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Test stand and procedures for estimating parameters of microbolometer detector

Abstract

In this paper we present a test stand and a procedures to test the functionality of a microbolometer detector. Presented test stand is integrated with temperature driver to stabilize the temperature of a black body and the detector. Digital board with implemented application allows for capturing raw data, correcting non-uniformity, testing noise, sensitivity and NETD (noise equivalent temperature difference). Integration with temperature driver allows for more accurate and repeatable measurements.

Keywords: microbolometer parameters, non-uniformity correction.

1. Test stand and procedures for estimating parameters of microbolometer detector

Microbolometer belongs to the group of thermal detectors and consists of temperature sensitive resistor which is exposed to measured radiation flux. Bolometer array employs a pixel structure prepared in silicon micromachining technology (MEMS). Each individual detector has different sensitivity and offset due to detector-to-detector spread in the FPA fabrication process, and additionally can change with sensor operating temperature, biasing voltage variation or temperature of the observed scene. The difference in sensitivity and offset among detectors (which is called non-uniformity) additionally with its high sensitivity, produces fixed pattern noise (FPN) on produced image [1, 2]. Fixed pattern noise degrades parameters of infrared cameras like sensitivity or NETD [3]. Additionally it degrades image quality, radiometric accuracy and temperature resolution. To compare the image quality of two cameras we need a test stand which allow to control the readout circuit of the detector and to register the raw data. Presented test stand allows to test the functionality of the detector by capturing raw data, correcting non-uniformity, testing noise, sensitivity, NETD and determine bad pixels map. Finally we can display corrected image at the LCD screen.

2. Parameters of microbolometer detector

NETD calculation is presented by equation

$$NETD = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{N_{ij}}{S_{ij}} \tag{1}$$

To calculate NETD we need to measure noise N_{ij} and sensitivity S_{ij} for each detector. M is a number of columns and N is a number of rows. The procedure of measuring noise is described by formula:

$$N_{ij} = \sqrt{\frac{1}{L}\sum_{n=1}^{L}\left[Y_{ij} - U_{ij,n}\right]^2} \tag{2}$$

where N_{ij} – standard deviation of the pixel [i,j] in time, Y_{ij} – mean value of the pixel, U_{ij} - value of output signal for bolometer i,j in frame n, L - number of frames. For the noise calculation one needs to place the camera at the front of a black body. In the next step we must to set the black body temperature to 25°C. Next must be collected 64 frames and calculated standard deviation of each pixel over the 64 frames. In the last step the standard deviation of each pixel to memory array must be written.

For the sensitivity calculation we need to register output signal of the detector array for two temperatures of the black body. We must to place the camera at the front of black body, set its temperature to 20°C and collect 64 frames. In the next step we have to average the value of each pixel's value over a 64 frames and save the result in memory array.

Next we must to set the temperature of the black body to 30°C and wait for stabilization. Than we must to repeat the procedure of recording and averaging.

The sensitivity calculation is presented by equation:

$$S_{ij} = \frac{Ub_{ij} - Ua_{ij}}{T_b - T_a} \tag{3}$$

where S_{ij} – sensitivity of the pixel [i,j], Ua_{ij} – pixel [i,j] value representing response of the detector to radiation of the black body at 20°C, Ub_{ij} – pixel [i,j] value representing response of the detector to radiation of the black body at 30°C, T_b - temperature of the black body at 30°C, T_a - temperature of the black body at 20°C.

3. Temperature influence on detector's output signal

Infrared detectors are characterized by high sensitivity to changes in ambient temperature. As reported [1,2], the sensitivity of the bolometer to change the temperature of the camera and the matrix (S_b) is much higher then sensitivity to temperature changes of a scene (S_{sc}), (S_b= −20 mV/K, S_{sc}=7 mV/K). Consequently, even insignificant change of detector temperature has a crucial influence on quality of non-uniformity correction process [2].

Therefore, it is nesesery to stabilize the temperature of the micro-bolometer during calibration process. To investigate the influence of environmental temperature on the microbolometer array, the detector was placed in a climatic chamber (Fig. 1).

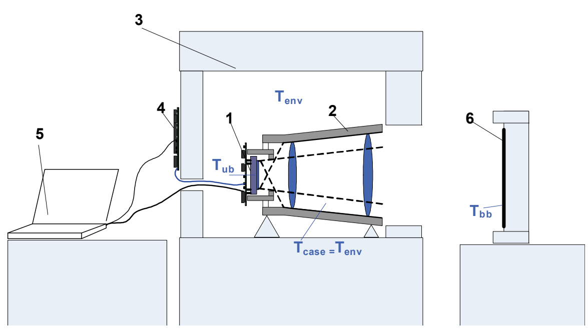

Fig. 1. Test stand for determining an influence of ambient temperature on detector parameters
1 - microbolometer detector with thermoelectric cooler, 2- lens, 3- climatic chamber, 4- thermoelectric controller, 5- computer with an application to control the climatic chamber and register RAW data from camera, 6- black body, Tub- detector temperature, T_{env}- temperature in climatic chamber, T_{case} - case temperature

In the study we tested Ulis detector with resolution 640×480, and 17 µm pixel-pitch. The temperature of the detector was stabilized by TEC controlled by a driver. The detector registered radiation of two black bodies where first had temperature 15°C and the second 35°C. The temperature of microbolometer detector was changed in a range from –20°C to +40°C. A voltage response to black body radiation at a temperature of 15°C as a function of the temperature of the detector is presented in Fig. 2.

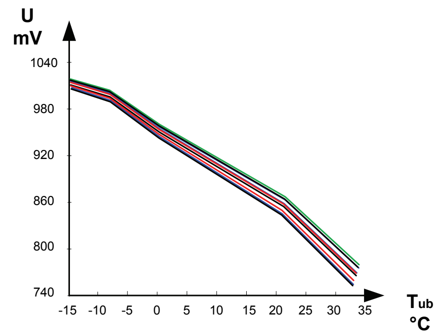

Fig. 2. Signal value of a microbolometer, converted by ADC as a function of detector temperature

Based on the measurements , it can be seen that the output signal decreases as a function of the detector temperature (Fig. 2). Additionally, it should be noted that the signal change is not the same for all detectors. This is evident from the comparison of the voltage values of the group of microbolometer. In wider temperature range the trend from Fig. 2 is changing. In higher temperature of the detector (40°C – 60°C), output signal is growing up. This is due to increasing detector sensitivity and self-heating effect [4, 5].

In the next step, the average sensitivity of all detectors to the incident radiation as a function of the detectors temperature was measured.

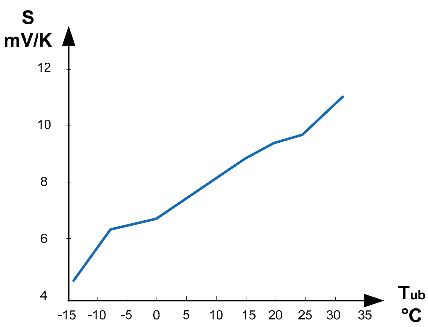

Fig. 3. Mean sensitivity of microbolometer detector to black body radiation as a function of the detector temperature

The sensitivity was measured according to formula (3). The measurement result is shown in Fig. 3. The average sensitivity of the detectors increases with the temperature of the detector.

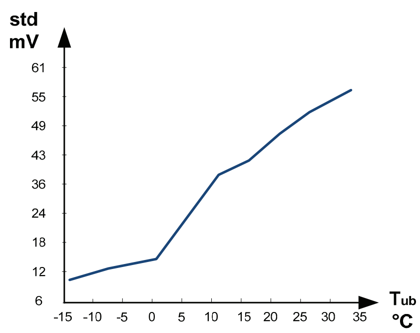

Fig. 4. Spread of the signal value from single image as a function of detector temperature before non uniformity correction

In the last study a voltage spread of single frame as a function of the detector temperature was measured. The measurement result is shown in Fig. 4. Based on the measurements taken, it can be seen that the spread of the output signal value increases with the detector temperature. This therefore confirms the result of the first measurement.

4. Test stand and measurement with stabilized detector temperature

Prepared test stand is presented in Fig. 5. We can divide it in to blocks:
- lens and black body,
- analog readout circuit for detector,
- FPGA with digital control blocks,
- processor Cortex A9 with operating system and control application,
- Tec drivers to controll temperature of black body and detector,
- LCD screen,
- Tec driver.

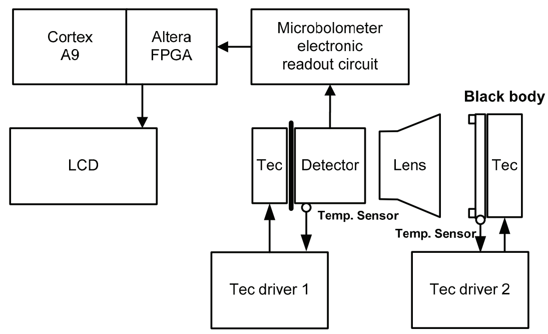

Fig. 5. Blok diagram of the test stand

Black body is used to radiate an uniform flux which is focused by the lens at the detector. Next the signal from the microbolometer detector is gained, converted from analog to digital signal by electronic readout circuit. Raw data after conversion are registered by FPGA in to a memory. In the next step the processor reads image data from the memory. Control logic designed in FPGA is presented in Fig. 6.

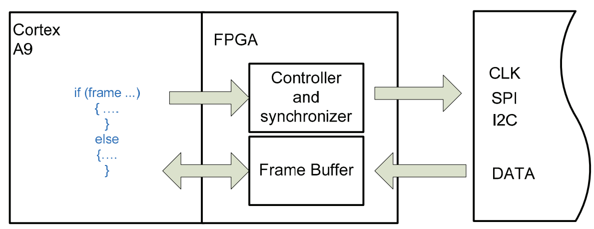

Fig. 6. Blok diagram of the digital processing module

Digital circuit designed in FPGA may be divided into two main blocks:
- controller and synchronizer,
- frame buffer.

The controller and synchronizer is designed to generate clock and others signals needed to drive the detector and readout circuit. Additionally this module was prepared to receive comments from processor and controls the frame buffer and readout circuit.

Frame buffer has to synchronize with generated signals and to collect raw data from external board. Received data are stored in internal dual port ram. Second port of the memory is connected to the processor. In this way the processor may read image from the memory asynchronously. Processor is developed together with FPGA in single chip designed by ALTERA.

The processor and the FPGA can operate independently, they are tightly coupled via a high-bandwidth system interconnect (Fig. 7). Processor bus masters have access to bus slaves in the FPGA fabric via the HPS-to-FPGA bridge. In this case the combination of the performance of the applications processor with the flexibility of Altera's FPGA fabric allow to build efficient system.

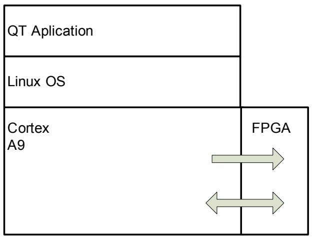

Fig. 7. Blok diagram of the processor system

Arm Cortex A9 allow to install an operating system. Designed test stand is running on Linux. Altera corporation develops an lightweight Linux version with frame buffer. It is ready to use Linux image with drivers to run at DE1-SOC starter kit.

Control application was designed in Qt platform. This platform allow to design an application with graphic interfaces.

Main task of the application is:

- reading raw image from dual port ram implemented in FPGA,
- calculate statistic parameters to make dynamic range compression,
- calculate 1- point non uniformity correction,
- calculate 2- point non uniformity correction,
- correct image non-uniformity,
- transmit image data to FPGA and display on a screen.

Additionally prepared application allow to calculate parameters mentioned before like: NETD, pixel noise, residual non-uniformity.

5. Measurements

Black body was used to determine GAIN and OFFSET coefficients and for the NETD measurement. Temperature of detector array was set by thermoelectric module connected to the microbolometer array package. Tested detector allowed reading measurement data together with the temperature of detector array owing to temperature sensor inside.

The GAIN table was calculated for temperatures of the black body set to T_{bb1}=10°C and T_{bb2}=30°C, when the temperature of detector array was equal to T_{ub}=30°C. Presented test stand was checked in a laboratory environment with the use of an infrared camera. At the test stand we measured parameters of prototype camera with Ulis detector (640×480), 17 µm pixel-pitch. Prepared measurement allows to calculate value of pixel noise = 757 µV, NETD = 93 mK, sensitivity = 8.14 mV/K, image non-uniformity STD/MEAN = 0.044.

6. Conclusions

Presented test stand allows to test the functionality of the detector by capturing raw data, correcting non-uniformity, testing noise, sensitivity and NETD. In the article the influence of the ambient temperature on the parameters of microbolometer detector is presented. Integrated thermoelectric cooler in presented test stand allow to control the temperature of microbolometer detector and minimize the influence of temperature fluctuations during measurements.

7. References

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Received: 21.10.2016 *Paper reviewed* *Accepted: 05.01.2017*

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