Infrared line cameras for industrial temperature measurement

Peter Drögmöller [a], Günter Hofmann [b], Helmut Budzier [b,c], Thomas Reichardt [b], Manfred Zimmerhackl [b]
[a] MIKRON Instruments Co., Inc.; [b] DIAS Infrared GmbH;
[c] Dresden University of Technology, Institute for Solid State Electronics

Abstract

The PYROLINE/MikroLine cameras provide continuous, non-contact measurement of linear temperature distributions. Operation in conjunction with the IR_LINE software provides data recording, real-time graphical analysis, process integration and camera-control capabilities.

One system is based on pyroelectric line sensors with either 128 or 256 elements, operating at frame rates of 128 and 544 Hz respectively. Temperatures between 0 and 1300 °C are measurable in four distinct spectral ranges; 8–14 µm for low temperatures, 3–5 µm for medium temperatures, 4.8–5.2 µm for glass-temperature applications and 1.4–1.8 µm for high temperatures.

A newly developed IR-line camera (HRP 250) based upon a thermoelectrically cooled, 160-element, PbSe detector array operating in the 3–5 µm spectral range permits the thermal gradients of fast moving targets to be measured in the range 50–180 °C at a maximum frequency of 18 kHz. This special system was used to measure temperature distributions on rotating tires at velocities of more than 300 km/h (190 mph). A modified version of this device was used for real-time measurement of disk-brake rotors under load.

Another line camera consisting a 256 element InGaAs array was developed for the spectral range of 1.4–1.8 µm to detect impurities of polypropylene and polyethylene in raw cotton at frequencies of 2.5–5 kHz.

1 Introduction

Temperature measurement plays an important role in many industrial-processing applications. Of particular importance is the frequent need for non-contact measurements and data to be presented in the form of a two-dimensional image. Since most industrial production processes will involve the movement of objects in one direction at a known speed, one-dimensional array cameras can be used to produce such images by repetitive, high-speed scanning, thereby avoiding the considerably higher costs associated with cameras based upon two-dimensional sensor arrays.

Many IR-line cameras are available which utilize cooled, IR-semiconductor detectors and opto-mechanical scanners for one-dimensional beam deflection. Principle disadvantages of these line scanners brought about modern IR-line cameras using linear arrays that do not need opto-mechanical scanners. In contrast to line scanners where the circular measurement area is linearly moved over the measured object by the scanner, linear arrays can record the temperature distribution in multiple points on one line of the object simultaneously. More advantages occur through operation of uncooled IR-arrays.

In the following chapter, IR-line cameras based on linear arrays will be described. These cameras were specifically developed to satisfy the demands of industrial-process measurements, which often include the need for continuous operation in harsh environments. In such applications, high reliability, long-time stability and, most significantly, an optimal price-performance ratio play important roles.

2 Uncooled Infrared line cameras based on pyroelectric linear arrays

The key component of an IR-line camera (PYROLINE/MikroLine) is the uncooled pyroelectric linear array. Fig. 1 shows the fundamental structure. The detector array consists of 128 or 256 pixels, each with an active area of $A_S = a \cdot b$, aligned in the y-direction with center-to-center pitch c. The chopped radiation signal Φ_s passes through an IR-transmissive window before striking the active surface of the pyroelectric chip where it is absorbed, causing a temperature change which generates an electrical charge via the pyroelectric effect. With an integrated read out circuit, (ROIC) a multiplexed voltage output signal u'_S will be produced.

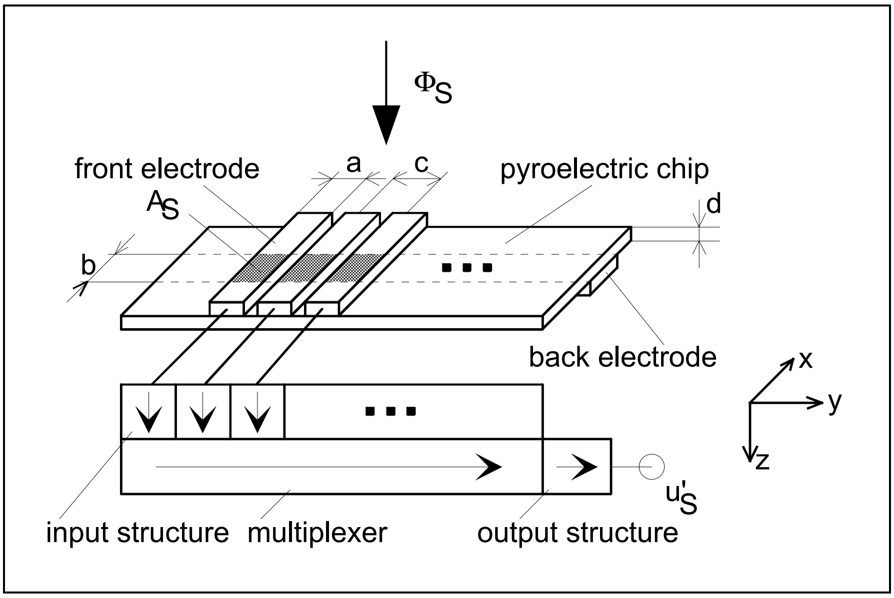

Fig. 1: Fundamental structure of a linear pyroelectric array

The linear array, 128-LT, includes a lithium-tantalate chip with 128 sensitive elements and a thickness of 20 µm. The pixel size is $a \times b = 90 \times 100$ µm^2 with a pitch, c, of 100 µm. The signals generated in the sensitive elements are processed in a CMOS-circuit that contains both analog and digital sections. The analog part realizes the sensor signal processing which includes the multiplexer, a low-noise pre-amplifier (with individual gain control for each pixel), the output amplifier, an RC low-pass filter and a sample-and-hold circuit. The digital section is responsible for the clock pulse supply for the analog part. The pyroelectric chip and CMOS-read out circuit are located on a thick-film wiring carrier, which is mounted into a hermetically sealed, metal housing. Incident light arrives at the detector elements through an IR-filter. Filters with specific pass-band characteristics are used to optimize the performance of the detector arrays for operation in the 8–14 µm, 3–5 µm, 4.8–5.2 µm and 1.4–1.8 µm spectral bands. The sensitivity of the detector array was maximized through the use of reduced-thickness (5 µm) pyroelectric chips fabricated using ion-beam etching techniques. This detector type is named 128-LT-I. Improved spatial resolution was achieved using arrays with 256 elements and a center-to-center pitch of 50 µm (type 256-LT-I)[1].

The camera system PYROLINE 128/MikroLine M2128 was developed primarily for use with pyroelectric, linear, 128-element-arrays, 128-LT and 128-LT-I. Fig. 2 shows the complete camera. It consists of a robust, industrial housing that can be equipped with integrated water-cooling and air purge for lens system. The camera assembly (Fig. 3) includes the pyroelectric array, a chopper module (chopper frequency 128 Hz), the IR-optics (not shown in Fig. 3) as well as the entire analog and digital signal processing. The analog-digital converter operates with 16-bit resolution. The cameras are configured with a signal processor that can fulfill several process control tasks beyond the standard analysis of measurement data. The signal processor converts the measured data into temperatures taking account of ambient temperature, emissivity, transmissivity, as well as the different sensitivities of each individual pixel. Up to 128-scanned temperature distributions can be stored in real time. Multiple control commands or alarm signals based upon measured data are available via a standard COM-port and dedicated I/O lines.

Fig. 2: Infrared line camera PYROLINE/MikroLine

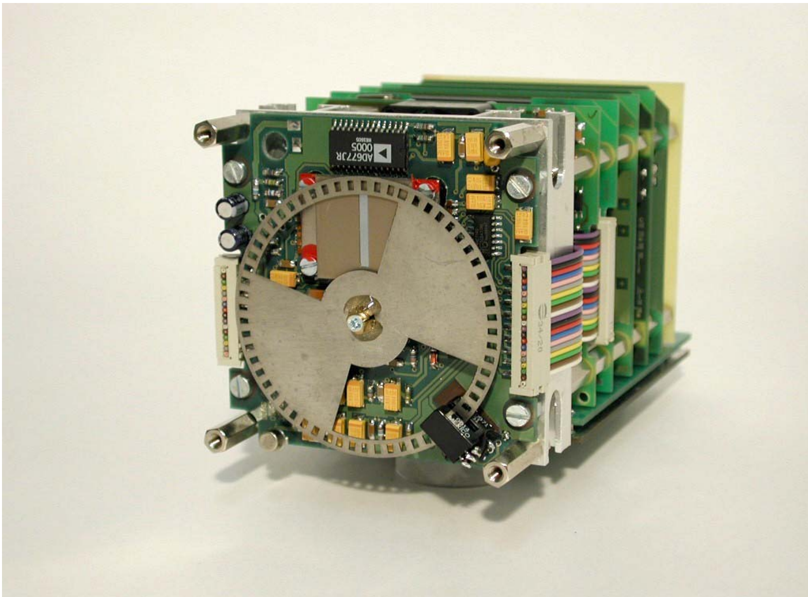

Fig. 3: IR-line camera assembly (without optics)

Two trigger inputs allow the synchronization of the data recording, independent of outside events: one for the recording and the other for the complete picture. For instance, the inclusion of an incremental encoder makes it possible to measure the temperature of rotating objects independently of the rotation speed where the spatial correlation between the measured temperature and the position on the measured object is required.

Since the camera must be located near the process away from the control room, an RS232 COM-port serves for control, monitoring and data transmission. In combination with a computer, this connection is used to program, parameterize and record measurement data. Optionally data transmission in real time (up to 128 Hz frame rate) over long distances can be realized by fiber optic connections in combination with a PCMCIA-transceiver card.

A user-friendly analyses and control software is available to operate the camera with an external computer. This software includes:

- Control and configuration of the camera
- Display of the measured data normalized to different temperature distributions or images
- Up to 32 regions of interests and alarms
- Load, save and print of temperature distributions (profiles) or images
- Single point temperature determination
- Drivers for analog and digital computer output cards
- Remote control via serial COM-port or network

A data recording function permits postprocessing, e.g. time delayed replay of fast processes, display using a different scale or change in emissivity. Additional software options include data export and password protection.

The cameras also work independently of an always-connected computer. Easy process control can be fulfilled via four independent, isolated inputs or outputs. All parameters for stand-alone operation can be configured with a computer through the RS232 COM-port. An integrated, non-volatile memory guarantees that the cameras remains programmed after a power loss.

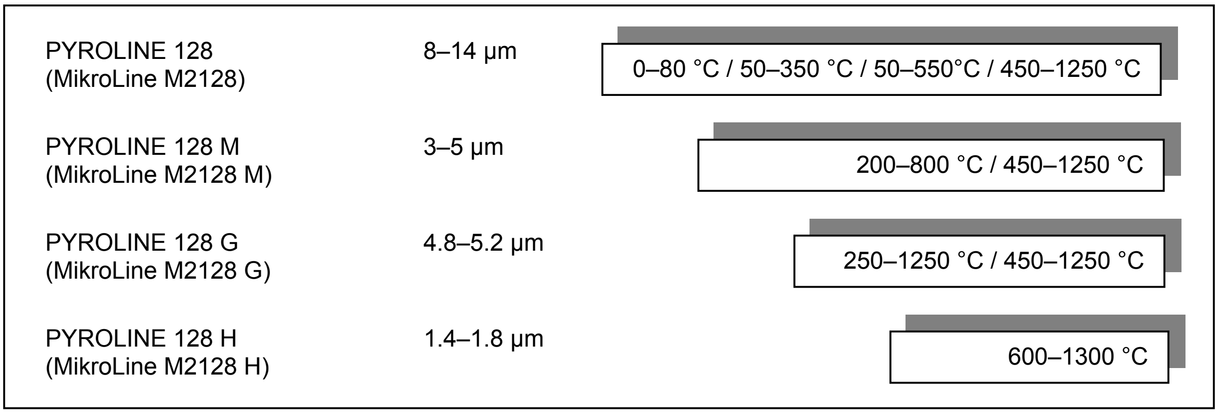

Fig. 4: Temperature and spectral ranges of pyroelectric IR-line camera (PYROLINE 128/MikroLine M2128)

Four basic device variations for different applications were developed. Essential technical data are summarized in Table 1. The standard temperature ranges include temperatures of 0–1300 °C. Spectral ranges are 8–14 µm for low-temperature applications, 3–5 µm for measurement of medium temperatures, 4.8–5.2 µm for glass applications and 1.4–1.8 µm for high temperature measurements (Fig. 4). Four exemplary applications are shown in Fig. 5–8.

Table 1: Selected technical data of the line camera PYROLINE 128/MikroLine M2128

PYROLINE MikroLine	128 M2128	128 M M2128 M	128 G M2128 G	128 H M 2128 H
Spectral range	8–14 µm	3–5 µm	4.8–5.2 µm	1.4 –1.8 µm
Measurement temperature range [a]	0–80 °C / 50–350 °C *) 50–550 °C / 450–1250 °C	200–800 °C 450–1250 °C	250–1250 °C 450–1250 °C	600–1300 °C
Aperture	40° × 0.3°	60° × 0.5°	60° × 0.5°	60° × 0.5°
Spatial resolution (50 % modulation)	6 mrad	9 mrad	9 mrad	9 mrad
Measurement distance	10 cm – infinity	20 cm – infinity	20 cm – infinity	50 cm – infinity
Accuracy [b]	2 K at 100 °C or 1 K + 1 % of true value	1 K + 1 % of true value	1 K + 1 % of true value	1 K + 1 % of true value
NETD[b]	< 0.2 K *) resp. < 0.5 K	< 0.5 K	< 1 K	< 1 K
Frame rate	internal 128 Hz, selectable 128 Hz, 64 Hz, 32 Hz, ...			
Response time	internal 16 ms, selectable: 2/measurement frequency			
Interface	RS 232 wire (4 Hz max), RS 422 wire (32 Hz max), RS 232 fiber optic (32 Hz max), PCMCIA-fiber optic (128 Hz max)			
Digital interface Digital input (trigger) Digital output (alarm)	4 independently programmable I/O lines optoisolator inputs (LED's: 5 V ≤ V_E ≤ 25 V) optically coupled, electrically isolated open-collector outputs (I_C ≤ 50 mA, V_E ≤ 25 V)			
Connectors[c]	round connector with thread interlocking (16-pins) interlocking fiber optic- connector (2-fibers) water supply tubing (nominal width 4 mm, 2 bar max) compressed air tubing (nominal width 4 mm, 2 bar max)			
Housing	IP65, optional with integrated water cooling system, air purge, swivel base			
Weight	ca. 3.2 kg			
Supply voltage	11–36 V DC / 10–20 VA			
Operating temperature	camera: 0 to 50 °C, –25 to150 °C (with water cooling) system cable: –25 to 150 °C fiber optic: 0 to 70 °C			
Storage condition	–20 to 70 °C, relative humidity 95 % max			
Software	computer control and display program for Windows™			

[a] different on request
[b] for 32 Hz frame rate, black body, ambient temperature 25 °C
[c] depending on configuration

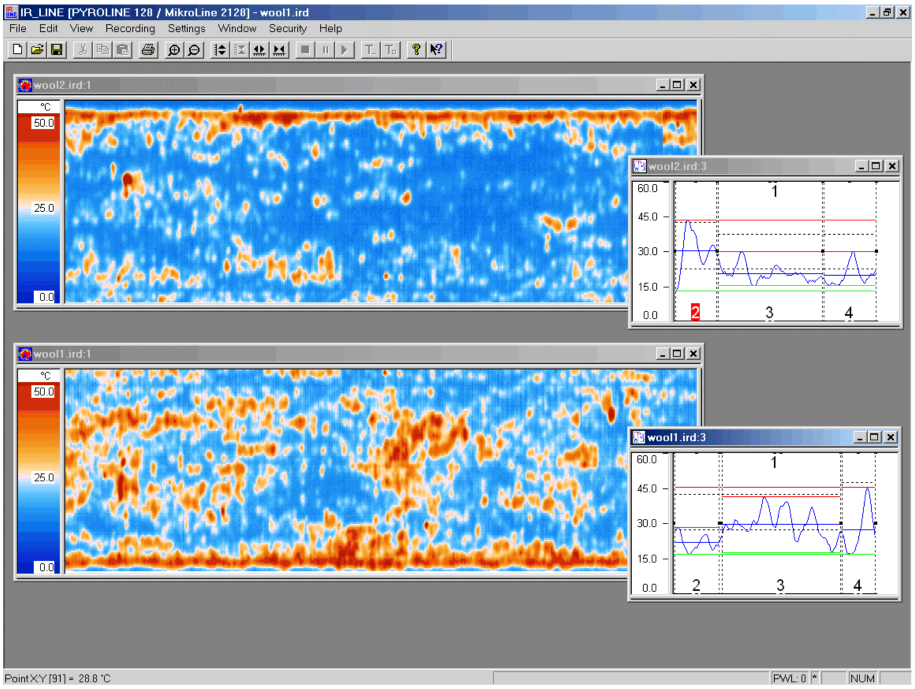

Fig. 5: Hot-spot recognition in mineral wool production[4]

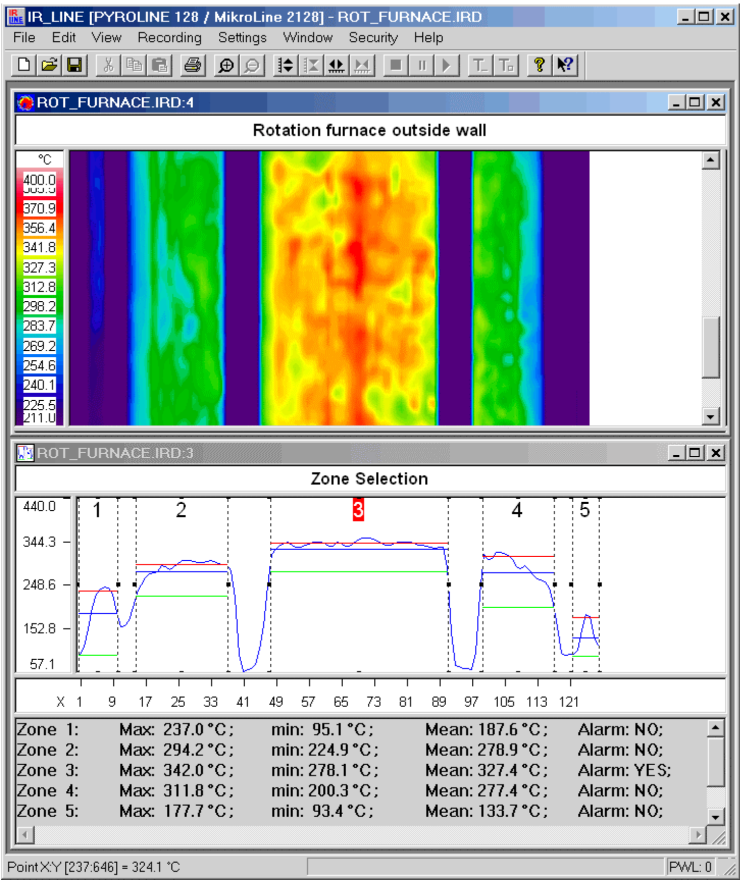

Fig. 6: Temperature measurement of the outside wall of a rotating kiln[4]

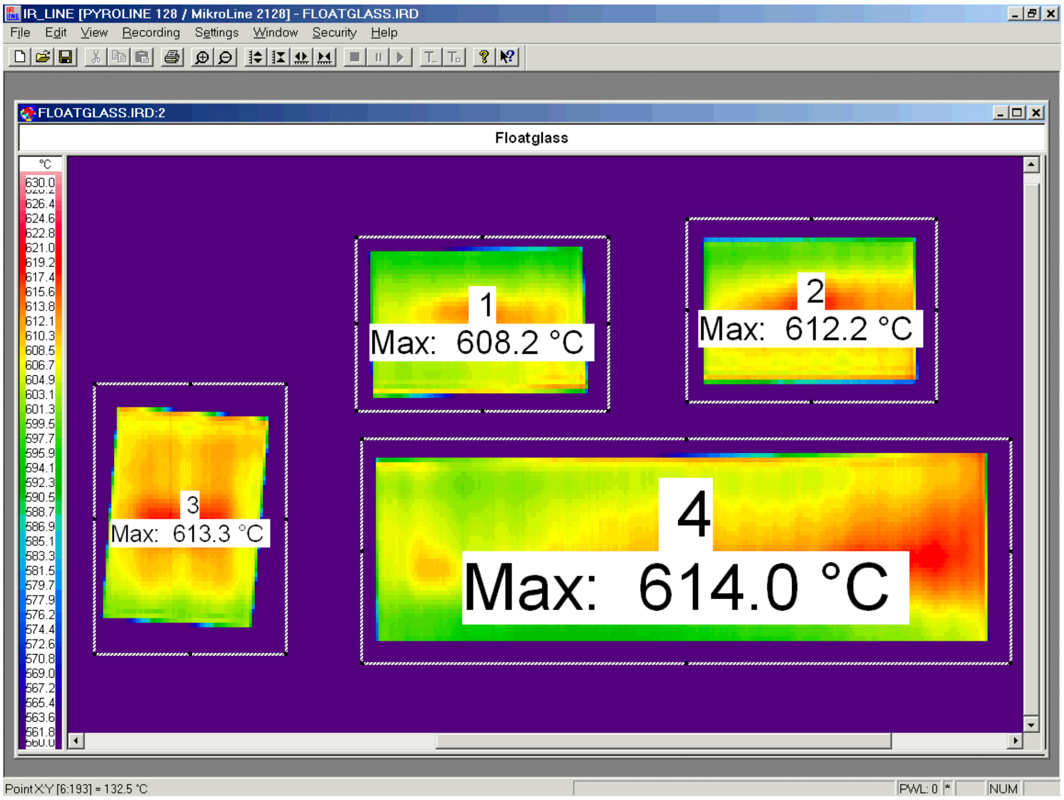

Fig. 7: Temperature measurement of float glass after the annealing process[4]

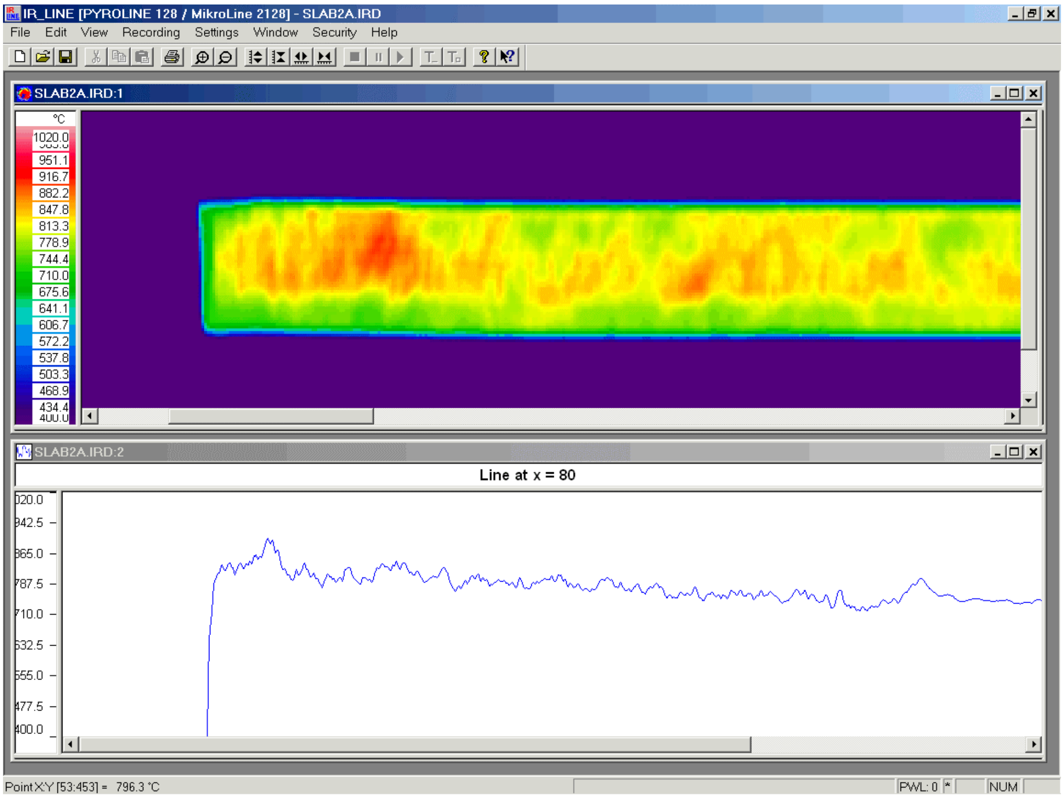

Fig. 8: Measurement of temperature distribution in steel ingots[4]

In order to expand the range of applications, a new camera series using an uncooled, pyroelectric, 256-element array (256-LT-I) was developed. These cameras (PYROLINE 256, MikroLine M2256) provide improved spatial resolution and measurement frequencies up to 544 Hz.

Note: The performance improvements listed above have not necessitated any changes to the camera's mechanical or optical-path dimensions.

Fig. 9 shows the block diagram of this camera. The signal processing electronics includes:

- Close to sensor electronics
- Digital clock pulse generator
- Analog-to-digital converter
- Image difference processing (IDP)
- Chopper motor controller
- Sensor temperature stabilization
- Printed circuit board for signal input and output
- DC/DC- printed circuit board

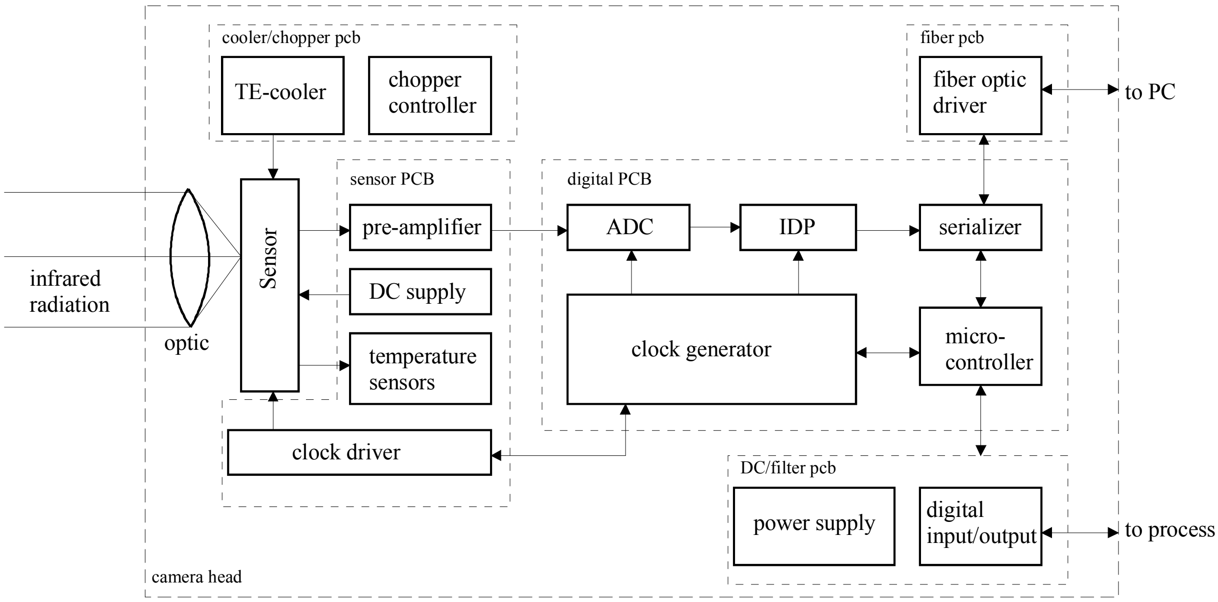

Fig. 9: Block diagram of the camera electronic PYROLINE 256/MikroLine M2256

Operation of the camera, image acquisition and data processor are controlled using the "IR_LINE" software, which communicates with the camera via a dedicated PCI card and fiber-optic cable. At this time, different spectral ranges (1.4–1.8 µm, 3–5 µm, 4.8–5.2 µm and 8–14 µm) and temperature range of 50–1300 ºC (temperature resolution < 1 K, corresponding to the conditions in Table 1) are possible with the line camera (PYROLINE 256, MikroLine M2256).

3 High-speed infrared line cameras

High-speed infrared line cameras with frame rates in the kHz range were developed especially for the temperature distribution measurement of fast moving objects. One particular application is in a high-speed tire test station. Therefore, the special camera system, HRP 250, was developed. A linear array of 160 PbSe-photo resistors with a thermoelectric cooler is used as a detector. The time constant of the photo resistors is less than 10 µs. The camera system consists of a camera head, a controller, two black body sources for online calibration and a computer. The camera head and PCI-card, including the fiber optic data transmission, are basically the same as the earlier camera systems, PYROLINE 256/MikroLine M2256, only the IR-detector assembly is different. Zero and Angle impulses of the encoder are needed as an input signal for the camera. The data output is a profile on the screen, a file or a digital impulse. A computer controls the operating elements of the camera.

All 160 pixels of a line are measured simultaneously. Due to the rotation of the object, a two dimensional picture (profile) is generated. The encoder synchronizes the camera with the turning object. An encoder with 1º resolution (360 lines per rotation) is preferred. The accruing profile (e.g. tread area of a tire) consists of 160 columns (recorded by 160 pixels) and 360 rows (triggered by the encoder with 1º resolution). Different encoders with higher resolutions are possible also. The following selected technical data were achieved by the camera system HRP 250:

Table 2: Selected technical data of the camera system HRP 250

Measured temperature range	50–180 ºC
Spectral range	3–5 µm
Temperature resolution	0.5 K at 50 ºC
Precision	2 K ± 2 % of true value
Aperture	30º x 0.13º
Spatial resolution	3 mrad
Frame rate	18 kHz

Temperature distributions in rotating tires at a speed up to 300 km/h can be measured with the aforementioned camera system. Exemplary measurement results are shown in Fig. 10.

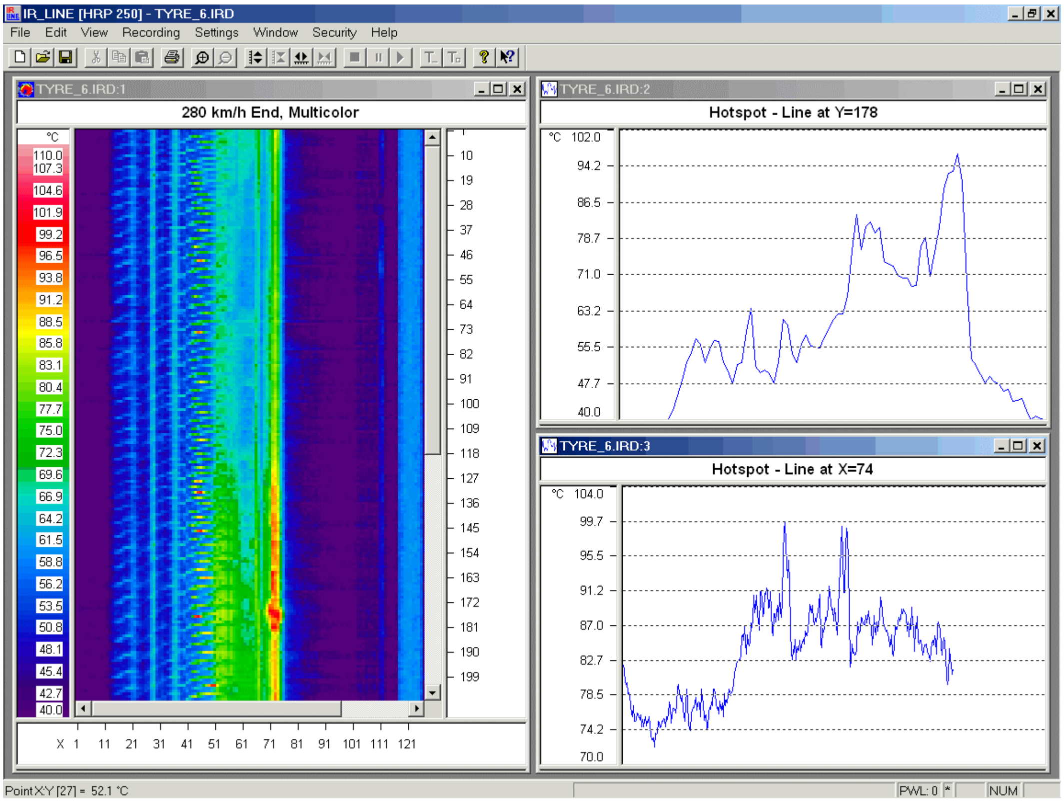

Fig. 10: Temperature profile of a rotating tire's tread area[4]

A modified version of the HRP 250 system was used for true time, temperature measurements of rotating brake disks. Therefore, the frequency was set to 1.2 kHz and the temperature range was extended up to 800 ºC. The results are shown in Fig. 11.

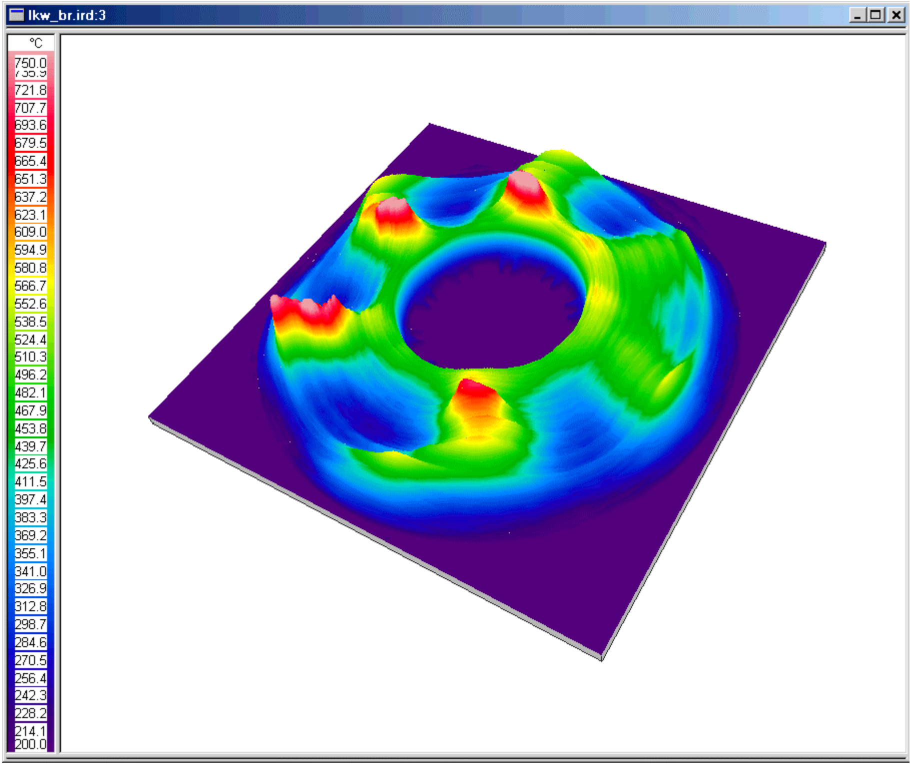

Fig. 11: Temperature distribution of one-face brake rotors[4]

Based on the same basic device concept, a 256 element InGaAs array with a spectral range of 1.4–1.8 µm was used to build a high-speed line camera system which was used to detect impurities of polypropylene and polyethylene in raw cotton at frequencies of 2.5–5 kHz. The material identification is done by wavelength selective, reflection measurements in the near infrared (NIR) range. The main components are two camera heads, each with a 256 element InGaAs line detector and a bandpass filter. Classification of the signal pairs through the similar distance method performs the material recognition. Fig. 12 shows a measured sample on an experimental setup[3].

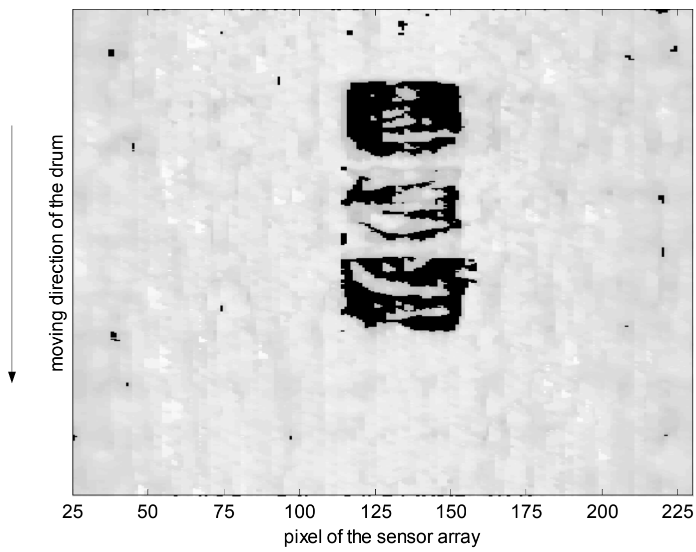

Fig. 12: Impurity detection in raw cotton (black pixel are classified as impurity)

4 Conclusion

The IR cameras PYROLINE 128/MikroLine M2128 allow the non-contact, continuous measurement of temperature distributions and their analysis. The principal part of the system is an uncooled pyroelectric line detector with 128 elements operating at a frame rate of 128 Hz. Standard measurement ranges include temperatures of 0 to 1300 ºC. Standard spectral ranges are 8–14 µm for low-temperature applications, 3–5 µm for measurement of medium temperatures, 4.8–5.2 µm for glass applications and 1.4–1.8 µm for high temperature measurements.

Based on a new universal camera concept, IR line cameras with uncooled pyroelectric, linear 256 element arrays, as well as special high-speed systems with linear PbSe- and InGaAs-arrays (frame rates in the kHz range) were developed. This basic camera system was also used for IR-2D camera systems with uncooled 2D pyroelectric and micro-bolometer arrays. Therefore a comprehensive variety of powerful cameras can be offered, which can be used to monitor industrial processes.

Acknowledgements

This research was partially supported by the German Federal Ministry of Education and Research.

References

1. V. Norkus, G. Gerlach, and G. Hofmann*, „High-resolution pyroelectric linear arrays based on $LiTaO_3$“*, SPIE 4369, pp. 322-331, 2001
2. H. Budzier, M. Zimmerhackl, V. Krause, and G. Hoven, *„High speed IR camera for contactless temperature measurement on rotating tires“*, Proc. Sensor 99, pp. 41–46, Vol. 1, 1999
3. B. Vollheim, H. Budzier, V. Krause, G. Gerlach, T. Pusch, M. Mägel, and P. Offermann, *“NIR Camera System for the Detection of Contamination in Raw Cotton“*, Proc. Sensor 2001, Vol. 1, pp. 155–160, 2001
4. www.cmv.de, www.dias-gmbh.de, www.dias-gmbh.com