International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol. 8, No. 4 (2015), pp. 59-72
http://dx.doi.org/10.14257/ijsip.2015.8.4.06

Heating Control Design of a Space Camera

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Abstract

When a space camera works on the track, it presents in vacuum environment, under the condition of low temperatures, the camera can only maintain its temperature level by absorption of radiation. If stayed in this environment for a long time, mechanical structure of the space camera may become brittle, lose strength, and an exfoliation phenomenon may appear, in addition, abnormal operation and malfunction of electronic equipments may also occur, these may affect imaging quality of the camera. In this paper, a heating control method is designed for a space flight off-axis camera. Firstly, heating control working platform of the camera is introduced, a design method of heating control is determined. After that, heating control treatment procedure is introduced. Finally, the ground temperature monitor is used to validate correctness of the method designed. The comparison diagram before and after thermal analysis and temperature data obtained from experiments are presented, results show that, the heating control method is simple and effective, it has wide applicability and strong generalization performance.

Keywords: *space camera, thermal control system, remote sensing, thermal analysis*

1. Introduction

Temperature is an important environment condition. It may affect occurrence and development of each thing on the earth. The main work environment of a space camera is the cosmic space beyond the earth's atmosphere. The thermal environment there existed is totally different from that on the earth [1, 2]. In order to make the camera operated in the scheduled environment, temperature variation of each point of the camera should be properly arranged and controlled timely [3, 4].

Low-temperature environment and uneven temperature distribution may have pessimistic effects on electronic equipments, optical modules, automatic equipments and so on [5-9]. These negative effects include generation of thermal stress and deformation, fatigue damage, mechanical breakage or permanent deformation of electron devices, so these may significantly affect working performance of the whole system.

Currently, most of the thermic control studies about space cameras mainly focus on thermo analysis, high effective cooling and heat dissipation [10-15], heat-resistant surface coating materials and so on; there is no deep research on thermal control devices and strategies. At present, electric heating thermostats are usually used for heating control of space cameras. So the thermal control strategies are very important [16-19].

This study starts from engineering practices, based on characteristic analysis of a camera subsystem on a satellite platform. Requirements of temperature uniformity and stability for the camera are considered, a heating control method which based on SMJ320C30 controller is proposed, in the method, there are 80 heating channels.

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Temperature of channels can be controlled independently, there are 160 collection channels. Two collection channels are distributed for each heating point, which can improve equipment stability. Treatment procedures of temperature collection and heating control can be obtained. Validity and stability of the temperature control method can also be verified.

2. Hardware System

Heating controller is used for temperature monitoring and control of the space camera. Its main functions include 1553B communication (reception of target temperature, collection of strategy information, sending of real time temperature data), temperature control of camera, temperature collection. Composition diagram of the system is shown in Figure 1.

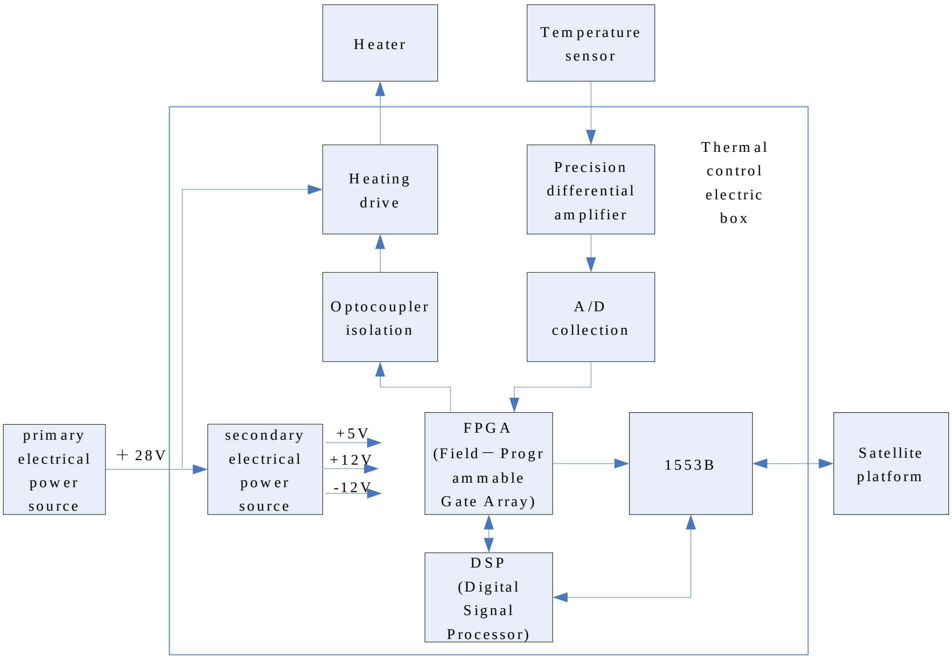


Figure 1. Heating Control System Structure Diagram

Heating controller procedure is solidified in FLASH (Flash Memory), after power up, the procedure runs, it has high reliability.

RAM (Random-Access Memory) is a data-storage area. It can be used for preservation of variables, stacks and related parameter tabulations, including reference resistance, thermal resistance, and reference voltage of each heating channel, which required for various temperature calculations in the operational process of heating control program, in order to improve calculation accuracy. Address section is 80000H~9FFFFH.

Heating controller communicates with the satellite platform by 1553B bus. It can interact with FPGA by address visiting.

3. Software System

3.1. Interaction between Satellite Platform and Heating Controller

Based on resources provided by satellite platform, information and sub addresses, which received by heating controller through 1553B is presented in Table 1.

Table 1. Content and Sub-address of Received Message Data

sub-address	Content
SA1	Collection type and target temperature of channel 1-channel 32(32 words)
SA2	Collection type and target temperature of channel 33-channel 64(32 words)
SA3	Collection type and target temperature of channel 65-channel 80(16 words)

The ground control platform sends collection type and target temperature to the satellite platform (a 5K RAM region in the satellite platform is used for preservation of orders and parameters from the ground). The satellite can send the information to the heating controller through 1553B protocol, sub-address 1~3 are used for reception of channel collection type and target temperature of 80 channels from the platform. The format is shown in Table 2.

Table 2. Collection Type Code and the Target Temperature Format of Each Channel

Bit	Content
Bit0~Bit9	The target temperature code
Bit10~Bit12	0
Bit13	Heating control code
Bit14~Bit15	Collection type code

Collection type code, the format is shown in Table 3.

Table 3. Collection Type Code Format

Bit15	Bit14	Content
0	0	No collecting
0	1	Collection of channel A
1	0	Collection of channel B
1	1	Collection of (A+B)/2

Heating control code, the format is shown in Table 4.

Table 4. Heating Control Code Format

Bit13	Content
0	No heating
1	Heating

Data range of target temperature code is 0-800(it is obtained by practical temperature×10). It occupies 10 bits by binary format (bit0~bit9).

Heating controller sends collected temperature and heating status to the satellite platform by 1553B serial bus communication. These are downloaded to the ground control center for temperature monitoring, information and sub addresses are shown in Table 5.

Table 5. Content and Sub-address of Sent Message Data

sub-address	Content
SA1	Heating status and current temperature of channel 1-channel32(32 words)
SA2	Heating status and current temperature of channel 33-channel64(32 words)
SA3	Heating status and current temperature of channel 65-channel80(16 words)

Heating status and temperature format of each channel is shown in Table 6.

Table 6. Heating Status and Current Temperature Format of Each Channel

Bit	Content
Bit0~Bit11	The current temperature code
Bit12~Bit13	The heating status code
Bit14~Bit15	0

Heating status code, the format is shown in Table 7.

Table 7. Heating Status Code Format

Bit13	Bit12	Content
0	0	No heating
0	1	30% Pulse heating
1	0	60% Pulse heating
1	1	Continuous heating

The current temperature code has 12 digitals. Normal temperature range is 0-800. It occupies 10 bits by binary format (bit0~bit9), when the temperature is out of range of 0-800, it can be taken as an error value. The code value is actual temperature×10, practical operating ambient temperature of the camera is-30℃~50℃, the temperature value should be divided by 10 and minus 30 for the ground monitoring equipments. Correct temperature is shown on display after calculated. Temperature precision after calculation is 0.1 ℃. When temperature collection is stopped, the current temperature code is set as 0xfff and sent to the ground detection equipments, so it can be distinguished from other temperature data.

3.2. Interaction of Heating Controller DSP and FPGA

Interaction of heating controller DSP and FPGA can be performed by address bus, addresses used and their meanings are shown in Table 8.

Table 8. Addresses Used and Meanings

Address	Content
0x60001	Selection of step1 analogue switch channel
0x60002	Selection of step2 analogue switch channel
0x60003	Control of AD (Analog to Digital) change-over switch
0x60004	Temperature read
0x70000	Heating control

Analogue switch is used for selection of 160 collection channels. 160 channels are divided into two separate collection system. Group A and group B, there are 80 channels in each group. Where, there are 10 channels in step1 analogue switch and 16 channels in step2 analogue switch. They are connected by the series system, so the controller can control temperature collection of 160 channels (10×16).

DSP writes FH to control address of the AD change-over switch, then FPGA works for AD convert. INT2 interrupt appears after converting, DSP reads temperature from addresses in interrupt processing, temperature corresponding code is obtained after AD converted, practical operating ambient temperature is obtained by follow-up calculation.

DSP can independently perform heating control according to temperature collected from different channels, heating control format is shown in Table 9.

Table 9. Heating Control Instruction Format

Bit	Content
Bit0~Bit7	Heating mode
Bit8~Bit15	Heating channel

Heating channel range is 1 to 80, representing the 80-way heating channels, data range of heating types is 0~100, 0 refers to no heating, 100 refers to continuous heating, if 30% pulse heating is performed, set the value as 30, if 60% pulse heating is performed, set the value as 60.

4. Heating Control Method

Heating control method mainly includes temperature collection and heating set. Collection channels are distributed according to form and position of heater bands. Automatic heating set can be performed by temperature collection, temperature calculation and temperature comparison of each channel.

4.1. Temperature Collection

DSP uses 1 out of 16 selectors (MAXIM company, model MAX306CPI) as analogue switch, and can select collection channels through controlling analogue switch. 11 slices of analogue switches (two steps) are required for 160channels. The circuit design schematic diagram is shown in Figure 2.

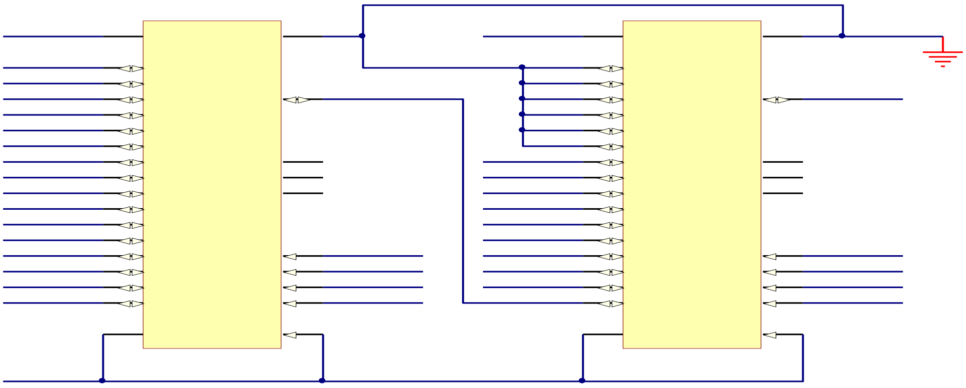


Figure 2. Collection Channel Switching Circuit Schematic

Using bridge circuit, it can transform resistance value to voltage. An op amp amplifier can magnify voltage, then the analog-digital converter can transform to digital quantity and output to DSP for processing, the circuit design schematic diagram is shown in Figure 3.

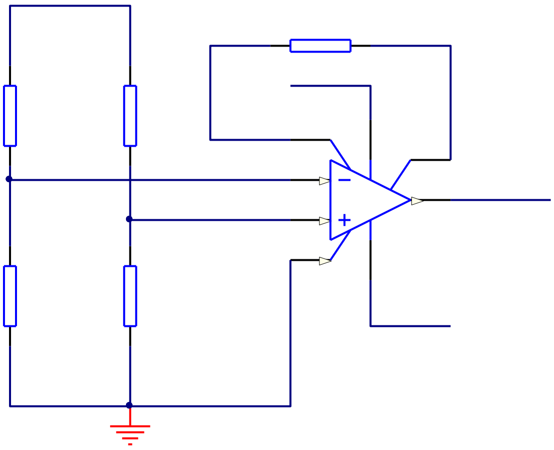


Figure 3. Bridge Circuit Schematic

AD584 drives Wheatstone bridge in the diagram. Using AD620 as op amp amplifier, service voltage is ± 15V. Reference voltage is input into the negative terminal of the op amp amplifier, and voltage to be tested is input into the plus end. It adopts AD574AL as ADC (Analog to Digital Converter), service voltage is ±15V, measuring range is ±10V, and the maximum linear error is ±1/2LSB. In order to obtain the maximum sampling precision, reasonable op amp gain is selected, suitable bridge arm is designed, and output of the op amp amplifier should be mostly close to measuring range of the analog-digital converter. So it is obtained that

$$(V_{+\max} - V_{-}) \times G = +10 \tag{1}$$

$$(V_{+\min} - V_{-}) \times G = -10 \tag{2}$$

Where, V_{+max}/V_{+min} is the maximum/minimum positive voltage, V- is the negative voltage. G is the gain of the op amp amplifier, Substituting Equation (1) into Equation (2) gives

$$V_{+\max} - V_{+\min} = \frac{20}{G} \tag{3}$$

Figure 3 shows that:

$$V_{+} = V_{RKREF} \times \frac{R_t}{R_2 + R_t} \tag{4}$$

$$V_{-} = V_{RKREF} \times \frac{R_3}{R_1 + R_3} \tag{5}$$

Where, V_{RKREF} is the reference voltage, set V_{RKREF}=+10V; R_1, R_2, R_3 is the selected resistance value of circuit; R_t is the thermistor that can get from the temperature-resistance curve. When the temperature t is -30℃, R_t =100.7679KΩ; when t is +50℃, R_t =1.7604KΩ; when t∈ (-30℃, +50℃), 100.7679KΩ≤R_t≤1.7604KΩ. From Equation (4), V_{+max} and V_{+min} can be obtained as

$$V_{+\max} = 10 \times \frac{100.7679}{R_2 + 100.7679} \tag{6}$$

$$V_{+\min} = 10 \times \frac{1.7604}{R_2 + 1.7604} \tag{7}$$

From Equation (3), it can be calculated as

$$R_2^{\,2} + (102.5283 - 49.5038G)R_2 + 176.04 = 0 \tag{8}$$

Take G=4, R_2=93 or 1.8KΩ, in order to reduce the power consumption of the bridge circuit, R_2 can be selected as 100KΩ, from Equations (6)-(7), it can be obtained as

$$\begin{cases} V_{+\max} = +5.019\text{V} \\ V_{+\min} = +0.173\text{V} \end{cases}$$

V_{+max} and V_{+min} are substituted into Equations (1)-(2), then it is known that V-∈ (+2.519V,+2.673V). Take R_1=100KΩ, from Equation (5), it can be obtained that R_3∈ (33.67KΩ,36.48KΩ). Take R_3=34.8KΩ, V-=+2.582V, so main parameters of the bridge circuit are as follows:

Resistance value of bridge arm: R_1=100KΩ, R_2=100KΩ, R_3=34.8KΩ;

Output voltage: V_-=+2.582V, V_+∈(+0.173V, +5.019V);

Voltage difference: V_+ - V_-∈(-2.409V, +2.437V);

Minimum operating resistance: $1 \big/ \left(\frac{1}{100+34.8} + \frac{1}{100+1.7604}\right) = 57.99\,\text{k}\Omega$;

Maximum operating current: 10V/57.99KΩ=0.172mA.

An external gains set resistance R_G can adjust gain G of operational amplifier AD620. They are designed as

$$G = \frac{49.4\text{K}\Omega}{R_G} + 1 \tag{9}$$

$$R_G = \frac{49.4\text{k}\Omega}{G - 1} \tag{10}$$

Let G=4, from Equation (10), it is obtained that R_G =16.4667KΩ; let R_G=16.5KΩ, from Equation (9), it is obtained that G=3.994. Output of the operational amplifier $V_o = G \times (V_+ - V_-)$, it is given that V_o∈ (-9.621V, +9.733V). AD574 can detect analog input of ±10V, so V_o is within the legal range.

Thermistor is selected from series MF61 of NTC. Before used, it performs screening, thermo sensitive calibration tests, and formula fitting for data obtained from the tests, to improve measuring veracity. So it is designed as

$$T = {}^{2C}\!\Big/\!\left(-B+\sqrt{B^{2}-4C(A-LnR)}\right) - 273.15 \tag{11}$$

where, T is the calculated result of temperature in ℃; R is thermistor resistance value in Ω; A, B, C is the thermistor coefficient, which can be obtained from formula fitting. DSP selects coefficient of each thermistor through looking up table, and uses them to calculate according to the formula.

4.2. Heating Devices

After temperature collection, DSP compares and judges target temperatures received, and it can perform heating set automatically, its processing flow chart is shown as follows.

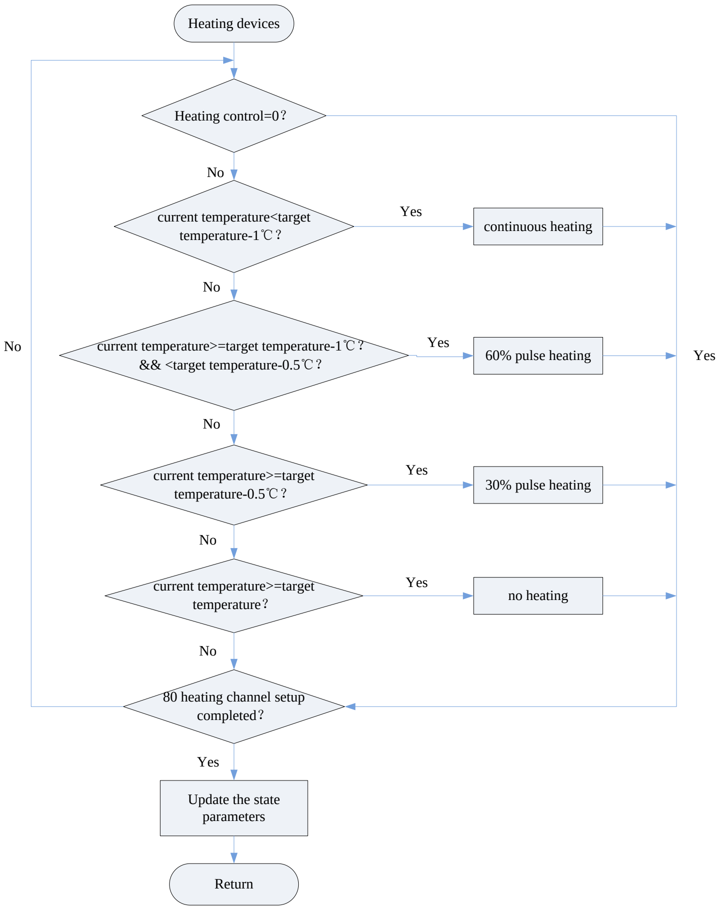
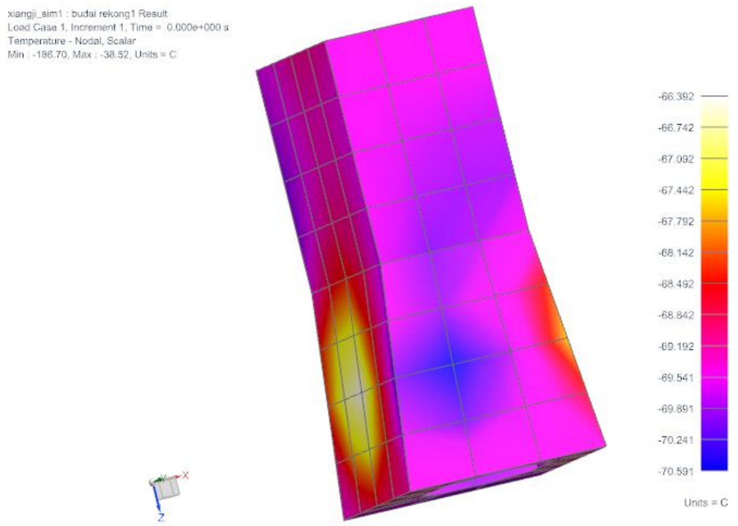


Figure 2. Heating Devices of Flow Chart

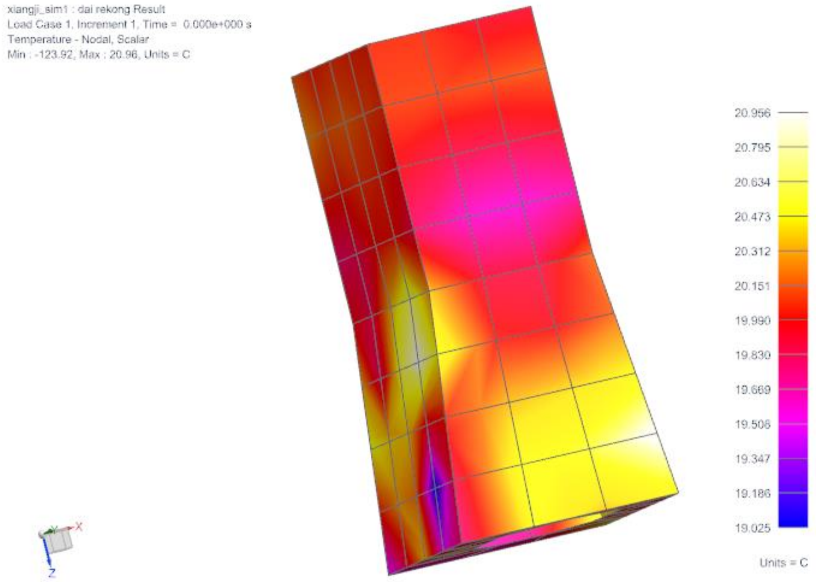
5. Test and Analysis of Experiments

5.1. Thermal Analysis Before the Experiment

A space flight camera performs a thermo analysis, temperature distribution before and after the analysis is shown in Figure 5. The figure shows that, after analysis, heat distribution consistency of the camera is better, so it can confirm operation temperature of each heating point.



(a) Cloud Picture of Temperature Distribution before Heating Control

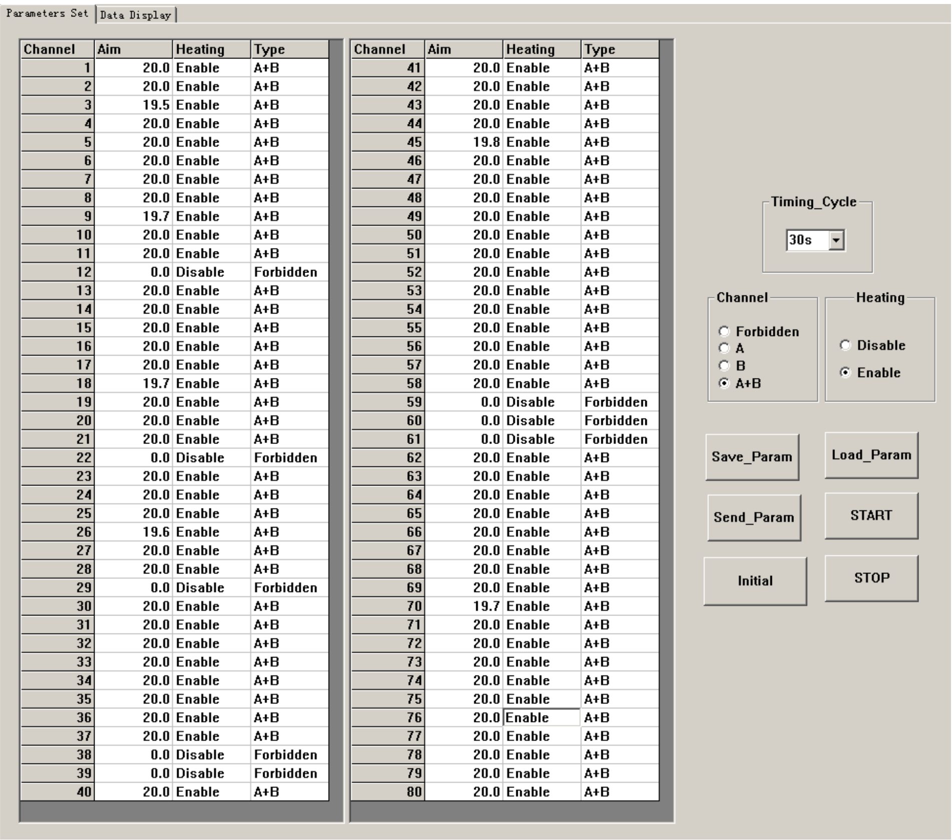


(b) Cloud Picture of Temperature Distribution after Heating Control

Figure 3. Comparison Chart of Temperature Distribution Before and After Heating Control

5.2. Heating Control Stability Test

Proceed from actual engineering, it sets up target temperature of each heating channel according to results after thermo analysis, its setup interface is shown in Figure 6, the heating controller performs heating control, set state return interface is shown in Figure 7. The interface shows that, the practical controlled temperature is accord with the target temperature.



Channel	Aim	Heating	Type
1	20.0	Enable	A+B
2	20.0	Enable	A+B
3	19.5	Enable	A+B
4	20.0	Enable	A+B
5	20.0	Enable	A+B
6	20.0	Enable	A+B
7	20.0	Enable	A+B
8	20.0	Enable	A+B
9	19.7	Enable	A+B
10	20.0	Enable	A+B
11	20.0	Enable	A+B
12	0.0	Disable	Forbidden
13	20.0	Enable	A+B
14	20.0	Enable	A+B
15	20.0	Enable	A+B
16	20.0	Enable	A+B
17	20.0	Enable	A+B
18	19.7	Enable	A+B
19	20.0	Enable	A+B
20	20.0	Enable	A+B
21	20.0	Enable	A+B
22	0.0	Disable	Forbidden
23	20.0	Enable	A+B
24	20.0	Enable	A+B
25	20.0	Enable	A+B
26	19.6	Enable	A+B
27	20.0	Enable	A+B
28	20.0	Enable	A+B
29	0.0	Disable	Forbidden
30	20.0	Enable	A+B
31	20.0	Enable	A+B
32	20.0	Enable	A+B
33	20.0	Enable	A+B
34	20.0	Enable	A+B
35	20.0	Enable	A+B
36	20.0	Enable	A+B
37	20.0	Enable	A+B
38	0.0	Disable	Forbidden
39	0.0	Disable	Forbidden
40	20.0	Enable	A+B

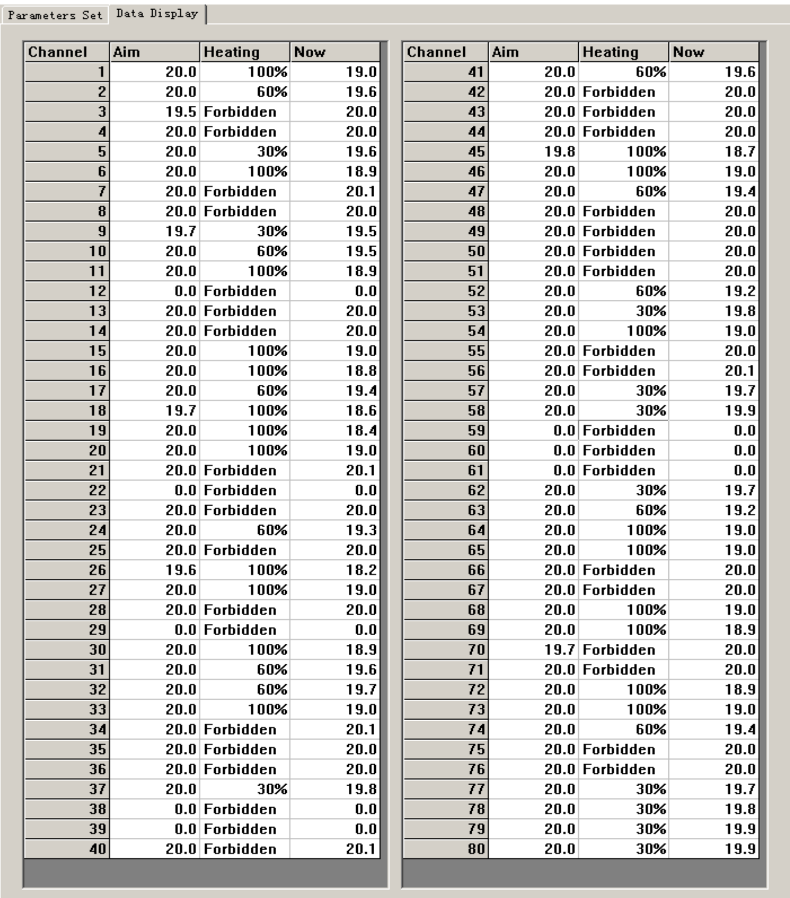
Channel	Aim	Heating	Type
41	20.0	Enable	A+B
42	20.0	Enable	A+B
43	20.0	Enable	A+B
44	20.0	Enable	A+B
45	19.8	Enable	A+B
46	20.0	Enable	A+B
47	20.0	Enable	A+B
48	20.0	Enable	A+B
49	20.0	Enable	A+B
50	20.0	Enable	A+B
51	20.0	Enable	A+B
52	20.0	Enable	A+B
53	20.0	Enable	A+B
54	20.0	Enable	A+B
55	20.0	Enable	A+B
56	20.0	Enable	A+B
57	20.0	Enable	A+B
58	20.0	Enable	A+B
59	0.0	Disable	Forbidden
60	0.0	Disable	Forbidden
61	0.0	Disable	Forbidden
62	20.0	Enable	A+B
63	20.0	Enable	A+B
64	20.0	Enable	A+B
65	20.0	Enable	A+B
66	20.0	Enable	A+B
67	20.0	Enable	A+B
68	20.0	Enable	A+B
69	20.0	Enable	A+B
70	19.7	Enable	A+B
71	20.0	Enable	A+B
72	20.0	Enable	A+B
73	20.0	Enable	A+B
74	20.0	Enable	A+B
75	20.0	Enable	A+B
76	20.0	Enable	A+B
77	20.0	Enable	A+B
78	20.0	Enable	A+B
79	20.0	Enable	A+B
80	20.0	Enable	A+B

Timing_Cycle: 30s

Channel
○ Forbidden
○ A
○ B
● A+B

Heating
○ Disable
● Enable

Figure 6. Setup Interface of Heating Control Parameters



Channel	Aim	Heating	Now
1	20.0	100%	19.0
2	20.0	60%	19.6
3	19.5	Forbidden	20.0
4	20.0	Forbidden	20.0
5	20.0	30%	19.6
6	20.0	100%	18.9
7	20.0	Forbidden	20.1
8	20.0	Forbidden	20.0
9	19.7	30%	19.5
10	20.0	60%	19.5
11	20.0	100%	18.9
12	0.0	Forbidden	0.0
13	20.0	Forbidden	20.0
14	20.0	Forbidden	20.0
15	20.0	100%	19.0
16	20.0	100%	18.8
17	20.0	60%	19.4
18	19.7	100%	18.6
19	20.0	100%	18.4
20	20.0	100%	19.0
21	20.0	Forbidden	20.1
22	0.0	Forbidden	0.0
23	20.0	Forbidden	20.0
24	20.0	60%	19.3
25	20.0	Forbidden	20.0
26	19.6	100%	18.2
27	20.0	100%	19.0
28	20.0	Forbidden	20.0
29	0.0	Forbidden	0.0
30	20.0	100%	18.9
31	20.0	60%	19.6
32	20.0	60%	19.7
33	20.0	100%	19.0
34	20.0	Forbidden	20.1
35	20.0	Forbidden	20.0
36	20.0	Forbidden	20.0
37	20.0	30%	19.8
38	0.0	Forbidden	0.0
39	0.0	Forbidden	0.0
40	20.0	Forbidden	20.1

Channel	Aim	Heating	Now
41	20.0	60%	19.6
42	20.0	Forbidden	20.0
43	20.0	Forbidden	20.0
44	20.0	Forbidden	20.0
45	19.8	100%	18.7
46	20.0	100%	19.0
47	20.0	60%	19.4
48	20.0	Forbidden	20.0
49	20.0	Forbidden	20.0
50	20.0	Forbidden	20.0
51	20.0	Forbidden	20.0
52	20.0	60%	19.2
53	20.0	30%	19.8
54	20.0	100%	19.0
55	20.0	Forbidden	20.0
56	20.0	Forbidden	20.1
57	20.0	30%	19.7
58	20.0	30%	19.9
59	0.0	Forbidden	0.0
60	0.0	Forbidden	0.0
61	0.0	Forbidden	0.0
62	20.0	30%	19.7
63	20.0	60%	19.2
64	20.0	100%	19.0
65	20.0	100%	19.0
66	20.0	Forbidden	20.0
67	20.0	Forbidden	20.0
68	20.0	100%	19.0
69	20.0	100%	18.9
70	19.7	Forbidden	20.0
71	20.0	Forbidden	20.0
72	20.0	100%	18.9
73	20.0	100%	19.0
74	20.0	60%	19.4
75	20.0	Forbidden	20.0
76	20.0	Forbidden	20.0
77	20.0	30%	19.7
78	20.0	30%	19.8
79	20.0	30%	19.9
80	20.0	30%	19.9

Figure 7. Display Interface of Temperature Collection

5.3. Heating Control Validity Test

This is a 96 hours' low temperature (-40℃) test in a vacuum, heating controller returns state parameter within a cycle of 30s, we analyze the partial parameter result of a heating channel, which is compared with target temperature. Its corresponding curve is shown in Figure 8. The figure shows that, the temperature difference of practical temperature and target temperature is within the range of -0.5℃~+0.2℃, heating control accuracy is high.

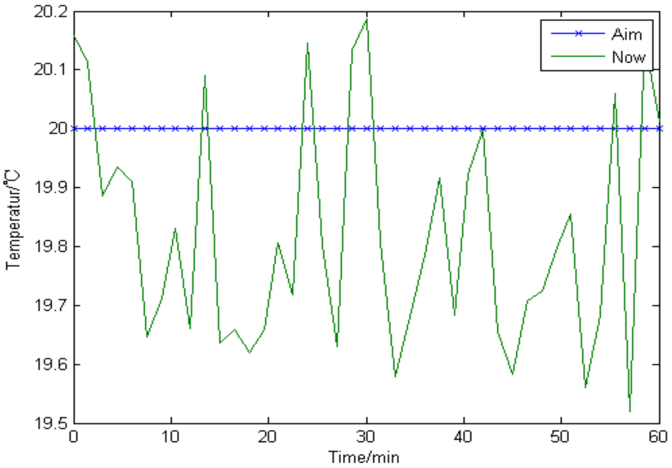


Figure 8. Correlation Curve of Target Temperature and Collection Temperature

6. Conclusion

Proceed from actual engineering, the heating control method of a space camera described in this paper is combined with operation status of software and hardware platform of the camera, it can meet the requirements of operation temperature for space cameras during the working period.

Control method has high stability and veracity. It improves reliability of the space camera.

Control method is simple and explicit, has wide practical application value.

Acknowledgement

This work was co-supported by the National Natural Science Foundation of China (No. 60506014).

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