Uncooled Infrared 2D-Cameras with Fast 16-bit Signal Processing for Industrial Use

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1 Introduction

The infrared (IR) sensor market is developing rapidly. A growing number of high-performance focal plane arrays is available for commercial applications. The progress in the sensitivity and resolution of the sensor arrays leads to higher demands on the IR camera systems. The increased pixel numbers result e.g. in higher data rates and the lower sensor NETD values request higher dynamic ranges.

This paper presents a new IR camera system which is based on uncooled high-performance focal plane arrays. The required system dynamic range is discussed in detail. Two prototypes of the camera system containing a pyroelectric and a microbolometer sensor array, respectively, are introduced.

2 IR camera system

The newly developed IR camera system is based on an universal device concept [1,2]. Figure 1 shows the system set-up. Each system consists of a camera head and a PC plug-in board which are connected via fiber optic. The camera system is designed for a stationary use in harsh industrial environments. The robust housing may be completed by integrated water–cooling and air purge for the lens system. The camera head is equipped with trigger inputs to synchronize the camera system to an industrial process. The frame grabber is realized as a bus master adapter.

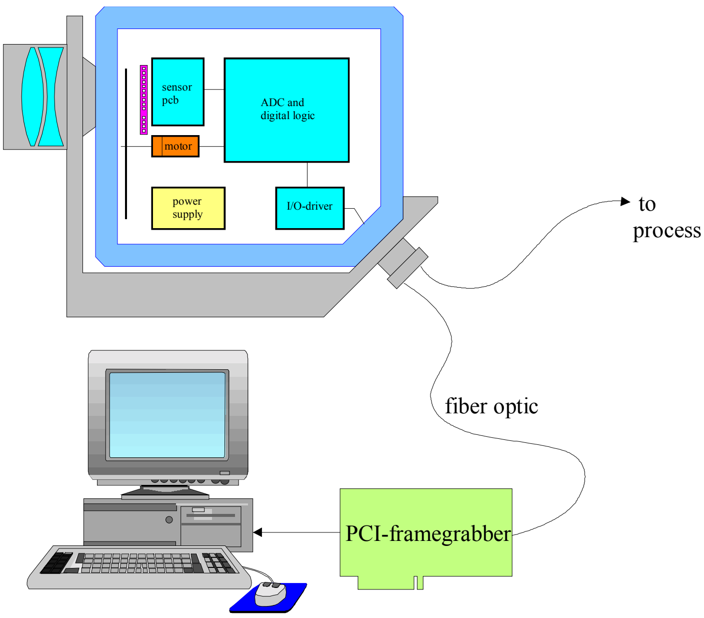

Figure 1: Setup of the universal camera system

3 Camera head

The camera head contains the close-to-sensor electronics and some standard packages. Figure 2 represents the block diagram of the camera head. The layout is the same for all applicable IR sensor arrays. Only the optic unit, the sensor PCB and the cooler/chopper pcb have to be adjusted to the special used sensor.

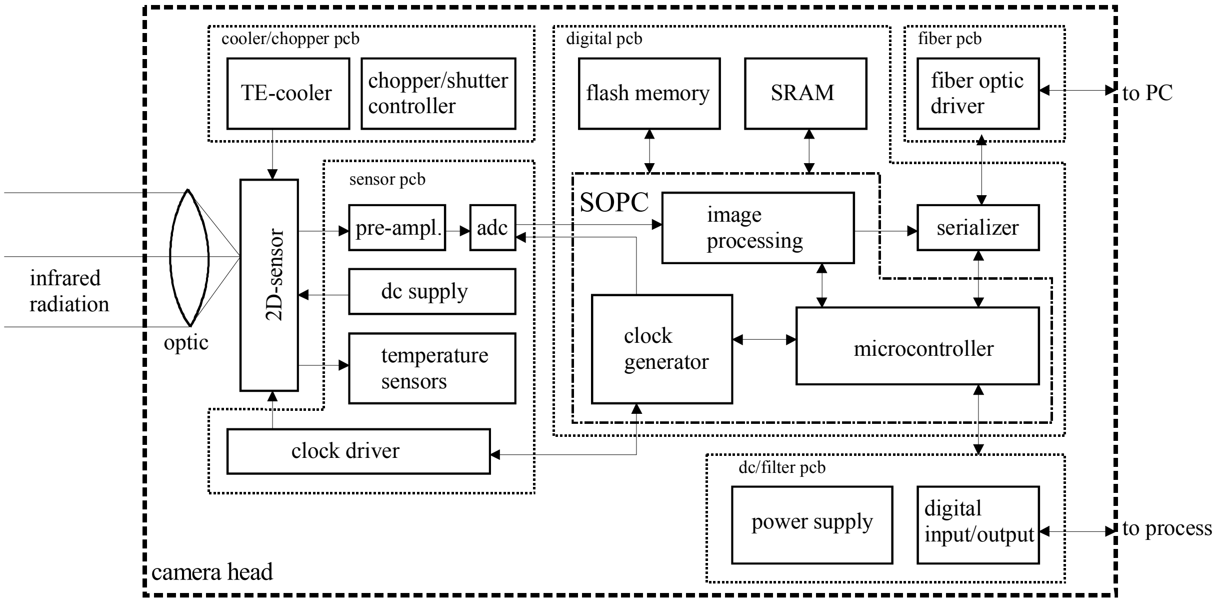

Figure 2: Block diagram of the camera head

An IR-transmissive optic images the object radiation onto the sensor array. The standard lens system has an *f*-number of 1.0, a focal distance of 18 mm and a field of view of 58 degrees. It allows the irradiation of large sensor arrays with diagonal dimensions up to 20 mm.

The sensor array transforms the infrared radiation into a serial electric signal. It is supplied with various low-noise direct voltages and several clocks which are closely generated on the sensor PCB. The sensor output signal has to be adjusted to the ADC input range. Thus, the sensor PCB contains low-noise clock drivers, low-noise DC supplies, sensor-specific electronics, a pre-amplifier and the analogue-to-digital converter (ADC). The ADC determines the maximum pixel rate which is 10 MHz for a conversion width of 16 bits.

The digital PCB is based on a System of Programmable Chip (SOPC) solution using a PLD with embedded processor. This allows an inexpensive adaptation to different sensor types and various industrial applications by re-programming the PLD. The PLD fulfills the tasks of a clock generator and a microcontroller and executes the signal processing including the necessary signal corrections. The microcontroller task controls and monitors the camera head. Among others it monitors the operation of the chopper / shutter motor and the four internal temperature sensors. It can also be used to control various functions, such as triggering or frame rate. The PC communicates with the microcontroller via an asynchronous interface. A serializer, a flash memory and an SRAM are the other essential components of the digital PCB. Figure 3 shows a fabricated digital PCB.

A DC/DC-PCB for the power supply, a thermo-electric cooler and a controller for the chopper or shutter motor, respectively, are further packages of the camera head.

The data communication to the PC is serial. All in all three bytes, two data bytes and one control byte, are communicated. The bytes are fed to a 10:1 serializer one at a time. Two bits are used as control information. Only the asynchronous interface signal for the microcontroller is transferred from the PC to the camera head. The output is suited for a frame rate of 50 Hz.

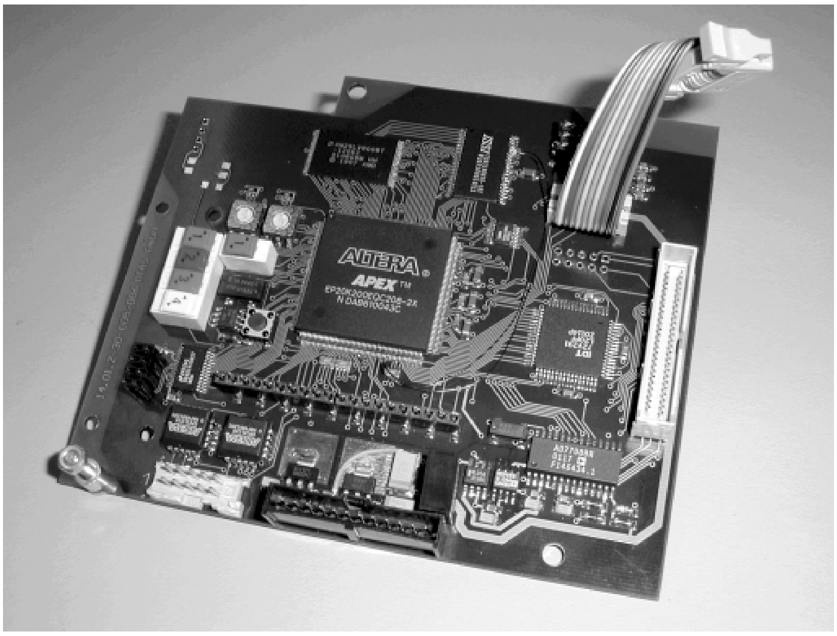

Figure 3: Digital PCB

4 Dynamic Range

The analog sensor output signal is digitized with a 16-bit resolution to achieve a high dynamic range. Owing to its noise and nonlinearity, the real dynamic range of the ADC is lower than the theoretical one of 96 dB. The available fast 16-bit ADCs have an effective number of bits (ENOB) of about 14 which corresponds to an effective dynamic range of 84 dB.

According to important application demands – measurement temperature range and NETD – the required dynamic range has to be estimated for the conception of the new camera system.

The dynamic range is defined as the ratio between the maximum signal and the minimum resoluble signal:

$$DB\,[dB] = 20 \cdot \log \frac{maximum\ signal}{minimum\ resoluble\ signal}. \tag{1}$$

Both the maximum and minimum signal can be quantified by including the irradiance. Figure 4 shows the dependence of the detected irradiance E on the object temperature T_{Obj} for two relevant spectral ranges. The represented curves were calculated for a chopped IR camera system with an *f*-number of 1.0 and a pyroelectric detector which responds only to an alternating irradiation. The chopper temperature is 35 °C. All emittance and transmittance values are assumed to be unity. The calculation for a camera system with a microbolometer array yields similar results.

The minimum resoluble signal is the amount of irradiance which corresponds to the effective noise value. The noise of IR cameras is usually transformed to the system input and expressed by the NETD value. For a given NETD the dynamic range amounts to:

$$DB = 20 \cdot \log \left| \frac{E\,(T_{Obj})}{NETD \cdot \partial E \,/\, \partial T_{Obj}} \right| \tag{2}$$

Presuming a constant NETD value, the dynamic range is independent on the detector area and the *f*-number.

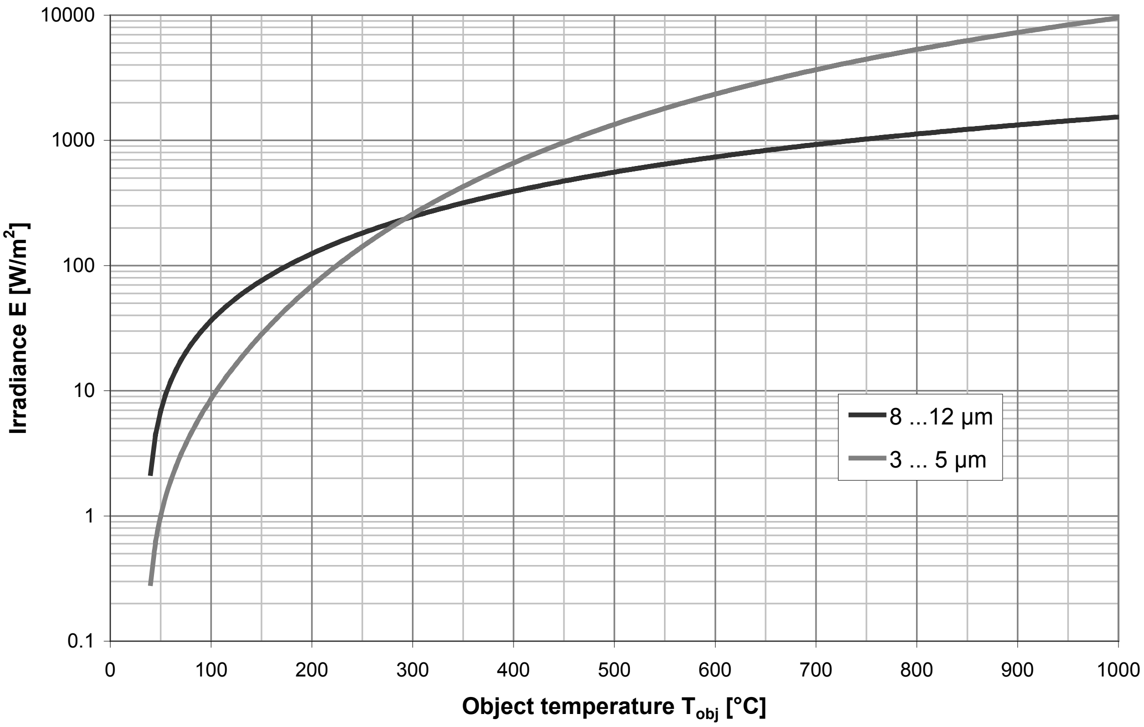

Figure 4: Irradiance detected by a chopped IR sensor

Figure 5 represents the influence of the dynamic range on the maximum measuring temperature for different spectral responsivities and NETD values. The system parameters are the same as above. The sensor responsivity is assumed as wavelength independent within the chosen spectral range and the system noise is assumed as signal independent. Figure 5 shows that measuring ranges of a few 100°C already request a remarkable high dynamic range.

Furthermore, the available dynamic range will also be reduced by the signal offsets between the sensor elements and the signal drift owing to internal temperature changes. Assuming a summarized signal offset of 10.000 LSB the effective dynamic range would drop from 84 to 76 dB.

Table 1 shows calculated values of measurement temperature ranges for different spectral ranges, NETD values and effective dynamic ranges of 76 dB and 84 dB, respectively. The nominal measuring ranges can be increased by reducing the system gain which again will cause higher system NETD values.

The investigations underline that IR camera systems with NETD values below 0.1 K require a signal processing unit with at least 16-bit resolution to get practicable measuring ranges.

System parameter		Measurement temperature ranges			
Spectral range	NETD	for 84 dB		for 76 dB	
3 to 5 µm	0.1 K	0 to 195 °C	35 to 200 °C	0 to 145 °C	35 to 150 °C
8 to 12 µm	0.1 K	0 to 530 °C	35 to 550 °C	0 to 290 °C	35 to 300 °C
3 to 5 µm	0.01 K	0 to 85 °C	35 to 90 °C	0 to 55 °C	35 to 65 °C
8 to 12 µm	0.01 K	0 to 115 °C	35 to 135 °C	0 to 60 °C	35 to 80 °C

Table 1: Nominal temperature ranges for dynamic ranges of 84 dB (16-bit-ADC with ENOB = 14) and 76 dB (considering signal offsets)

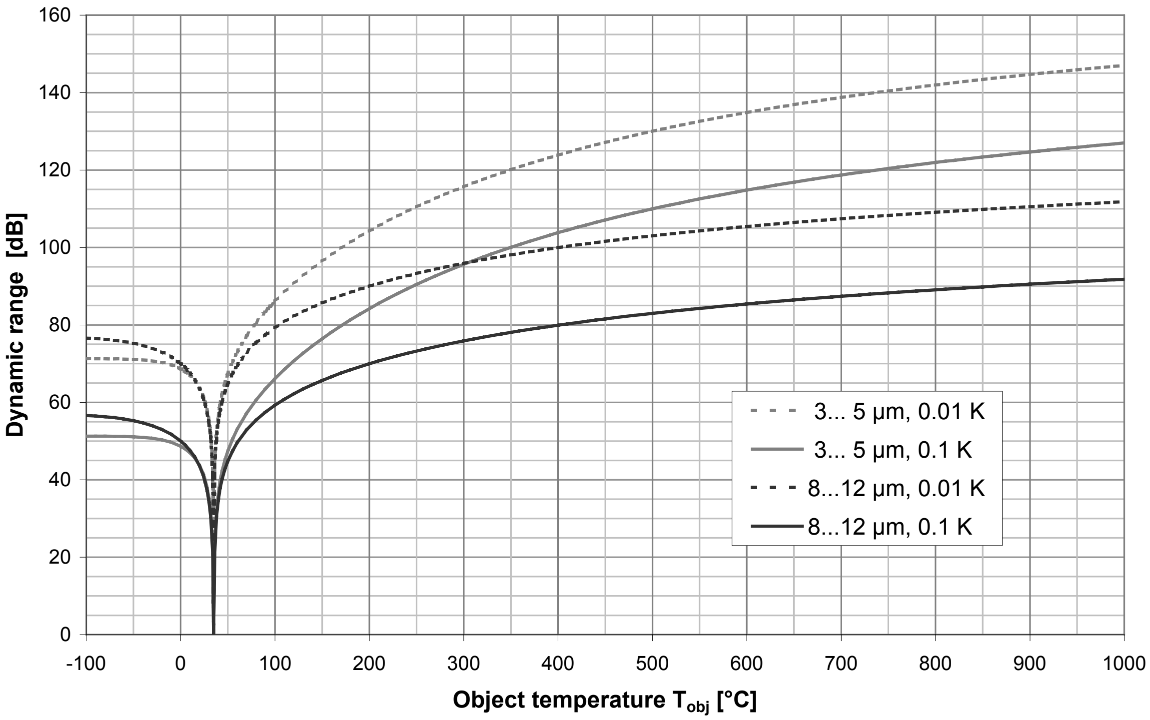

Figure 5: Required dynamic ranges for different spectral responsivities and NETD values

5 Realized systems

Two different prototypes of the camera system have been built and tested so far. The PYROVIEW 256 is based on a pyroelectric sensor array with 256 × 128 pixels and a pitch of 56 µm. In this camera the radiation flux is chopped at 50 Hz. The NETD is lower than 0.2 K for an object temperature of 30°C. Two spectral ranges (8 to 14 µm and 3 to 5 µm) are available.

The PYROVIEW 320 contains a 320 × 240 element microbolometer array with a 45 µm pitch. The microbolometer camera operates with a shutter to compensate the pixel offsets and to reduce the influence of the internal temperature. The shutter can be synchronized to an external process. This camera has an NETD of about 0.1 K for the same object temperature of 30 °C.

Figure 6 shows two thermo images of a human hand taken by the 320 × 240 microbolometer camera system.

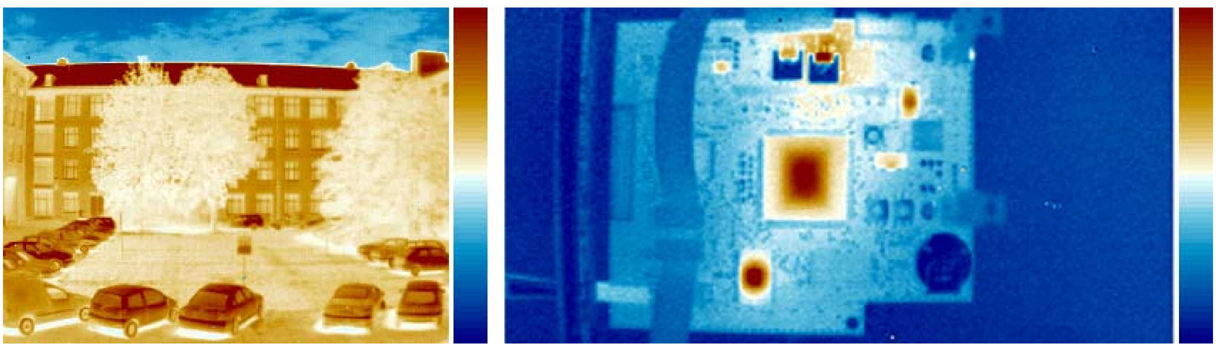

Figure 6: Thermo images taken by a 320 × 240 microbolometer camera system (left) and by a camera system with pyroelectric sensor array with 256 × 128 pixels (right)

6 Conclusions

A new IR camera system based on uncooled high-performance focal plane arrays (pyroelectric or microbolometer) was developed. It shows for both FPA types extraordinary high resolution and sensitivity values which allow its use for sophisticated measuring tasks.

The camera system is especially suited for the most different applications in the field of non-contact temperature measurement. The system is designed in such a way that its behavior will be kept constant regardless which kind of sensor and which wavelength ranges have been chosen.

Acknowledgement

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