Study of Battery Management for Micro Air Vehicle Power System

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***Abstract* –Micro air vehicle has attracted significant attention on its potential application. This report studies the possible combination of selected available commercial batteries, propellers, motor, transmitter, receiver and electronic speed controller to provide maximum lift force under present restriction of micro air vehicle requirement. The possible combinations are suggested.**

All systems of unmanned aerial vehicle with strict limitation of weight and size must accomplish the mission in the conditions of low noise, long-range flight, and fast response. The requirement for accuracy is pretty restricted. This study explores the combination fulfilling the requirement, and utilizes power supply and micro components of transmit system available in the market to carry out optimal combination. We planned to select battery, motor, propeller, transmitter, receiver, and electrical transmission to carry out optimal combination to be used as power supply system of MAV (Micro Air Vehicle).

Keywords: power management, micro air vehicle, lithium battery, propeller.

I. INTRODUCTION

If MAV utilizes Internal Combustion Engines as propulsion system, the heat energy efficiency is lower, but the high power density could supply sufficient propulsion power for MAV. However, the disadvantage is too noisy, so it is not proper to the MAV; and this type of engine would be affected by the climate more easily. Therefore, most existing developed micro(small) air vehicles are equipped with combination of micro-motor and secondary battery [1] for power supply.

Secondary battery (rechargeable battery) can be used as power supply for remote communication and image transmission systems in micro air vehicle because of its reusable feature [2-3]. Therefore, it is the first choice of power supply in this study. Features of battery such as electricity storage capacity, energy density, power density, discharge rate, voltage, weight, price, auto-discharge rate, sand the circular life for recharge and discharge are all under considerations.

All kinds of secondary batteries indicate Cadmium-Nickel battery has higher power density; it can release the maximum energy in unit time. Actually, since the inner resistivity is low, when large current is supplied, the voltage has little change during discharging. It seems that the secondary batteries are more appropriate for powersupply of MAV. However, the voltage of Ni-Cd battery is small (about 1.2V), for common receiver and server which require voltage from 4.8V to 6V, 4 to 5 batteries would be required. The additional weight of battery would increase the weight of MAV during taking off. Another disadvantage of Ni-Cd battery is that the capacity is small, and energy density is low. If it supplies the energy for motor, the time of usage would be extremely short due to large current discharging, and it could not complete MAV mission. In addition, the increase of discharge rate would further decrease the battery power and shorten the life span of battery.

As to MAV, if chosen existing Ni-H battery, the weight would be still the major issue. Voltage of Lithium battery is about triple of Ni-Cd battery, the advantage is low energy density, light weight, small volume, and large capacity[1,3], which would be more appropriate for fulfilling requirement of MAV. The restrictions are high internal resistance, when discharge large current, the voltage of battery would drop dramatically, output power would be decreased and affect the driving force of the motor.

Various secondary batteries have various disadvantage and advantage when applied in MAV, the optimal battery product for application in MAV is still absent. For now, there is not one kind of battery can be applied broadly to all sizes of MAV.

Electrical transmission would provide different current to produce different driving force in accordance with signal. There is an upper limit of current, to elevate the upper limit would definitely increase the weight. If the weight is too large, the loading would be increased and affect the sensitivity and success of the vehicle as well. This study would consider factors mentioned above to carry out testing and look for the optimal combination [4].

Uses should be efficiently informed of present residual current and issues regarding lack of current should be efficiently to deal with the issue on time. The test for electric capacity is focused on the following criteria:

- Inform user of the working time corresponding to present residual electric capacity
- Reserve sufficient time for dealing with the issue of current shortage
- Avoid hazard resulted from over discharge of battery

II. SYSTEM STRUCTURE

Based on different studies of battery management [8-16], the power management system of micro air vehicle in this article is illustrated in Figure 1. It is mainly composed of microprocessor control circuit and battery voltage detection circuit. The following would describe different parts respectively system.

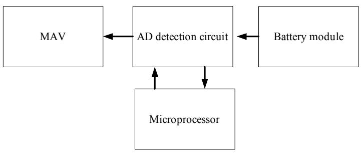


Figure 1. System block diagram

A. Microprocessor control circuit

Power management control circuit core of this system is a single chip microprocessor. Advantages of using microprocessor are lower circuit complicated level, lower circuit cost, increase design flexibility and programmable level [5-7]. Therefore this article utilized HT46R23 developed by Holtek semiconductor Inc. as the processor. There are maximum 23 bi-directional I/O pins, 8 channels 10 bytes resolution analogy/ digital transmission, 2 sets of PWN modules and one 16 bytes timer. Used analogy/ digital transmission of microprocessor with output voltage of battery set and current feedback sampling circuit to carry out microprocessor power management to accomplish optimal control of microprocessor and achieve better flight range. In addition, microprocessor still needs to detect battery voltage for battery set switch management. When individual battery set voltage reaches 10.8V, the system will switch to next battery set to provide capability of continuously flying.

B.Battery set output voltage and current feedback sampling circuit

What illustrated in Figure 2 is battery voltage and current feedback sampling circuit of power management system in micro air vehicle. Since this system utilizes 3 lithium series batteries, the voltage upon battery set is 11.1V, and the maximum voltage is 12.5V. Because upon the channel of analog/ digital transmission in microprocessor, the input voltage must be in the range between 0V~5V, battery set voltage would be first passed voltage division network and then connected to analog/digital transmission channel of microprocessor. The resistance value of voltage division network is calculated as the following:

$$V_{sense} = V_{BT} \times \frac{R_1}{R_1 + R_2} \leq 5V \qquad (1)$$

Resistances of voltage division are respectively R_1=10kΩ、R_2=20kΩ.

Output current in this article utilized low resistance resistor as current detecting component, which detects the magnitude of current by difference of voltage division. For simplifying the system, therefore only utilized resistance matching to obtain reasonable detection range and eliminated the traditional method of enlarging signal by OPA to decrease system energy consume and complicated level. Therefore the set resistance value is lower here (about only 0.5Ω), when the motor uses maximum current 7A, we can obtain 3.5V transmitted signal upon detecting resistance. This signal falls in the normal input range of single chip.

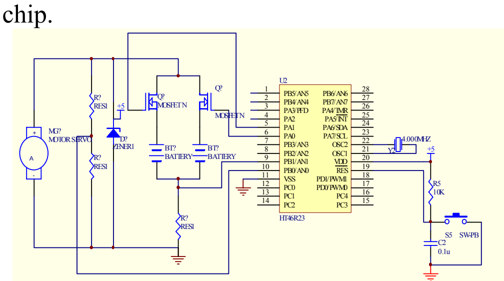


Figure 2. System circuit diagram

C. Lithium battery set

This study chose to use serial connection of lithium battery with the specification below. We series connect three lithium batteries to become an 11.1V battery set. Two battery sets used in the system. The specification of battery is listed as Table 1. Electrolyte in typical lithium battery is flammable organic solution; therefore over-charge or over-discharge would cause the hazard of inflammation or burst. That would make the power management of lithium battery more important.

Table 1 . Electric characteristics of lithium battery

Item	Specification	Remark
Nominal Capacity	3700mAh	0.2C discharge
Nominal Voltage	3.7V	
End Voltage	2.75V	
Charging Current (Std.)	0.2CA(=740mA)	0~+40°C
Charging Current (Max.)	1.0CA(=3700mA)	0~+40°C
Charging Voltage	4.2 ± 0.03V	
Charging Time (Std.)	6~7.0 hours	
Charging Time (Max.)	2~3.0 hours	
Discharging Current (Std.)	740mA	-20~+60°C
Discharging Current (Max.)	7400mA	-20~+60°C
Internal Resistance	<20mΩ	AC Impedance 1KHz
Weight	73.25g	

D . Lithium battery set protection mechanism

For protect from unpredictable error happened to micro air vehicle in flight phase, battery set is equipped with protection mechanism. First the limited current resistance to restrict the maximum current and avoid damage of system and motor resulted from over current and results in fail of mission. Except for limited current, over-discharge alarm mechanism is also added to the system control. When mal-action of system causes malfunction of battery set switch and results in over-discharge of system, the system must give alarm and carry out immediate risk management.

E. Temperature detection

This system would detect temperature of environment and battery. It will detect battery temperature when the battery is functioning, when any abnormal elevated temperature occurs in battery, the system will carry out appropriate protection mechanism to avoid hazard of inflammation and burst resulted from battery temperature elevation. Detection of environmental temperature, this parameter can provide control for flight phase of micro air vehicle to avoid micro air vehicle entering hot environment and affect control and communication functions and results in failure of mission.

F. Battery aging determination

Battery aging issue is often one of the causes for system instability. When error occurs between battery capacity and system predicted capacity, the system has to record and send out error value to provide user the reference for battery aging determination and replace the energy storage system in time.

G. Power management

Micro air vehicle must have optimal control for fire-up, flight phase, cruising and return evaluation. Therefore, power management is very important. To avoid lose of information in flight procedure, MAV has to calculate the residual flight time through systemized power management to make MAV expresses the optimal control and information in flight phase and transmit related information to related users before termination of power supply to obtain most accurate information. This functional flow chart of this system is illustrated in Figure 3. The system eliminated parallel connection method and uses combination of power management and switching control. That way would avoid interference between batteries with different status and ensure maximum efficiency of individual battery.

As shown in Figure 4, in power management control system, one of the cores is estimation of required current capacity for return flight to reserve sufficient for MAV flight mission. When the capacity of battery reaches the system predicted return point, MAV will launch return message, reduce to rotation speed of air vehicle and executive return activity control to return to control base.

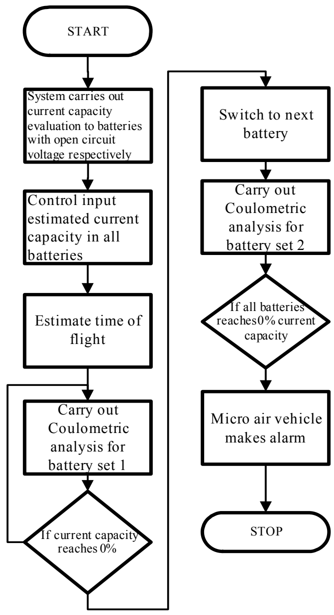


Figure 3. System flow chart

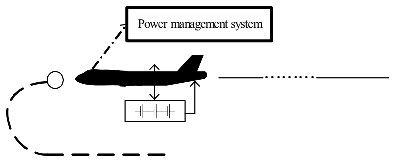


Figure 4. Return point control illustration

III. METHOD

3.1 Optional specification

A.Battery specification

Series connected by three 3.7V lithium batteries respectively. The weight including connector is less than 90 grams. The current capacity is above 800mAh. The chosen batteries are as the following:

- ➢Battery 1:11.1V, current capacity 850mAh, weight 46g.
- ➢Battery 2: 11.1V, current capacity 1300mAh, weight 75g.
- ➢Battery 3: 11.1V, current capacity 1250mAh, weight 86g.

To activate the battery for ten times before usage, the temperature of discharging environment: 25～30℃; stop discharge when voltage on battery reaches 9V; temperature of charging environment: 25 ～ 45℃; storage temperature: -10～10℃.

B. Propeller specification

The first two digits are length (inches) and the later two digits are circular pitch (inches/10). Fig. 5 is type of batterys and propellers.

✓6030(length 6 inches, pitch 0.3 inches)
✓5030(length 5 inches, pitch 0.3 inches)
✓4220(length 4.2 inches, pitch 0.2 inches)

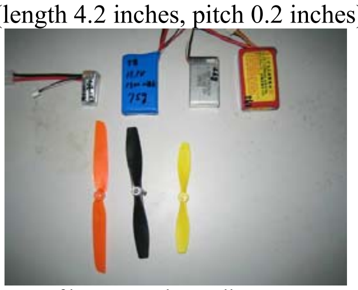


Figure 5. Type of batterys and propellers

C. Motor specification

The motor chosen to be used in this study weighted 25g, its maximum rotation speed is 21000RPM (without loading); maximum current is 7A. 9 poles brushless high magnet outer rotor motor, stator is protected by high strength resin to resist high temperature and create low vibration.

D. Brushless motor controller

Frequency can be switched among 11KHz、22KHza and 41KHz; can be used with existing brushless motor selling in the market, the low voltage disconnection setting is 7.2V. Figure 6 1s structure of test platform.

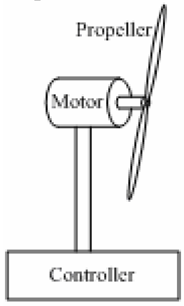


Figure 6. Structure of test platform

3.2 Battery testing

Charged by 200mA constant current, it would stop charging until the battery voltage reaches 12.5V and record the time. The battery is continuously discharging with 0.3A constant current and will stop discharging until the battery voltage reaches 7.9V and record the time.

Combined three types of batteries and three types of paddles and measure the voltage value, propeller force and propeller rotation speed. Set all batteries to discharge with 3A and record the required time and propeller force when voltage drops from 12.5V to 9V.

IV. RESULT AND DISCUSSION

In Figure 7, it shows the relation between voltage and time during secondary battery charging phase (curve a) and relation between current and time (curve b). We can see from curve (a), when t=13,000sec, voltage value can raise from 10V to 12.5V; from curve b, we can see when t=13,000sec, current would drop from 0.2A, when t=20,000sec approximately, the current is approaching zero and the battery charging has finished.

In Figure 8, curve c indicates the variation of voltage versus time. From the variation of curve c, it is shown that voltage value stays stable, dropping from 12V to 7.9V takes about 9,000sec; and the current (curve d) remains table at 0.3A.

Calculated from data in Figure 7 and 8, it shows the charging capacity is 760mAh（area of curve b I-t in Figure 7）, discharge capacity is 730mAh（area of curve d I-t in Figure 8）. After compared two values, it indicates the discharging rate reaches 96%.

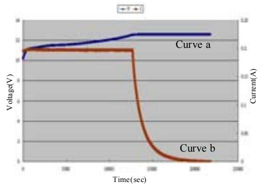


Figure 7. Charging phase: Relation among voltage, current and time

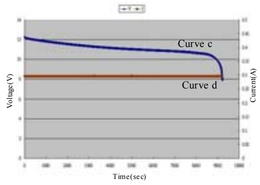
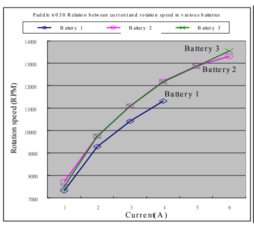
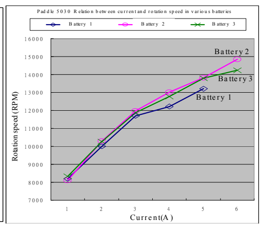


Figure 8. Discharging phase: Relation among voltage, current and time

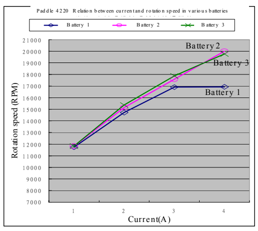
In fixed propeller type, we compared the relation between rotation speed and current among three different batteries. It is illustrated as Figure 9. (a)(b)(c). In Figure 9.(a) and (b), they both show that the larger input current value would lead to larger paddle rotation speed. However, in Figure 9.(c), when battery reaches over 3A, the rotation speed will not increase even with higher input of current. That means, propeller force does not increase accordingly. What is worth our attention is that battery 3 expressed largest rotation speed 13,500 rpm when used with paddle 6030 (Figure 9. (a)); battery 2 showed greater rotation speed when used with paddle 5020 and paddle 4220 (Figure 9. (b) and 9. (c)). That said, it is better to use battery 2 when using paddle 5020 or 4220.



(a)



(b)



(c)

Figure 9. In fixed propeller type, relation between rotation speed and current among three different batteries (a) Paddle 6030 ;(b) Paddle 5030;(c) Paddle 4220.

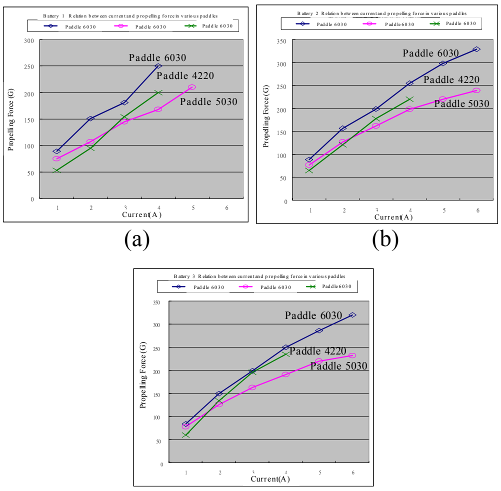
In fixed battery type, we compared the relation between current and propelling force among three different paddle. The results are shown as Figure 10. (a)(b)(c). When using battery 1 with paddle 6020 would accomplish maximum 250 g propelling force; whereas the propelling force of using with paddle 4220 is larger than with paddle 5020 when the current is over 3A (Figure 10. (a)). When using battery 2 (Figure 10(b)) with paddle 6020 can accomplish maximum propelling force, if instantaneous elevation of propelling force (such as climbing requirement), battery 2 with paddle 6030 obviously performs better than with the other two paddles. When using battery 3 (Figure 10. (c)) with 6030 still has the best propelling force; with 4220 paddle below 4A, the propelling force is still close to 6030. In addition, since paddle 4220 is lighter than paddle 6030, we should consider choosing paddle 4220.

In this test, from combination of battery and paddle, data of propelling force, time and momentum could be obtained and summarized as the following. We can see:

1、When using battery 1, combined with 4220 will accomplish maximum momentum.
2、When using battery 2, combined with 6030 will accomplish maximum momentum.
3、When using battery 3, combined with 6030 will accomplish maximum momentum.
4、In fixed paddle 6030, combined with battery 3 would accomplish maximum momentum.
5、In fixed paddle 5030, combined with battery 3 would accomplish maximum momentum.
6、In fixed paddle 4220, combined with battery 2 would accomplish maximum momentum.

Table 2. Propelling force, time and momentum corresponding to various combinations of battery and paddle

		Paddle 6030	Paddle 5030	Paddle 4220
Battry1	Propelling force (g)	244	174	180
	Time (sec)	297	294	587
	Momentum(g*t)	72468	51156	105660
Battery2	Propelling force (g)	272	182	180
	Time(sec)	903	1056	1158
	Momentum(g*t)	245616	192192	208440
Batter3	Propelling force (g)	256	186	181
	Time(sec)	1295	1204	1056
	Momentum(g*t)	331520	223944	191136



(a) (b)

(c)

Figure 10. In fixed battery type, relation between propelling force and current among three different paddles (a) Paddle 6030 ;(b) Paddle 5030;(a) Paddle 4220.

V. CONCLUSION

Evaluation of battery management system applied to micro air vehicle discussed in this article could provide more efficient control to evaluation of power system of micro air vehicle, and elevate accomplish rate of mission implementation, moreover, to avoid lose caused by micro air vehicle collapse and resulted from error in current capacity control. Except for to avoid failure of flight mission, by calculation and accurate control of current, micro air vehicle can be provided with control with longer flight range, sufficient usage of battery and appropriate feedback of system operation status. Operator can be provided with more clear status and all kinds of information.

Battery management and circuit control in this study would be able to detect various characteristics and allow micro air vehicle to be placed in optimal situation. Except the battery management system mentioned in this article, it is possible to provide micro air vehicle with more stable power source if it can combined with other energy-saving control such as utilizing other power recharge battery, control of motor activation to reduce energyconsume, or ever more, to look for energy storage system better than lithium battery such thin-film battery [18] to reduce the weight; lately launched Li-Fe battery[19], which has advantages of high circulation times, high safety, long life span and high temperature tolerance.

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