Estimate method research at working life of wireless sensor network nodes

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Abstract. Process deep research at disposable lithium sulfite chloride battery discharge characteristics and current-voltage characteristics when wireless sensor panel point working. Test the voltage-current time domain signal during the disposable lithium sulfite chloride battery discharge process and wireless sensor panel point working process through high precision power consume test instrument. Research and design one calculate method of wireless sensor panel point power consume. Build the estimate model for wireless sensor used battery power. Develop the wireless sensor network battery working life estimate and early warning method which based on the power consume calculate method of wireless sensor and wireless sensor used battery power estimate model, make users able to real time and accurately grasp all wireless sensor network panel point’s working life through this method, at the same time, can real time monitored whether battery of wireless sensor network panel points or the relate electric circuit of power supply exist problems, do well at wireless sensor panel point running and maintain works in advance. Finally, use high precision instrument process test and verify pulse voltage characteristics at wireless sensor panel point actual work which supply power by disposable lithium sulfite chloride battery, the test results are unanimous with theory research.

1. Introduction
The lithium sulfite chloride battery has advantages at high ratio energy and long storage working life, widely applied in the wireless sensor network panel points. Currently in the monitor area, most of the wireless sensor panel point or apparatus and instrument all use disposable lithium sulfite chloride battery supply power. The wireless sensor network panel points have the characteristics at complex distribution environment and large quantity panel points, these make staffs not convenient to arrive in most of the application environment. However, the power consume and power supply performance of wireless sensor network panel points directly affect the application prospect of wireless sensor network panel points. [1~3].

In view of this, this article designed one wireless sensor power consume calculating method through process deep research and actually test at disposable lithium sulfite chloride battery discharge characteristics and current-voltage characteristics when wireless sensor panel point working, and build the estimate model of wireless sensor network panel points used battery power. Develop the wireless sensor networks battery working life estimate and early warning method which based on the wireless sensor’s power consume calculate method and used battery power estimate model, make user able to real time and accurately grasp the working life of all wireless sensor network panel points through this method, at the same time, can real time monitor whether the battery of wireless sensor network panel
points or relate electric circuit of power supply existing problems, do well at the wireless sensor panel points running and maintain works in advance.

2. Discharge characteristics research at sulfite chloride battery

The positive pole material of lithium sulfite chloride (Li-SOCl2) battery is sulfite chloride(SOCl2), the negative pole material is metal lithium(Li), it has many advantages: 1. higher ratio energy, generally reach up to 420Wh/Kg, the highest reach up to 650Wh/Kg when low speed discharging; 2. High battery voltage, single piece battery’s open circuit voltage is 3.65V; 3. Stable working voltage, above 90% power all can use above 3V voltage discharge when discharging at rated current; 4. Widely used temperature range able to work at (-40~85)℃ temperature range; 5. Long working life, its annual self-discharge ratio less than 1%, most excellent storage performance, the working life in the electric performance allowable range reach up to above 10 years[4,5]. To verify the discharge characteristics of lithium sulfite chloride battery, the experiment adopts high precision battery parameter test instrument process actually discharge test at lithium sulfite chloride under room temperature. The Figure 1 is to test the actually discharge parameters of lithium sulfite chloride battery.

The panel points be at dormant status when wireless sensor at actual working and under the normal situation, the panel points wake up in a certain time and process data collecting, send out the abnormal data when collected data occur abnormal, during it’s whole process, the sensor working voltage and current all are different under the status like dormant, wake up, data collect and data sending[6,7]. Figure 2 is the working current test when wireless sensor be at fix time collect data and sending data mode.

Figure 1. Discharge test of lithium sulfite chloride battery.

Figure 2. The actual working current time domain diagram.

3. Create model and algorithm design

3.1. Research at the wireless sensor battery discharge model

Through above electric parameter characteristics research at lithium sulfite chloride battery and when wireless sensor working, and research the relation between battery pulse voltage and capacity in document [8], we can get the below conclusion:

(1) When wireless sensor lithium sulfite chloride battery working, the battery voltage will gradually reduce along with the increasing of pulse times.

(2) The battery voltage will suddenly be descending when single piece pulse signal happening, then will recover rapidly. The difference between the recovered voltage after pulse signal happened and voltage before pulse signal happened increasing.

(3) If the sensor send out the same time length pulse signal then the difference between the recovered voltage after pulse signal happened and voltage before pulse signal happened increasing along with the increasing of pulse signal times, if the recovered voltage after the later one time pulse happened are same to the recovered voltage value after early one time pulse signal happened, then recover voltage used time after later one time happened pulse signal obviously longer than the recover voltage used time after early one time happened pulse.
(4) Along with the increasing of quantity of wireless sensor generated quantity of pulse signal, the recovered voltage value after happened same time length pulse will gradually be descending, and the voltage relate to the battery capacity.

(5) When the battery capacity lower than about 60%, the battery voltage descending range increasing along with the increasing of sensor generate the pulse signal times.

(6) When the battery capacity lower than about 60%, the battery voltage descending range further increasing along with the increasing of sensor generate the pulse signal times, and, the voltage unable to recover in short time after pulse happened.

(7) The relation between the battery voltage and it’s capacity are fixed at the same type battery, means that recover voltage after recovered same time are relate to the battery remained capacity after the same pulse signal happened, more low voltage more few capacity, especially when this voltage value fallen at about 90% of battery discharge model, more bigger voltage descending range at each happened one time pulse signal.

(8) The battery will no power immediately when monitored that battery voltage fallen at 90% of battery discharge model, though it still has about 10% power but the voltage maybe unable to guarantee the sensor normally working.

3.2. Create battery power estimate model

First step: measured the current is $I_{\text{max}}$ when under the status that generated max pulse working current during the sensor in the normally working process, the max pulse current continue time is $T_1$, the lowest voltage is $V_{\text{min}}$ when the sensor able to normally working. In this article, during the sensor collecting data and ADC electric circuit starting, generate the max pulse current $I_{\text{max}}=230$ mA, continue time $T_1=2.8$ ms(millisecond), the lowest working voltage $V_{\text{min}}=2.5V$.

Second step: use the high precision power consume test instrument to process pulse discharge at the sensor used lithium sulfite chloride battery, the max pulse current is $I_{\text{max}}$, each time pulse continue time is $T_1$. Instruction: through research and actually test the discharge characteristics of lithium sulfite chloride battery, we can know that, the lithium sulfite chloride battery exist the below characteristics: during the battery voltage at battery early period use and after each time generated pulse current, the voltage all have micro reduce, but able to quickly recover the similar voltage before generate pulse; during the battery voltage at battery later period use and after each time generated pulse current, the voltage all have bigger reduce, but able to quickly recover the similar voltage before generate pulse after pass through a period time.

Third step: suppose that, measured the battery, the battery is $V_1$ before each time process discharge at pulse current $I_{\text{max}}$, the lowest voltage is $V_s$, measure the recovered voltage is $V_{s1}$ start from the lowest voltage and after recovered time $t_1$ seconds. Instruction: the power of lithium sulfite chloride battery is the power when the reduce the voltage to 2V at the constant current, set the tested battery’s nominal electricity is Q. Pulse discharge according to $I_{\text{max}}$ current $T_1$ seconds for sensor used new battery, measured the relation between recover voltage $V_{s1}$ which recover $t_1$ second(example 10 seconds) after discharged and the percentage of discharge electricity, among, the discharge power percentage is the percentage between the measured discharge Q1 and battery nominal electricity. Further more, measure multiple groups battery samples, the measured recover voltage $V_{s1}$ when recovered $t_1$ second after fitting battery discharge through min square method, the relation between measured discharge electricity Q1 and the discharge electricity percentage,means the battery discharge curve graph, shown as Figure 3, among, the discharge electricity percentage is the percentage between the measured discharge electricity Q1 and battery nominal electricity Q. In this article, the battery nominal electricity Q=19000 mAh (milliampere each one hour).
3.3. The power consumes algorithm design of sensor

Suppose, when at experiment, the test time is \( T_2 = 30 \) min (Minute). Suppose, within the test time \( T_2 \):

**First step:** Measured the sensor consumed power is \( W_0 \) when the sensor not happen any high power consume mode and be at the dormant mode.

**Second step:** Suppose, each happen one time first working mode, the sensor consumed power electricity is \( X_1 \), each time first working mode continue time is \( \epsilon_1 \). Suppose, measured the sensor consumed electricity is \( W_{1C_1} \) during the \( T_1 \) time length and when the sensor first time happen \( C(C=5) \) times first working mode (only collect data), measured the sensor consumed electricity is \( W_{1C_2} \) when the sensor second time happen \( C(C=5) \) times first working mode, measured the sensor consumed electricity is \( W_{1C_3} \) when the sensor third time happen \( C(C=5) \) times first working mode, then each time measure sensor consumed power electricity is \( W_{1C_i}(i = 1, 2, 3) \), then, within \( T_1 \) time and sensor happen \( C(C=5) \) times first working mode, the sensor consumed electricity is:

\[
W_1 = \frac{\sum_{i=1}^{3} W_{1C_i}}{3}
\]  

**Third step:** Suppose, each happen one time second working mode (this second working mode is collect and send data), the sensor consumed power electricity is \( X_2 \), each time first working mode continue time is \( \epsilon_2 \). Suppose, measured the sensor consumed electricity is \( W_{2D_1} \) during the \( T_1 \) time length and when the sensor first time happen \( C(C=5) \) times second working mode, measured the sensor consumed electricity is \( W_{2D_2} \) when the sensor second time happen \( C(C=5) \) times second working mode, measured the sensor consumed electricity is \( W_{2D_3} \) when the sensor third time happen \( C(C=5) \) times second working mode, then each time measure sensor consumed power electricity is \( W_{2D_i}(i = 1, 2, 3) \), then, within \( T_1 \) time and sensor happen \( D(D=5) \) times second working mode, the sensor consumed electricity is:

\[
W_2 = \frac{\sum_{i=1}^{3} W_{2D_i}}{3}
\]  

In this article, the sensor only has above two working mode. Then from the below formula:

\[
W_1 = X_1 \times 5 + \frac{(T_1 - 5 \times \epsilon_1) \times W_0}{T_1}
\]  

\[
W_2 = X_2 \times 5 + \frac{(T_1 - 5 \times \epsilon_2) \times W_0}{T_1}
\]  

Can get:

\[
X_1 = \left\lfloor \frac{W_1 - \frac{(T_1 - 5 \times \epsilon_1) \times W_0}{T_1}}{5} \right\rfloor
\]  

\[
X_2 = \left\lfloor \frac{W_2 - \frac{(T_1 - 5 \times \epsilon_2) \times W_0}{T_1}}{5} \right\rfloor
\]  

The sensor consumed electricity calculation during the working: Suppose, the sensor already worked time is \( T_2(T_2 = 60 \) min), already happened working mode has two types, the times of happen the first
working mode $H_1=12$, the times of happen the second working mode $H_2=3$. Then, the sensor already consumed power electricity $W$ is:

$$W = X_1 \times 12 + X_2 \times 3 + \left[ T_2 - (12 \times t_1 + 3 \times t_2) \right] \times \frac{w_0}{T_1}$$

(7)

4. Realize sensor panel points working life estimate method

This article firstly calculate the sensor electricity, then build the sensor used battery electricity’s estimate model, build wireless sensor network battery working life estimate and early warning algorithm which based on the electricity consume calculating method of sensor and sensor used battery electricity estimate model, real time monitor and early warning for the using sensor used electric status. The detail process is as below:

**Step 1** After the sensor network panel point start machine and the sensor in the sensor network panel point first time happen max pulse current, the battery of collect sensor network panel point recover the output voltage, confirm and output battery’s remain electricity according to the relation curve of battery output voltage and electricity;

**Step 2** Confirm the first collect time interval according to the first level voltage early warning value, and collect the battery’s output voltage according to the first collect time interval, confirm and output battery’s remained electricity according to the relation curve of battery output voltage and electricity, obtain the sensor’s already consumed electricity;

**Step 3** When the collected battery output voltage reduced to lower or equal to the first level voltage early warning value and bigger than the second level voltage early warning value: send out level I alarm reminding, confirm the second collect time interval according to level I voltage early warning value and level II voltage early warning value, and collect the battery’s output voltage according to second collect time interval, confirm and output battery’s remain electricity according to the relation curve of battery output voltage and electricity, obtain the sensor’s already consumed electricity, estimate and output sensor remained working time;

**Step 4** When the collected battery output voltage reduced to lower or equal to the second level voltage early warning value and bigger than the limit voltage early warning value: send out level II alarm reminding, confirm the third collect time interval according to level II voltage early warning value and limit voltage early warning value, and collect the battery’s output voltage according to third collect time interval, confirm and output battery’s remain electricity according to the relation curve of battery output voltage and electricity, obtain the sensor’s already consumed electricity, estimate and output sensor remained working time;

**Step 5** Process power off operation for the sensor network panel points when the collected battery output voltage lower or equal to the first limit voltage early warning value. Estimate whether the battery self-discharge too fast according to the battery’s already used electricity and sensor’s already consumed electricity, send out the alarm reminding that battery self-discharge too fast when the estimate result is battery self-discharge too fast.

5. Experiment verification

This article uses the high precision power consume test instrument test the actual working process of wireless sensor with lithium sulfite chloride battery supply power. For more better verify out the battery discharge characteristics when wireless sensor working, this article used wireless sensor adopt fix time collect and send data. Generate one certain width pulse signal from the voltage and current time domain diagram when wireless sensor each collect one-time data. The voltage and current recovered after finish data collected. Research and reduction according to early theory: the battery recovered voltage appear downtrend along with increasing collect times and within the equal recover time. At this point, this article done analyse at the voltage and current time domain signal when this sensor working, the analyse data check table 1, the result shown: the voltage characteristics when the actual products working are in accordance with this article researched theory.
Table 1. The test results.

| SN | Nominal voltage | Recovered voltage | Voltage difference | Recovered time |
|----|-----------------|-------------------|--------------------|----------------|
| 1  | 3.5             | 3.48343326        | 0.01656674         | 29.08          |
| 2  | 3.5             | 3.480898221       | 0.019101779        | 29.08          |
| 3  | 3.5             | 3.479091962       | 0.020908038        | 29.08          |
| 4  | 3.5             | 3.476890865       | 0.023109135        | 29.08          |

6. Conclusion
This article has done large quantity research at the relate documents datum of discharge characteristics of disposable lithium sulfite chloride battery, use the high precision power consume test instrument process actually test disposable lithium sulfite chloride battery discharge characteristics, build lithium sulfite chloride battery discharge model based on these. Designed the sensor power consume calculating model according to electric parameter characteristics when sensor working. Research and designed the sensor panel point working life estimate algorithm through combine disposable lithium sulfite chloride battery discharge model and sensor power consume calculating model. Finally, process test and verify the pulse voltage characteristics in wireless sensor panel point’s actual works which supply power by disposable lithium sulfite chloride battery supply power through use the high precision instrument, the result shown that, the battery power gradually reduce along with the increasing times of sensor send out pulse signal, the voltage will reduce when pulse signal send out, the voltage will rapidly recovered after pulse signal send out, if start from the voltage start recover and pick the same long voltage recover time, then, the recovered voltage will gradually reduce along with the increasing times of send out pulse. The experiment result and theory research result are unanimous. The core research achievements in this article already applied to be invention patent and already opened.

Reference documents
[1] Lou Liangliang, Jing yanliang, Zhou Miao. Measurement of the Power Consumption for IOT Nodes and the Analysis of the Life Cycle of Battery[J]. Process Automation Instrumentation. December 2015, Volume 36, Issue 12, pp 52–55.
[2] Gudong yuan, Dongyong Yang, He wei. monitoring methods and devices for residual power of wireless sensor network nodes. China 201410029470. [P]
[4] Rongrong Guo, Zhen Dong Bei XuChao Song. Catalytic activity of a series of sub phthalocyanines in the electrolyte of Li/SOCl2 battery[J]. Journal of Solid-State Electrochemistry. February 2015, Volume 19, Issue 2, pp 345–353.
[5] Guo Bingkun, Li Xinhai, Yang Songqing. Chemical power supply-battery principle and manufacture technology[M]. Central South University Press, 2000:441–445.
[6] Lajara, R., Pelegri-Sebastia, J., Solano, J.J.P. Power consumption analysis of operating systems for wireless sensor networks[J]. Sensors, 2010, 10(6):5809-5826.
[7] Frank Bellosa. The benefits of enent: Driven energy accounting in power-systems [DB]. In: Proc.of the 9th workshop on ACM SIGOPS European Workshop: Beyond the PC: New Challenges for the Operating System. Kolding: ACM Press,2000.37-42. [dio:10.1145/566726.566736].
[8] Chen Demin, one sensor network panel point battery estimate and early warning method. China 109471036A[P].