The system design based on long-wave uncooled infrared detector

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Abstract. According to the requirement of high-definition surveillance of the status of space targets in low illuminance, a high SNR (Signal to Noise Ratio) uncooled long-wave infrared system is designed. Based on the detector of UL04371 with 640 × 480 array, the system scheme, acquisition system and real-time image processing algorithms are realized. On the basis of system implementation, the paper mainly focuses on how to reduce the noises from the aspect of hardware circuits and how to realize the real-time processing in the way of specified infrared image algorithms. Finally, the paper gives the test result which shows that the system has achieved a relatively good SNR characteristic with the average NETD (Noise Equivalent Temperature Difference) value of 220mK under the condition of the integration time of 64us and the radiation of 300K black body.

1. Introduction

With the development of microelectronics and signal processing technology, infrared uncooled focal plane sensor technology is becoming more and more mature. Infrared imaging system is widely used in the industry and military field, and the image quality of infrared imaging system directly affects the performance of infrared imaging system. In the previous literature reports, the infrared image processing algorithm was mainly reported, while few literatures introduced the design of the whole system and also the circuit design and the processing methods of how to improve the SNR from the perspective of infrared system [1-4]. So, this paper mainly presents the system design and the circuit design and the processing methods.

On one hand, the noise processing of the driving circuit for the sensor is very important. The introduction of significant noise will directly reduce the image quality of the imaging system and the dynamic range of the output signal. On the other hand, as the limitation of material and manufacturing technology, infrared focal plane sensors usually produce defective pixels and non-uniform noise. In the infrared system, the defective pixels and non-uniformity correction are required. In addition, since the image display device only outputs 8 bits of small dynamic range, in order to avoid much loss of the details of the original data and also display real-time infrared image on the display terminal, the realizing of the dynamic compression for the collected 16 bit infrared image is also the premise and basis for real-time display [5].

In this paper, 640 × 480 large array uncooled sensor is employed in the design. The scheme architecture, low noise acquisition system and image processing system of the infrared imaging system are introduced in detail. The reduction for the noises of sensor driving circuit, the processing of
infrared image and real-time display is described in detail. Finally, the signal-to-noise ratio and the actual imaging effect of the infrared imaging system are given at the end of the paper.

2. 640 × 480 imaging system scheme
The project scheme is shown in Figure 1. The infrared camera mainly includes driving circuit module and processing module. First, the driving module generates the bias adjustable voltage, fixed analog voltage and digital driving signals required by the infrared sensor. If the sensor gets the correct driving signals, the output analog signal is output and filtered by low-pass filter and then transmitted to an A/D for sampling. After that the timing control, reading and storage of each pixel values for the infrared image are carried out by FPGA and the data is sorted according to the frame format and sent to the processing module as serial data. Then, the FPGA of the processing module receives the serial LVDS signal of the infrared image. After the image processing including defective pixels correction, non-uniform correction and dynamic range compression, the images enter DSP for image coding and compression. After that, it outputs through the network port, and the display terminal receives the data to display the infrared image in real time mode.

![Figure 1. Infrared camera implementation scheme.](image)

3. Driving circuit design
In the design, the uncooled infrared sensor UL04371 [6] with resolution of 640 × 480 is employed. The average NETD of the pixels is about 80mK at 300K@50Hz. The sensor is shown in Figure 2.

![Figure 2. 640 × 480 uncooled sensor.](image)

3.1. Power supply and bias voltage design
The power supply circuit of the sensor needs to provide one analog power supply, four analog bias voltages and one digital power supply. The power supply and bias signals are shown in Table 1.

It can be seen from Table 1 that the analog power supply and bias voltage of the sensor have very high requirements for noise performance, and the selection and control of the power supply and bias voltage will directly affect the quality of the output image of the sensor. It can be seen from above that the maximum RMS noise of VDDA and VBUS bias signal is required within 100μV, so LT1962 is selected for VDDA. LT1962 is a low-voltage differential voltage regulator with low noise and low power consumption, and its noise value is 20μV RMS (10Hz to 100kHz). The output of VBUS is 2.8V, ADR433B is adopted in the design, and the noise voltage value is 3.75 µVp-p (0.1Hz to 10Hz), which can meet the design requirements [7].
Table 1. Power supply and bias signals.

| Name | Optical Value | Current | Max RMS Noise       |
|------|---------------|---------|---------------------|
| VDDA | 5V±100mV      | 60mA    | ≤100uV              |
| GFID | 0-5V adjustable | 1mA    | 2uV (1Hz-1kHz)      |
|      |               |         | 5uV (1Hz-10kHz)     |
|      |               |         | 100uV (1Hz-10MHz)   |
| VSK  | 2.0-5.5V adjustable | 5mA | 2uV (1Hz-1kHz) |
|      |               |         | 5uV (1Hz-10kHz)     |
|      |               |         | 100uV (1Hz-10MHz)   |
| VBUS | 2.8V±25mV      | 1mA    | ≤100uV              |
| GSK  | 2.2±50mV      | 1mA    | 2uV (1Hz-1kHz)      |
|      |               |         | 5uV (1Hz-10kHz)     |
|      |               |         | 100uV (1Hz-10MHz)   |
| VDDL | 3.3V±300mV    | 5mA    | ≤100mV              |

In addition, the maximum RMS noise requirements of GFID, VSK and GSK signals are the same, but different LDO chips are selected according to different output voltages. GFID output requires 0-5V adjustable, using ADR445 produced by ADI company. The maximum voltage output of the chip is +5V, and its voltage noise is 2.25 μVp-p (0.1Hz to 10Hz). VSK voltage is required to be adjustable between 2.0-5.5V and Linear LT1962 is adopted. The output voltage range of the device is from 1.22V to 20V and the noise value is 20μV RMS (10Hz to 100kHz). GSK signal acquisition is similar to VBUS by using voltage reference chip ADR433b with 2.2K and 0.8K resistance divider.

3.2. Infrared signal filtering

Before the signal enters into the 14 bit A/D AD9240, in order to ensure the low noise of the signal for filtering, the second-order LF filter circuit is adopted, as shown in the figure below [8]. In this design, the input bandwidth of analog signal is 2.5MHz. To ensure that the readout video signal does not be undistorted, the 3dB bandwidth of filter is set at 10MHz and the design diagram is shown in Figure 3.

4. Image processing design

For the infrared image processing, the processing module mainly completes the pre-processing and image compression of infrared image data format, such as framing, non-uniformity correction, defective pixels correction, dynamic range compression, BT656 or BT1120 format conversion and etc.

4.1. Defective pixels correction

The defective pixels refer to those that respond too high or too low in IRFPA. Defective pixels include dead pixels and overheated pixels. Dead pixel refers to a pixel whose response rate is less than 1/10 of
the average response rate, while overheated pixel refers to a pixel whose response rate is 10 times greater than the average response rate [9]. The number and distribution of defective pixels have a great influence on the performance of the device. If there are too many defective pixels, a large number of bright spots or dark spots will appear in the infrared output image, which will seriously affect the performance of the image. For point-to-point data processing, the linear interpolation between rows or columns can achieve better results. If a pixel is a defective pixel and then the linear interpolation algorithm of 4 points between lines is adopted, the output of defective pixels compensation is:

$$I(i, j) = \frac{I(i-2, j) + I(i-1, j) + I(i+1, j) + I(i+2, j)}{4}$$  \hspace{1cm} (1)

In which, $I(i,j)$ means the compensation result. $I(i-2,j)$, $I(i-1,j)$, $I(i+1,j)$, $I(i+2,j)$ means the points of the 4 neighboring lines.

### 4.2. Two-point correction method

In order to improve the real-time performance, two-point correction method is used for non-uniformity correction, and the process of the two-point correction method is as follows:

When the black body temperature is $T_1$, the $N$ frames image data are collected, and the average response $X_i(T_1)$ of $N$ frames for each pixel is:

$$X_i(T_1) = \frac{\sum_{n=1}^{N} X_{in}(T_1)}{N}$$  \hspace{1cm} (2)

Where $X_{in}(T_1)$ stands for the response value of one frame with temperature $T_1$.

When the black body temperature is $T_2$, the $N$ frames image data are also collected, and the average response of each pixel of $N$ frames is measured as follows:

$$X_i(T_2) = \frac{\sum_{n=1}^{N} X_{in}(T_2)}{N}$$  \hspace{1cm} (3)

Where, $i$ represents for a pixel, $1 \leq i \leq 640 \times 480$. $X_{in}(T_2)$ stands for the response value of one frame with temperature $T_2$.

Calculate the correction factor of each unit and specify two fixed response values $Y_i(T_1)$ and $Y_i(T_2)$ for $T_1$ and $T_2$. The values should be set according to the dynamic response range of different detectors, and then calculate the correction coefficient $G_i'$ and $O_i'$:

$$G_i' = \frac{Y_i(T_2) - Y_i(T_1)}{X_i(T_2) - X_i(T_1)}$$

$$O_i' = Y_i(T_1) - G_i'X_i(T_1)$$  \hspace{1cm} (4)

Finally, each pixel is corrected according to the correction equation:

$$Y_i = G_i'X_i + O_i'$$  \hspace{1cm} (5)

Where $Y_i$ is the corrected result of the non-uniformity algorithm.

Because the temperature change will influence the non-uniformity of the sensor, that is, the correction coefficient should be adjusted. In the actual operation, the piecewise linear method can be used for calibration, and a group of temperature coefficients can be stored at every temperature point, such as 5°C or 10°C. In the real-time calibration, which group of coefficients adopted is determined according to the temperature value of the focal plane.

### 4.3. Dynamic range compression

The original data of infrared images is 16-bit data, which has a large dynamic range, while the image display device only outputs a small dynamic range of 8 bits. So, in order to avoid losing too much detail information of the original data, it is necessary to compress the original data in its dynamic range.
range. According to the different mapping curves, the dynamic range compression adopts nonlinear transformation algorithm. To ensure that the image can retain the details of the low-temperature and high-temperature areas after the dynamic range compression, the Gaussian filter is employed for the infrared digital image in this design, and then the low-frequency image is linearly compressed before histogram equalization, and then the high-frequency part generated by the filter is superimposed, as can be seen in Figure 4.

![Figure 4. Dynamic range compression algorithm.](image)

Suppose \( f(x,y) \) is the raw image, \( w(x,y) \) is the Gaussian filter, the LF(low-pass filter) image \( R_{LF}(x,y) \) can be expressed as:

\[
R_{LF}(x,y) = \frac{1}{16} \sum_{i=-1}^{1} \sum_{j=-1}^{1} w(x,y) \times f(x,y)
\]

In order to improve the real-time processing performance, the Template of Gaussian filter is simplified as:

\[
w(x,y) = \frac{1}{16} \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}
\]

Then the HF (high-pass filter) image \( R_{HF}(x,y) \) can be calculated as:

\[
R_{HF}(x,y) = f(x,y) - R_{LF}(x,y)
\]

In the linear compression, we employ the gamma transformation, the gamma factor is taken as 0.5.

For the linear Transformation of the HF image, the formula is as follows:

\[
I_{HF}(x,y) = \frac{(R_{HF}(x,y) - \text{Min}(x,y)) \times 255}{\text{Max}(x,y) - \text{Min}(x,y)}
\]

Where \( \text{Min}(x,y) \) is the minimum value of the \( R_{HF}(x,y) \) and \( \text{Max}(x,y) \) is the maximum value of the \( R_{HF}(x,y) \).

4.4. DSP software design of processing module

The main infrared image compression is completed in DSP TMS320DM6467. The TMS320DM6467 is a SOC designed for high-resolution video encoding and decoding, which integrates two high-definition video and image coprocessors (HDVICP0 and HDVICP1) and a video data conversion engine. DSP software receives the original infrared image, calls the corresponding coding software library for compression and coding processing, and integrates the encoded image into UDP / IP package and sends it to the display terminal through the network port.

5. SNR test and imaging results

5.1. System SNR test

The SNR of LWIR sensor is measured by NETD [10]. Black body radiation target is employed in the test process. The system measures the black body surface with temperature \( T_1 \) and \( T_2 \) respectively. The average NETD of each pixel for the long wave sensor are calculated as 220mK under the condition of 64us and 300K black body irradiation. Figure 5 shows the NETD values of pixels from 1 to 1500.
5.2. Imaging results
In the imaging system, HGL325B optical system produced by Wuhan Gaode is used for principle prototype development. Its lens focal length is 25mm, F number is 1.0, and the imaging effect is shown in Figure 6. It can be seen from Figure 6 that the whole system has a good effect on noise processing performance. The brightness and contrast of the infrared image are relatively high, and the details of the image are well reflected.

6. Conclusions
For the surveillance of special targets with low illuminance in space, a high-definition and low-noise characteristic infrared camera was developed. The paper gives a detailed description of the system scheme, acquisition system and image real-time processing algorithms for the detector of UL04371 with 640 × 480 array. Test result shows that the system achieved the average NETD of the pixel is 220mK when the integration time of the sensor is 64us and black body irradiation is 300K. Therefore, the prototype has realized the key technologies and suggests a reference for the design of the uncooled infrared system.

However, the prototype only realized the original design of the uncooled infrared system. How to carry out the application of engineering is the future development direction for this technology.

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