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Lithium-ion Battery Charging System using Constant-Current Method with Fuzzy Logic based ATmega16

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ABSTRACT

In this charging system, constant-current charging technique keeps the current flow into the battery on its maximum range of 2A. The use of fuzzy logic control of this charging system is to control the value of PWM. PWM is controlling the value of current flowing to the battery during the charging process. The current value into the battery depends on the value of battery voltage and also its temperature. The cutoff system will occur if the temperature of the battery reaches its maximum range.

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1. INTRODUCTION

There are many charging methods for lithium battery such as constant-current method, constant-voltage method, conventional five-stage or proposed fuzzy-based algorithm method [1]. Charging Lithium battery with constant-current method is a technique to keep the value of the current when it flows into battery, while the value of its voltage is charging [2]-[5]. Even though the value of the current is fluctuating, but in this charging system, the maximum value will be 2Ampere. Here, the changing value of battery voltage is from range 2.7 volt to 4.2 volt.

The addition of fuzzy logic control of this Lithium battery charging system is the control of current flow into the lithium battery, so that it will meet its input and output requirements.

There are two inputs in this charging system, which are temperature and voltage of lithium battery. Temperature is the most vital parameter in lithium battery security that affected battery’s health. The lithium battery is easy to explode when it is overcharging that caused by over temperature.

The objective of this study is the current flows into the Lithium battery can be controlled, by changing the temperature and increasing the voltage of the battery.

2. CHARGING METHOD

There are many kinds of charging methods for battery, example constant–current, constant-voltage, and five-stage Li-ion battery charger [1]-[5]. During the constant current phase, the primary task of battery management is to control the flow of current to the maximum permissible battery current [4]-[5].

Battery use in this charging system is Panasonic CGR18650CG [6]. The specification of the battery shown in Table 1.

Table 1. Battery Specification

Measurements		Quantity
Nominal Voltage		3.6 v
Nominal Capacity	Minimum	2.150 mAh
	Typical	2.250 mAh
Dimension	Diameter	18.6 mm
	Height	65.2 mm

This charging system is using MOSFET's transistor as an active instrument. MOSFET is an instrument which read the electric signal and controls the output voltage from the charger system onto the battery.In this charging system, MOSFET is use because it has better durable than other common transistors. This MOSFET can resist the flow of the current up to 10Ampere. In charging system the PWM (Pulse Width Modulation) technology is applied to set the function of charging system to battery.

3. RESULTS AND ANALYSIS

The key design of software from this charging system is Fuzzy Algorithm. The Fuzzy inference system of this charging system is Sugeno's model. On Sugeno's model, to bring out the output we need four steps, which: forming of Fuzzy's set (fuzzification), function of implication, evaluation of rules, and defuzzification [7]. The evaluation rules use Max-Min mechanism and the defuzzification step use Center of Average (CoA) method.The flowchart of charging system is shown in Figure 1.

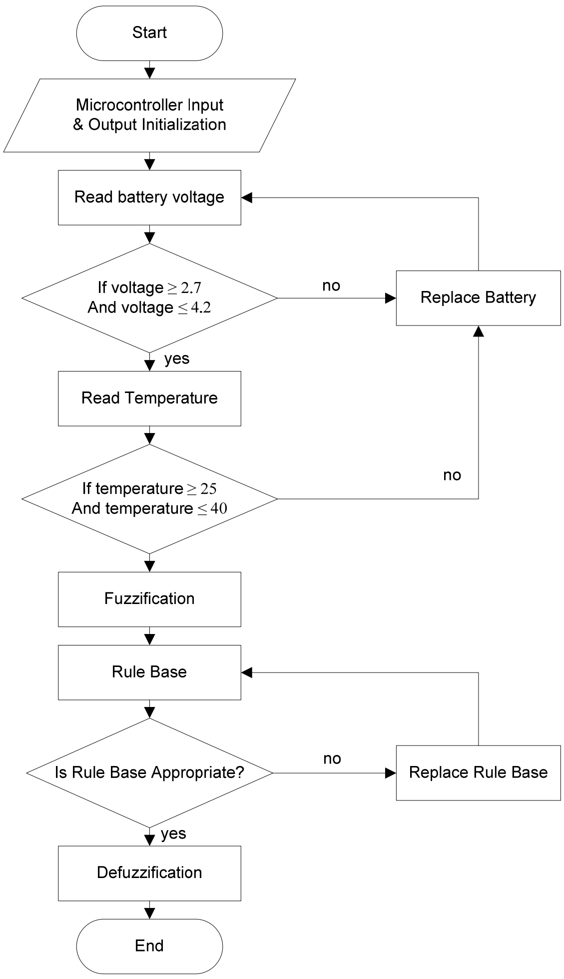

Figure 1. Flowchart Charging System

3.1. Fuzzification

This system uses two inputs which are voltage and temperature of the battery. First, ADC microcontroller read battery's voltage with sensor and set the linguistic form. Linguistic forms of battery voltage and battery temperature shown in Table 2 and Table 3.

Table 2. Input voltage

VOLTAGE (V)	LINGUISTIC
2.7 – 3.2	Low2
3.0 – 3.6	Low1
3.2 – 3.8	Normal
3.6 – 4.0	High1
3.8 – 4.2	High2

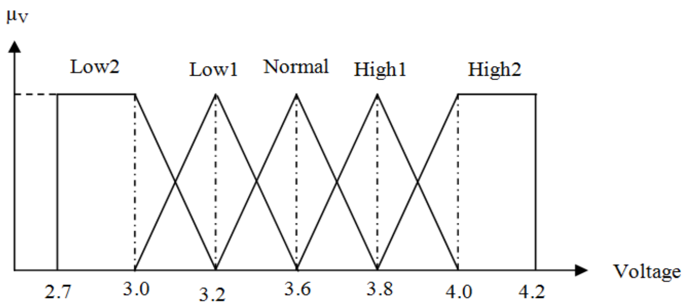

Figure 2. Fuzzy Voltage's range

Figure 2 shows the sets of voltage's range. It consist of five areas, starting from 2,7 volt until 4,2 volt, naming low2, low1, normal, high1, high2. System will run cut-off, once the voltage of the battery reach above 4,2 volt.

Table 3. Input - temperature

Temperature (^{0}C)	Variabel Linguistik
18-24	Inc1
21-29	Inc2
24-34	Inc3
29-37	Inc4
34-40	Inc5

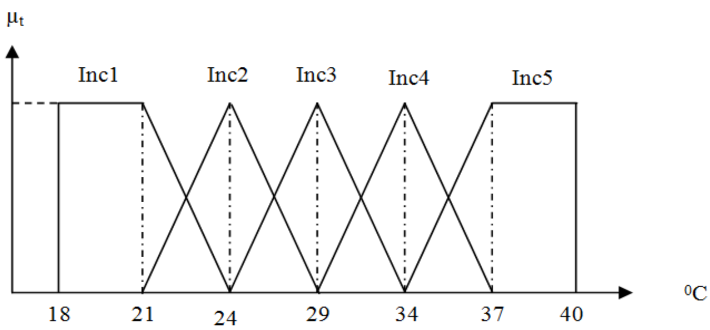

Figure 3. Fuzzy Temperature's range

Figure 3 shows the sets of temperature's range. It also consists of five areas that starting at 18^{o}C-40^{o}C. System will also run cut-off, once the temperature reach above 40^{o}C.

3.2. Rule Base

Rule base of this system is from each input of fuzzy logic. So that, there will be 25 rules, and shown in Table 4.

Table 4. Rule base

No	Input		Output
	Voltage	Temperature	Current
1	Low2	Inc1	Rapid
2	Low2	Inc2	Rapid
3	Low2	Inc3	Rapid
4	Low2	Inc4	Rapid
5	Low2	Inc5	Normal
6	Low1	Inc1	Rapid
7	Low1	Inc2	Rapid
8	Low1	Inc3	Rapid
9	Low1	Inc4	Rapid
10	Low1	Inc5	Normal
11	Normal	Inc1	Rapid
12	Normal	Inc2	Rapid
13	Normal	Inc3	Rapid
14	Normal	Inc4	Normal
15	Normal	Inc5	Normal
16	High1	Inc1	Normal
17	High1	Inc2	Normal
18	High1	Inc3	Normal
19	High1	Inc4	Slow
20	High1	Inc5	Slow
21	High2	Inc1	Slow
22	High2	Inc2	Slow
23	High2	Inc3	Slow
24	High2	Inc4	Slow
25	High2	Inc5	Slow

3.3. Mechanism of Inference

Mechanism of inference in this system transform into three ranges of percents, in duty cycles of PWM will run, which are rapid, normal and slow and shown in Table 5, and its formula in Equation (1)

$$\%PWM = \frac{\sum_{1=0}^{n} v_i \mu_v(v_i)}{\sum_{i=0}^{n} \mu_v(v_i)} \quad (1)$$

Where : % PWM is output, v_i is *crisp's value* of i's element, $\mu_v(v_i)$ is degree of every elements in Fuzzy's set of V. V isuniverse of Fuzzy, and n is quantization.

Table 5. Mechanism Inference

Duty Cycle (%)	Linguistic	Information
30	Rapid	Max1
60	Normal	Max2
90	Slow	Max3

3.4. Defuzzification

Defuzzification of this system is using CoA (center of Average), by formula in Equation (2):

$$y = \frac{\sum y \mu_R(y)}{\sum \mu_R(y)} \quad (2)$$

Where : y is crisp's value and µ_R (y) is membership of y.

3.5. Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a method for using pulse width to encode or modulate a signal. The width of each pulse is a function of the amplitude of the signal. While ADC detect the battery voltage and LM35 detect the changing of temperature, microcontroller will deliver and group those inputs into Fuzzy's set. Furthermore, microcontroller will control the IC to deliver the PWM signal into MOSFET series. The value of the current will depend on the mathematics calculation in the microcontroller.

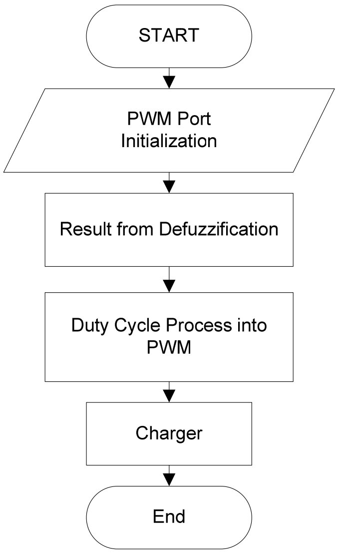

Figure 6 .Flowchart of PWM

4. RESULTS

4.1. First Experiment

In the first experiment (Figure 7), the room temperature was set at 25°C, in 2 hours (7200s) and the initial battery voltage was 2.7 volts. In the 1s , the battery temperature was 25.1°C, the current inflows was recorded at 2 amperes. At 238 second the voltage increase up to 2.8 volts, and the temperature was recorded at 25.5° C with a flow to the battery at 1.9 amperes. The decrease in flow occurs due to the temperature rise. At 469 second, the voltage increase up to 2.9 volts with battery temperature was 26.9° C and current was at 2 Amperes. At 3.0 volts, temperature was 27.3°C and the current was 1.9 Amperes. At 3.1 volts voltage of battery on 991 second, the temperature was at 29.2° C with current flows into the battery at 2 Amperes. At 1135 second voltage rise to 3.2volts with a recorded temperature of 29.8° C and the current flow of 1.8 Ampere.

It can be concluded that Fuzzy logic work when temperature is rising in the battery current flows. When the current flow increases, the temperature will increase, so the next current flow can be reduced, and the temperature can be decreased.

4.2. Second Experiment

In the second experiment (Figure 8), the room temperature was 25°C, experiments approximatelywith in 2 hours (7200s) with initial battery voltage at 2.7 volts. In the 1s, the temperature was 26°C, the flows of current was 2 amperes. At 240 second the voltage increased up to 2.8 volts, and the temperature was at 26.1°C with current flow to battery was 2 Ampere. At 500 second, the voltage increased up to 2.9 volts and the temperature was 26.3°C with current at 2 ampere. At 3.0 volts, temperature was 26.5°C and the current flows at 2 amperes. At 3.1 volts at 870 second, the temperature was at 27.1°C with current flows of 1.9 ampere. At 1019 second, voltage up to 3.2 volt and temperature was 27.2°C with the current flows at 1.9 amperes.

Similar to the first experiment: in conclusion the fuzzy logic control works similar to the first experiment.

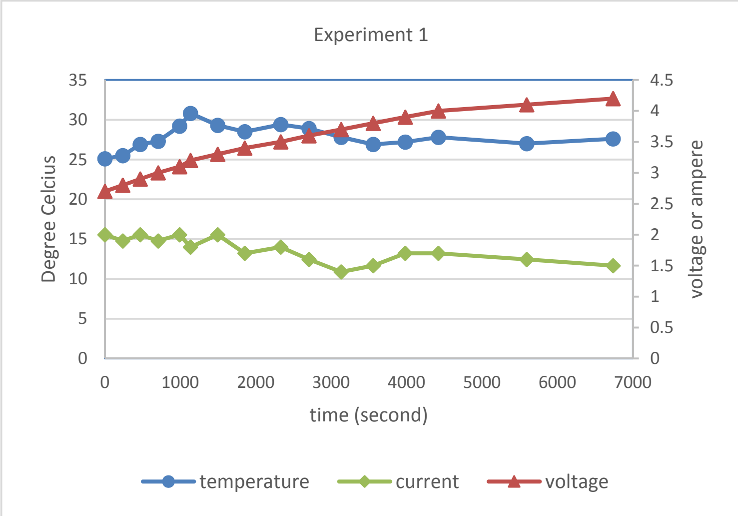

Figure 7. Graph of First Experiment result

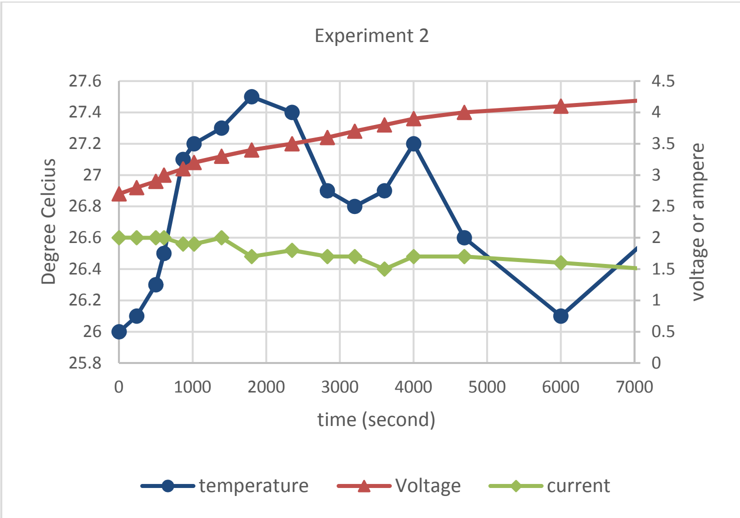

Figure 8. Graph of Second Experiment result

4.3. Third Experiment

In the third experiment (Figure 9), the room temperature was 25°C, approximatelywith in 2 hours (7200s) the initial battery voltage at 2.7 volts. In the first second, the temperature was at 25.1°C, the current flows to battery was 2 amperes. At 294 second the voltage increased up to 2.8 volts, and the temperature at 25.2°C with current flowed to the battery at 1.9 amperes . At 504 second the voltage increased to 2.9 volts with temperature was 25.4°C and the current was 2 amperes. At 3.0 volts , temperature 25.3°C and the current flow at 2 amperes. At 3.1 volts at 890 second, the temperature was 25.6°C and current flow at 2 Ampere. In 121 second the voltage rise to 3.2 volts and temperature was 26.1°C with the current flows at 1.8 Amperes.

In the charging system of the lithium ion battery, the critical parameter that should be considered is temperature, due to this the comparison between experiments was plot in the graph as shown in Figure 10. The results show that the temperature batteries are below the data sheet.

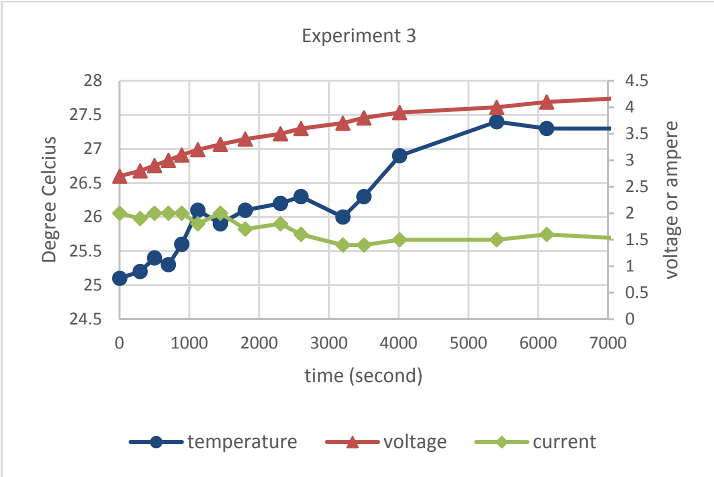

Figure 9. Graph of Third Experiment result

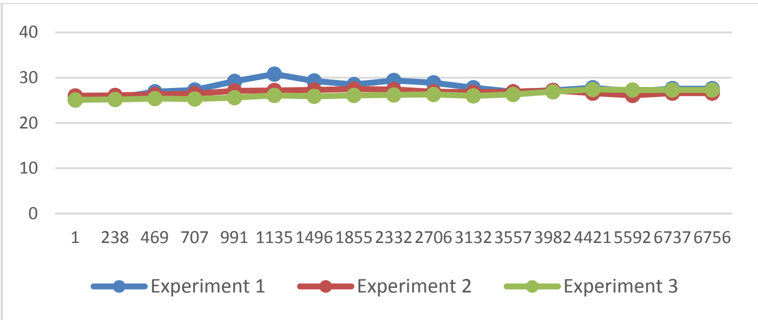

Figure 10. Comparison of the temperature from 3 experiments

At the end of the experiment, the averages of each battery parameters are shown in Table 6.

Table 6. The Average Battery parameter in Experiment

Parameter	BATTERY	
	Temperature (°C)	Current (A)
Experiment 1	27.75	1.65
Experiment 2	26.77	1.68
Experiment 3	26.21	1.62
Average	26.91	1.65

From the Table 6 shows that the average value of experiments for each battery starting from the first to the third trial are: temperatures of 26.91°C and current of 1.65 Amperes. In this experiment the current flows into the Lithium battery can be controlled, by changing the temperature and increasing the voltage of the battery.

5. CONCLUSION

a) This system consists of two parts, which are: microcontroller series function to calculate the Fuzzy, and MOSFET function for charger series.

b) The design algorithm to control the flows of current use PWM. The output from the microcontroller calculation will be delivered through MOSFET to control the value of the current flowing into the Lithium battery.

c) The total of current flows into Lithium battery is affected by the value of voltage and temperature while it is charging.

d) Fuzzy is still working despite the temperature of the Lithium battery changing. The voltage of the battery will constantly rises until it reaches 4.2 volt.

e) The value of the current flowing into the lithium battery is depending on the value of the temperature of the battery, as it is formulated in the rule base of Fuzzy.

The average temperature of the lithium battery while charging process running is 26^{o}C and the average of the current flowing into the battery is 1,75A.

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APPENDIX

Experiment #1

Time (s)	Battery			
	Time (^{o}C)	Volt (V)	Current (A)	
1	25.1	2.7	2	
238	25.5	2.8	1.9	
469	26.9	2.9	2	
707	27.3	3	1.9	
991	29.2	3.1	2	
1135	30.8	3.2	1.8	
1496	29.3	3.3	2	
1855	28.5	3.4	1.7	
2332	29.4	3.5	1.8	
2706	28.9	3.6	1.6	
3132	27.8	3.7	1.4	
3557	26.9	3.8	1.5	
3982	27.2	3.9	1.7	
4421	27.8	4.0	1.7	
5592	27	4.1	1.6	
6737	27.6	4.2	1.5	
6756	**27.6**	**4.2**	**0.0**	Cut-off
Mean	27.75	-	1.65	

Experiment #2

Time (s)	Battery			
	Temp (^oC)	Volt (V)	Current (A)	
1	26	2.7	2	
240	26.1	2.8	2	
500	26.3	2.9	2	
610	26.5	3.0	2	
870	27.1	3.1	1.9	
1019	27.2	3.2	1.9	
1393	27.3	3.3	2	
1802	27.5	3.4	1.7	
2350	27.4	3.5	1.8	
2830	26.9	3.6	1.7	
3201	26.8	3.7	1.7	
3605	26.9	3.8	1.5	
4002	27.2	3.9	1.7	
4690	26.6	4.0	1.7	
6001	26.1	4.1	1.6	
7201	26.6	4.2	1.5	
7220	26.6	4.2	0.0	Cut-off
Mean	**26.77**	**-**	**1.68**	

Experiment #3

Time (s)	Battery			
	Temp (^oC)	Volt (V)	Current (A)	
1	25.1	2.7	2	
294	25.2	2.8	1.9	
500	25.4	2.9	2	
699	25.3	3.0	2	
890	25.6	3.1	2	
1121	26.1	3.2	1.8	
1444	25.9	3.3	2	
1801	26.1	3.4	1.7	
2305	26.2	3.5	1.8	
2599	26.3	3.6	1.6	
3200	26	3.7	1.4	
3501	26.3	3.8	1.4	
4013	26.9	3.9	1.5	
5404	27.4	4.0	1.5	
6120	27.3	4.1	1.6	
7580	27.3	4.2	1.5	
	27.3	4.2	0.0	Cut-off
Mean	**26.15**	**-**	**1.73**	

BIBLIOGRAPHY OF AUTHORS

Rossi Passarella is a member faculty of Computer Science, University of Sriwijaya. He was joined to this faculty on December 2010. Bachelor degree in electrical engineering was held in 2002 from the university of Sriwijaya, In 2005, hejoined to the university of Malaya-Kuala Lumpur as master student, and research assistant for department of design and manufacture and graduated in 2007 (cum laude). After graduating, he is joining as a reseach assistant in Center of Product Design and Manufacture, until 2010. Since 2011, He has appointed as a head of Industrial Automation Laboratorium in Faculty of Computer Science, the research areas of the lab, included: Renewable energy in industry, robotic in industrial automation, and computer vision in industrial Automation.

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