

<Table 1> The SOH value corresponding to the increasing number of cycles

Number of Cycles	SOH (%)
1	95.47
10	94.75
20	93.67
30	92.22

6. Conclusion

The battery SOH state estimation method based on the EKF is described. According to the results, a BOL battery pack is already aged ($SOH = 95.47\%$), since it is kept unused for about a year. Also, we could notice that the SOH becomes about 92% after 30 discharging cycles. From the results, we verified that the SOH value indeed decreases as the number of cycles increases. In the future, increased number of discharging tests will be performed and compared with the calculated SOH estimation values.

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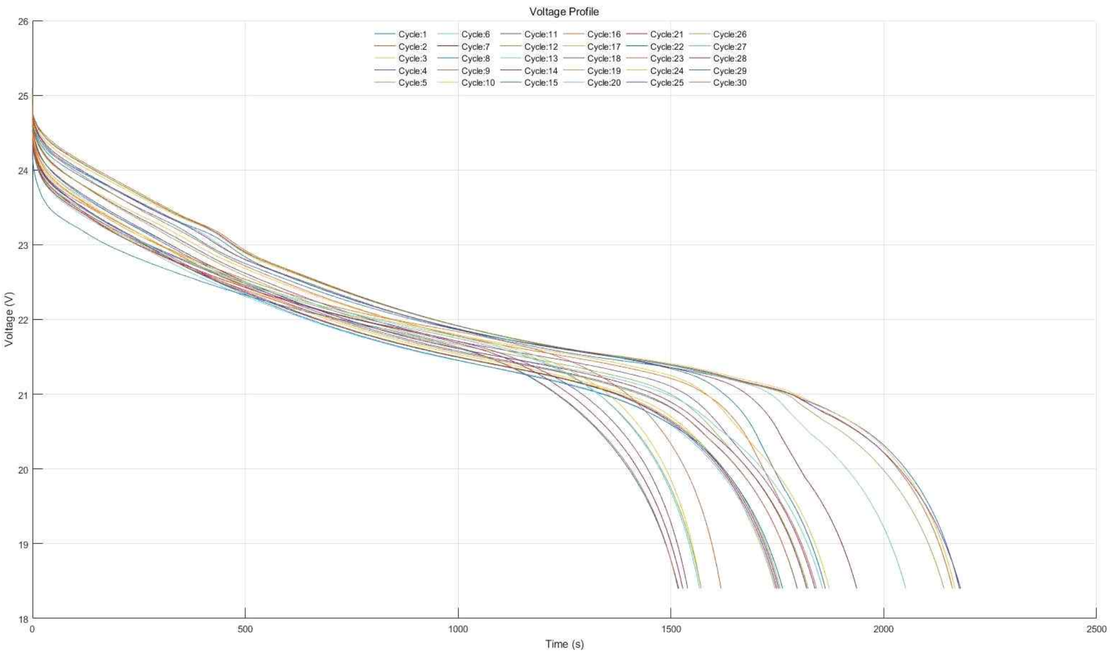
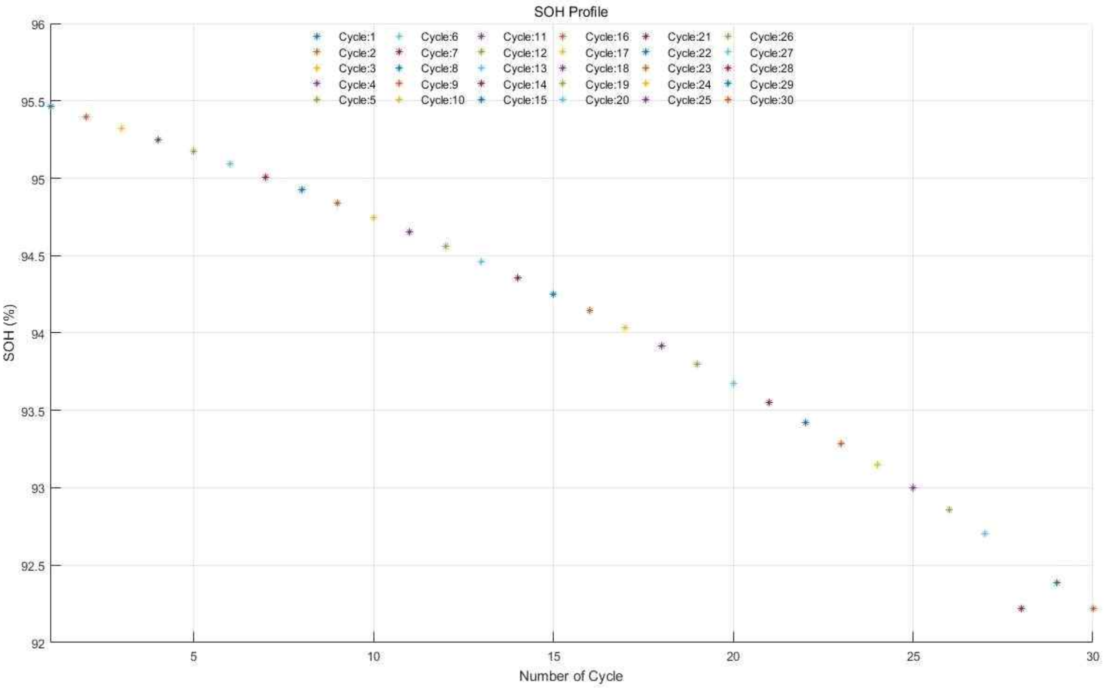


[Fig. 6] Aging test schedule



[Fig. 7] The SOH curve corresponding to the increasing number of cycles

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