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Power Estimation of a Battery in a Single-Wheel Mobile Robot by a Motion Analysis Approach

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Abstract – The estimation of battery state is quite important for the dynamical systems powered by a battery. This paper proposes a simple method of estimating the battery power state by the motion analysis of a single-wheel robot system, GYROBO. According to balancing control of single-wheel robot using gyroscopic effect, the condition of power can be estimated by the proposed warming up method. This method has advantages in its simplicity and practicability without the help of any electrical sensor. The proposal is verified by experimental studies.

Keywords – Battery state estimation, motion analytical sensing, single-wheel robot.

1. Introduction

The check of the power state is an essential work in operating dynamical systems, specially in the autonomous mobile robots [1]. Automaic estimation of the power is eccential for multiple mobile robots when the continuous work is required in its terain. Recently, automatic charging systems are widely used in the vaccum cleaning mobile robots in the commeral market.

GYROBO, which is a single-wheel mobile robot developed at Chungnam National University, has a mechanical amplifier in the system structure [2-3]. The gimbal system or CMG(Control Moment Gyro) produces a gyroscopic force using a flip motion of the highly spinning flywheel. CMG has an analogous characteristic with the transistor as an electrical amplifier device. By controlling a small amount of gimbal motion, the corresponding large force can be manipulated. The angular momentum of the highly spinning flywheel becomes an amplification factor. This amplification factor can be determined by the state of the supplied power source.

Therefore, the power state check before spinning the flywheel can help to predict the gain scheduling strategy according to the relation between the power state and the compliance of the gyroscopic force characteristic. And in opposite way, when the power state is exactly known, the real condition of the system can be estimated or predicted as well.

In this paper, when the real condition of the robot system is operated in a normal state, the power state can be estimated. There are many well-known methods in the literature to check the battery state. Using electrical devices such as digital multi-meter, measuring resistors, and battery charging system requires extra devices.

Here we are proposing a novel warming up method for detecting the battery power state. The advantage of the proposed method is not requiring extra electrical devices. The battery power state is estimated by the pre-equipped hardware system. Experimental studies on a single-wheel mobile robot, GYROBO are performed to estimate the battery power.

2. Power Estimation Concept

Power state estimation embodies the concept of a sensor-less approach to the problem. The equation can be used to estimate the voltage level of the current power state by deriving the power state estimation equation. The conceptual feature is described as Fig. 1.

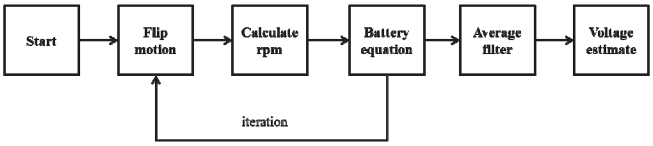

Fig. 1. Conceptual block diagram.

The start block means the state of sleep mode in the robot system. The power is supplied without spinning the flywheel to generate an angular momentum. And then, the flip motion is activated as a prescheduled manner. The rpm of the flywhel is calculated by analyzing the motor encoder of the flip motional motor system. The voltage level of current power state is estimated by the proposed battery equation. More precise results can be expected by the iteration of this sequence. Finally, the voltage level of current power state is calculated by the average filter.

There are three general states of the battery conditions: cut-off, operation, and saturation. Under the cut-off state, the battery cannot be rechargeable. In the application using a battery system: the alarm information before this state must be considered. The operational state is the range between these two states. In the condition of saturation, the battery is a fully charged.

In our system, the power source of GYROBO is 5 cells batteries of a packaged Li-Polymer type. To define a power state estimation range, the 5 cells packaged battery system is considered. The normal value per cell is +3.7V, the cut-off is +3V, and the saturation is +4.1V. 5 cells

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expanded properties are as followings: cut-off is +15V, normal is +18.5V, and saturation is +20.5V. Therefore, the measured quantities of power state as a voltage level from +15V to +18.5V can be determined.

3. Motion Analytical Sensing Method

3.1 Flip Motor Driver Characteristics

LMD18200 from TI Corporation is used as a flip motor driver. Its functional block diagram is shown in Fig. 2 [4].

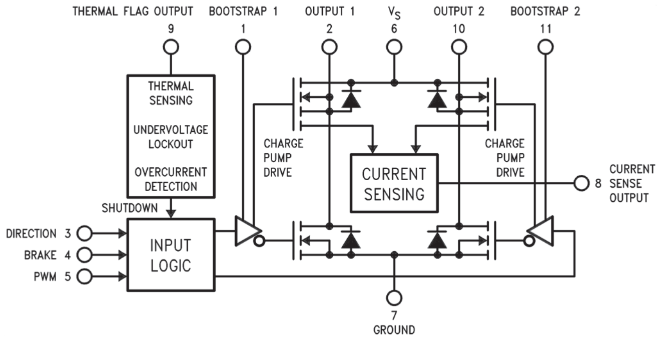
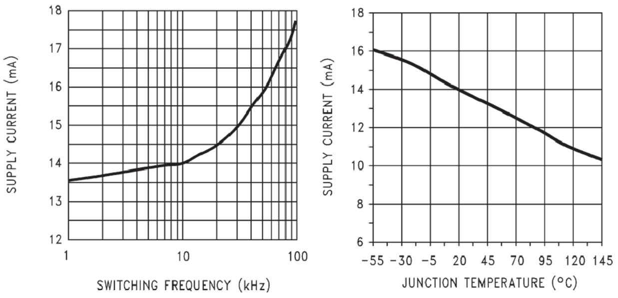


Fig. 2. Functional block diagram of LMD 18200.

Pin 6 can be replaced with power state in this paper. The flip motor is connected to the motor driver by two ports. One is the high side of H-bridge, or pin 2 when low side left switch is off state. Another is the low side of H-bridge, or pin 10 when high side right switch is off state. In this case, the current flows from high side to low side, or from pin 2 to pin 10. When the flip motor is connected with both pin 2 and pin 10, each pin has two kinds of currents. One is the motor load current and Another is the H-bridge operational current. These two types of currents share a same hardware H-bridge. Therefore, the motor current characteristic can be estimated by means of the H-bridge operational current analysis.

The magnitude of the H-bridge operational current is mainly dependent on three parameters: the power state, the switching frequency of pwm or pin 5, and the junction temperature. These properties are shown in Fig. 3 and 4.



(a) (b)

Fig. 3. Current performance of the driver.

A constant switching frequency of PWM is used in this application and the junction temperature effect is ignored. Under these constraints, the current flow of the driver is only dependent on the characteristic of power state as shown in the Fig. 3 (c).

The interesting region about LMD18200 shown in Fig. 3 (a) can be magnified as Fig. 4. Both current flows of the H-bridge show linear characteristics. The difference of slopes of the figure 4 is shown by the dissipation of current in the H-bridge circuits during the switching operations.

From this analysis results, the power state can be estimated through the linear relation with the flip motion.

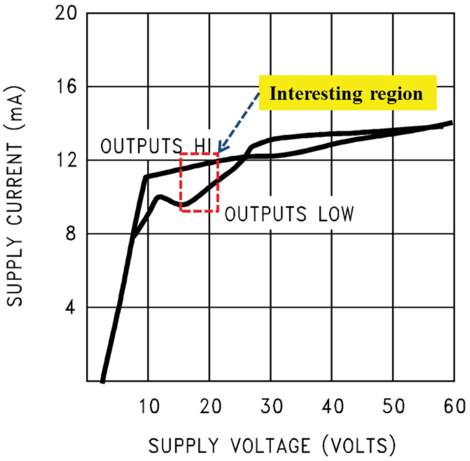


Fig. 4. Interesting region of the driver.

3.2 Experimental Setup

Based on the flip motor driver analysis results, an experiment is performed. GYROBO system is a single-wheel system which embodies all hardware systems in the outer wheel as shwon in Fig. 5. The controller manages the overall system with dsp-programmed control laws. A flywheel is a spinning device consuming a high power to generate an expected angular momentum during the control procedure. The flip motor makes a flip motion of the flywheel.

Fig. 5. GYROBO.

In this hardware, the power sate is closely related with the flip motion of the flywheel. The flip motor driver amplifies an input signal. The voltage level of the amplified signal determines its power state. According to this voltage level, the proportional current is derived. Since the flip motor system's agility is proportional to the current value, the agility of the flip motion is proportional to the power state. This is an original idea of this paper for achieving the power state estimation using the flip motion analysis.

The experimental setup to evaluate the flip motion according to the power state is described as in Fig. 6, where sensor systems such as a taco-meter, a flip motor encoder, and an AHRS sensor are used to derive the battery equation of Fig. 1 [5-6].

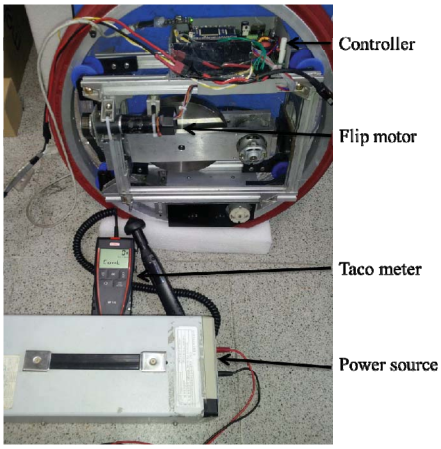


Fig. 6. Experimental setup.

3.3 Duty Ratio Selection

Firstly, the relation between the duty ratio and the flip motion is verified. The purpose of this experiment is to select the pilot duty. The detection of the flip motion is carried out by using a taco-meter sensor. The flip motor system has some transformation mechanism such as a gearhead, 1st pulley, and 2nd pulley, although their specifications are not exactly known. Also, an incremental encoder cannot read multi-turns. Therefore, we use a taco-meter in this experiment.

The flip motor can be controlled by its duty ratio from the controller. In this experiment, we fix the power state to the +20V level constantly using the power supply. Then, the duty ratio from 0 to 90% with 10% intervals is varied in 9 steps of which data are collected by the taco-meter sensor. Both the maximum and the minimum speed of flip motions are obtained. The average of three expeirmental data is calculated. The slope of this experiment between the duty ratio and the rpm of the flip motion can be obtained from Fig. 7.

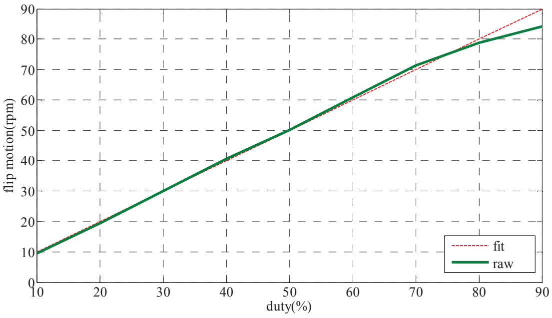


Fig. 7. Duty ratio to filp motion relation.

The relation has a linear characteristic within 70% duty ratio. Over than 70%, the nonlinearity is definitely shown as in Fig. 7. The 50 % duty ratio is selected as a pilot value of our experiments.

Under the fixed 50 % duty ratio condition, the relation between the power state and the flip motion can be linearly estimated as listed in Table 1.

Table 1 Estimated power states – gimbal rate (50%duty).

Power States(V)	Flip Motions(rpm)
16	40
18	45
20	50
22	55
24	60

3.4 Battery equation and velocity measurement

From Table.1, the linearized battery equation is derived as

$$\Phi(\text{volt}) = 0.4\Omega(\text{rpm}) \qquad (1)$$

where Φ is the power state and Ω is the flip motion. The relation (1) is a very easy way to estimate the power state by measuring the velocity due to the flip motion. However, there is a problem of detecting timing decision since the gimbal system has mechanical delay properties.

To decide the proper time of sampling, the response motion of the gimbal is analyzed.

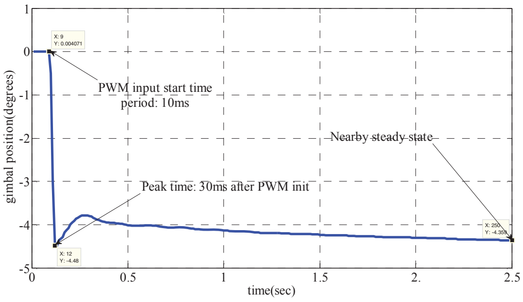


Fig. 8. Response characteristic of the flip motion.

Fig. 8 shows the response plot of the flip motion when 50% duty pulse having 10ms period is inputted. Where, the first peak time has 20 ms delay property. Then, it goes to the steady state condition. In this experiment, about 2.5 seconds later, the gimbal position goes to the almost steady state. We choose the gimbal position at 2.5 seconds as a steady state value. Therfore, Ω of (1) can be replaced as (2) and (3).

$$\Omega = 1.0275\ \Omega_{PEAK}\ (\text{rpm}) \qquad (2)$$

$$\Phi(\text{volt}) = 0.411\ \Omega_{PEAK}\ (\text{rpm}) \qquad (3)$$

However, in another experiment, we find out that the settling time property is dependent on the input duty ratio though the first peak time shows a similarities among the pilot inputs. The settling time differences are illustrated by Fig. 9 and the the first peak time similarities are shown as Fig. 10.

Based on the results, the coefficent of (3) can be dependent on the duty ratio of input PWM when the peak value of its response is sampled.

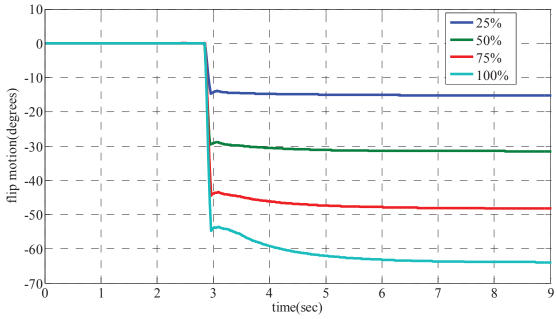


Fig. 9. Settling time properties.

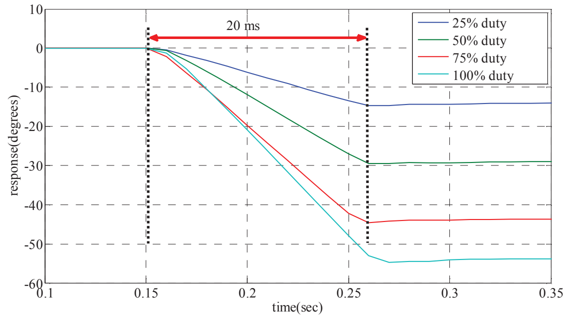


Fig. 10. First peak time similarities.

Using the analysis results, in this paper, we propose the power estimation method as followings.

At first, we assume that we have no idea the battery state of the system and also don’t have any electrical parts to monitoring the battery state.

Then, actuate the gimbal’s flip motor having 50% duty ratio.

Then, sampling its response at peak time.

Apply (3) to estimate the battery state.

Iterate what you want to for the higher accuracy of it.

4. Verification

The proposed method into the controller of GYROBO is implemented. The iteration value is 10. The sequence of verification process is summarized as followings.

At first, we set the power voltage randomly. Then, 50% duty ratio control of the PWM signal is commanded in 10ms by the controller. The rotary encoder of the flip motor counts pulses of the flip motion in every 30ms. The rpm is calculated by the battery equation given in (1). The flipped position is going back to the initial position in 600ms. Finally, this work is repeated 10 times and their average values are calculated by the average filter.

Test results are illustrated by Fig. 11. The maximum error is about 0.5V in the range of from 14 to 21 volts of power state of this application.

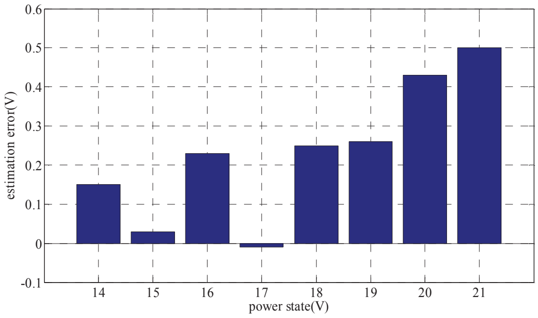


Fig. 11. Test results

5. Conclusion

The power state of a single-wheel robot system, GYROBO is estimated by warming up motions. Where, 6 seconds operation of equipped flip motor without highly consuming flywheel motor’s power consumption could give us power state information. In this paper, motion analysis-based approach to the estimation problem of supplied power condition was explained and verified.

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