High speed infrared camera for contactless temperature measurement on rotating tires

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The high-speed IR camera was designed for contactless temperature measurement of fast rotating objects such as assembly lines or rotating tires. Only cyclical processes can be recorded because of the function principle. Each temperature profile is assigned to a certain position of the measured object.

It was built for the stationary use in industrial environments, particularly for process control, process monitoring and data analysis at machines and plants.

The camera is equipped with a thermoelectrically cooled 160-element PbSe sensor with integrated CMOS multiplexer from TEXTRON, which allows real-time measurements with a frequency up to 18 kHz. A chopper guarantees stable and reproducible temperature measurements in the 3…5 µm spectral range. For protection under harsh conditions, the camera comes with robust housing with optional air flushing and water-cooling.

1 Design of high speed IR camera

The camera consists of a camera head, auxiliary equipment, a control unit, two blackbodies and a PC. The system is shown in figure 1. The PC is equipped with a frame grabber and a digital I/O card (see figure 3). Null and angle impulses from an incremental signal generator (360 x 1°) must be used for the input signal. The measured data can be output as a profile on the screen, as a file or as a digital impulse. All functions of the camera can be controlled by the PC.

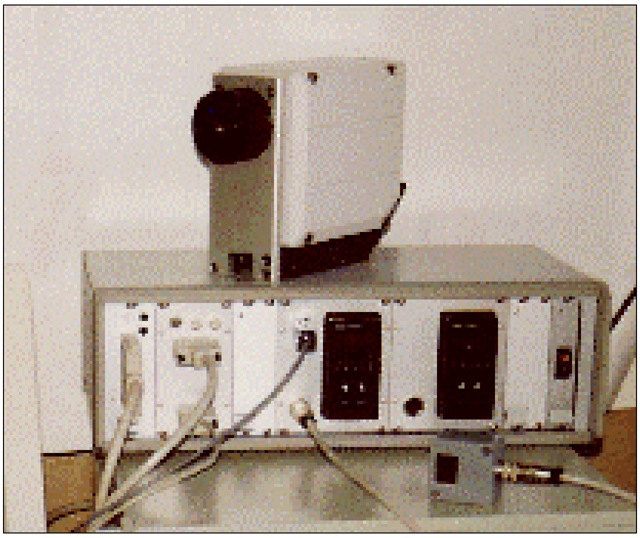

Figure 1: High speed IR camera system

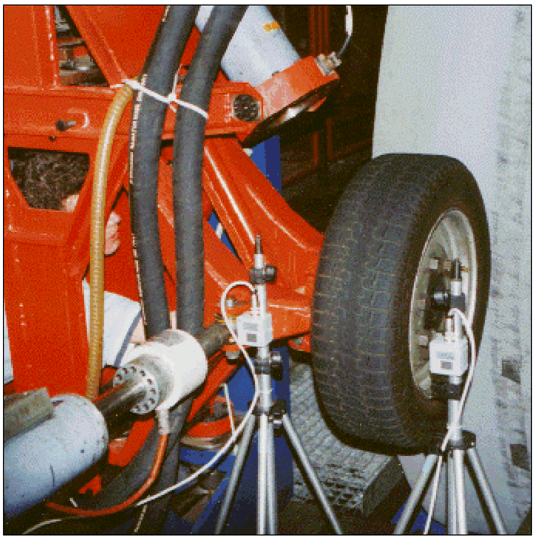

Figure 2: Tire testing system

The measuring is simultaneously carried out via a line with 160 pixels. During the rotation of the object a two-dimensional profile is produced. An encoder synchronises the camera with the unit under measurement. The encoder dissolves preferably 1° (360 measurement points per turn). The arising two-dimensional picture consists therefore of 160 tracks (recorded by the 160 pixels) and 360 lines (triggered by the encoder). If required, other trigger point numbers are possible.

The parts of the high-speed camera, which are decisive for the function, are described below. All figures are based on 360 trigger points per turn.

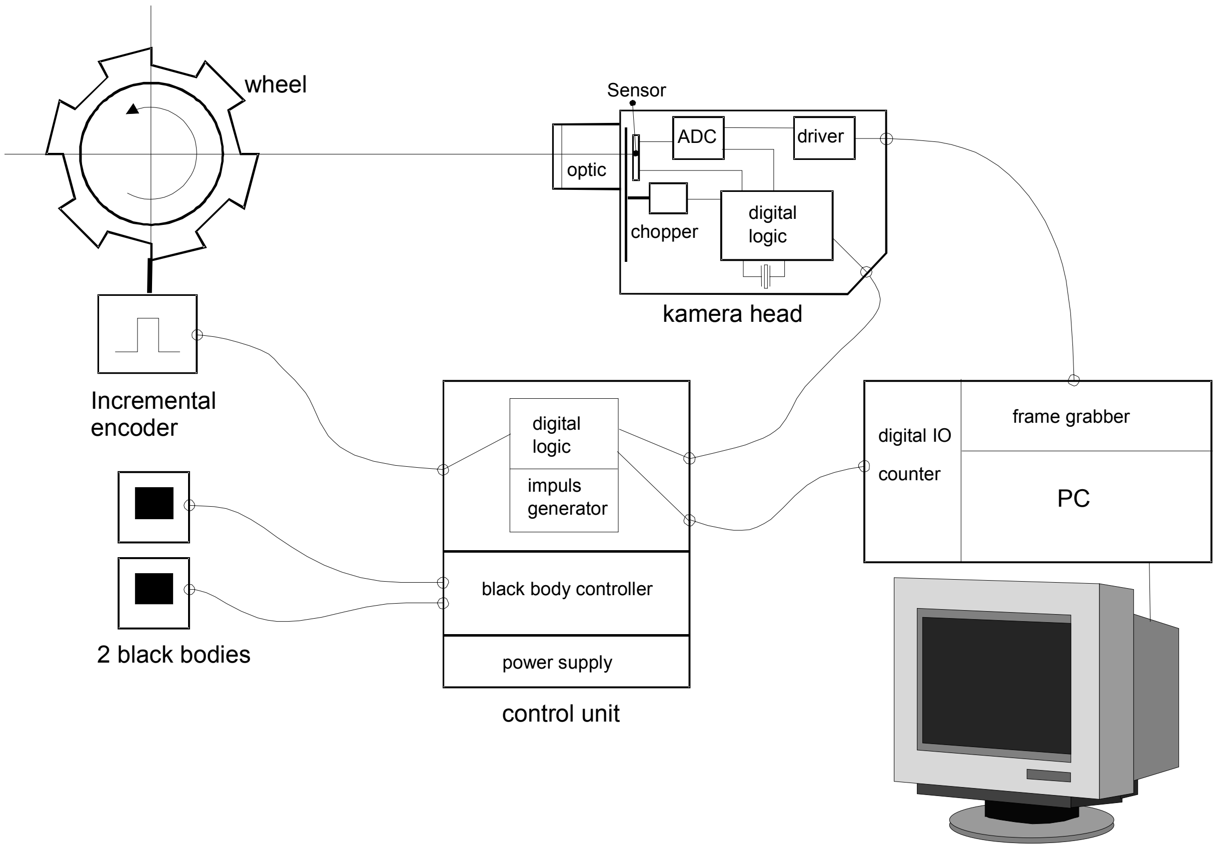

Figure 3: Overview of the camera system

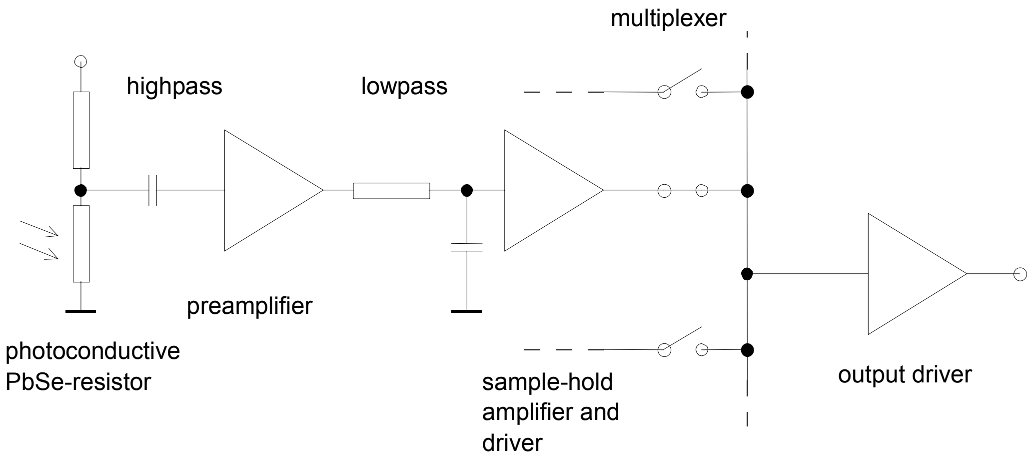

Figure 4: Principle of the sensor

2 Sensor

The used sensor consists of 160 photo resistors (pixels) of PbSe, disposed in one line, an integrated CMOS-multiplexer and a Peltier cooler. The sensor is made by TEXTRON (USA). The pixels have an area of 42 x 42 µm^2 and a pitch of 60 µm. The sensor works in the wavelength range of 3 to 5 µm. The pixels are cooled with the internal Peltier cooler to approx. 0 °C. The time constancy of the photo resistors is < 10 µs at this operating temperature.

Figure 4 shows the principle of the sensor electronics. A complete signal pre-processing exists for every pixel. It consists of a load resistance, a pre-amplifier, a band pass and operation amplifier. The band pass serves for noise limitation. It has a lower limit frequency of approx. 100 Hz and an upper band limitation of approx. 20 kHz. A chopper of the signal radiation is required for reason of this band pass. By analogous switches the signal becomes serial and is provided at the output.

3 Camera head

Besides of the sensor the camera head contains the required control electronics for the sensor, an analogous amplifier, an analogue-digital-converter (ADC), a chopper and a line driver.

For the operation the sensor needs various low-noise direct voltages besides of two digital clocks to work. Pixel clock is 6 MHz. Since 164 clocks per line are needed (160 pixels + 4 dummies), the line frequency is 36,585 kHz. Because only every second line can be processed by the frame grabber, the maximum theoretically utilisable line frequency is 18,293 kHz.

The output signal of the sensor is converted with 14 bits into a digital signal. The chopper frequency is approx. 500 Hz or approx. 625 Hz (switchable). A chopper synchronous signal is inserted in the signal as bit 15.

4 Trigger

The encoder generates the necessary trigger impulses and the null impulse. When required the trigger impulses can be pre-divided in the control unit. So for example at a trigger point number of 3600 per turn, the trigger signal is divided by 10 to get one trigger point for each degree. The null impulse is generally divided by 4.

Instead of the encoder the impulses also can be produced electronically to test the system. For that a counter circuit on the digital I/O-card is issued.

Both impulses are passed on to the camera head. The trigger impulse is inserted into the signal as bit 14. The divided null impulse is directly used as start signal for the frame grabber.

5 Frame Grabber

A frame grabber type ITI-ICP-2M (Stemmer Imaging, Germany) is used with a digital 16 bit differential input. It has 2 Mbytes RAM and can store max. 4096 lines per picture. The frame grabber requires three control signals: frame start, line start and pixel clock. The start signal is directly produced from the encoder null impulse. After the start 1390 lines are recorded. So a picture is always 76 ms long. Because no new starting is allowed during a picture recording, a minimum turn frequency of the object arises from these values. At start of every recording cycle 36 additional lines are read to synchronise the software. So the minimum trigger frequency is 396 / 76 ms = 5,21 kHz. Then the minimum turn frequency will be 14,5 Hz.

The maximum turn frequency is determined only by the maximum line frequency of 18 kHz and is 50 Hz.

6 Profile composing

From the data of the frame grabber a profile is combined. Two unusual features must be taken into account. The chopper cyclically covers the scene and a complete profile is composed of several single pictures. On the other hand a signal depending on the frequency arises by the band pass in the sensor and must be eliminated by a black body. Figure 5 shows a picture, like the frame grabber is receiving it. For the simple programming of the software the chopper signal is inserted into the picture and it is used as line-valid-signal. The chopper signal is shown in track 80 (pixel value = 0x0ffff). To simply explain the function, the triggering signal is made visible in track 40 (is not contained in the original program).

The structure of the profile depends on the recording mode. In the normal mode so many pictures there are recorded one after another until a complete profile can be composed. The necessary number of measurement cycles depends on the relation of the chopper frequency to the turn frequency and to the trigger frequency. Perhaps a complete profile cannot be achieved at a beat between chopper frequency and turn frequency. A change of the chopper frequency then is necessary, which is automatically done. For this purpose a maximum number of recording cycles is available in the program (standard: 100). When this number is reached, the chopper frequency switches over.

In the short recording mode the formation of the profile is already broken off when the profile is composed up to a definable number of lines. The remaining lines are restored from the previous picture. This of course cuts down the recording time.

Since the pixels of the sensor have different sensitivities (pattern), a correction of the signal is carried out after the profile-composition. A correction of the offset and the gains is carried out in two sectors. Supporting places are preferably 60 °C, 90 °C, 120 °C and 170 °C.

For the compensation of the frequency response caused by the band pass, an average value is linewisely formed in the tracks which are marked for the black bodies, and the difference to the set points is determined. Then the difference is added to the pixels in the line.

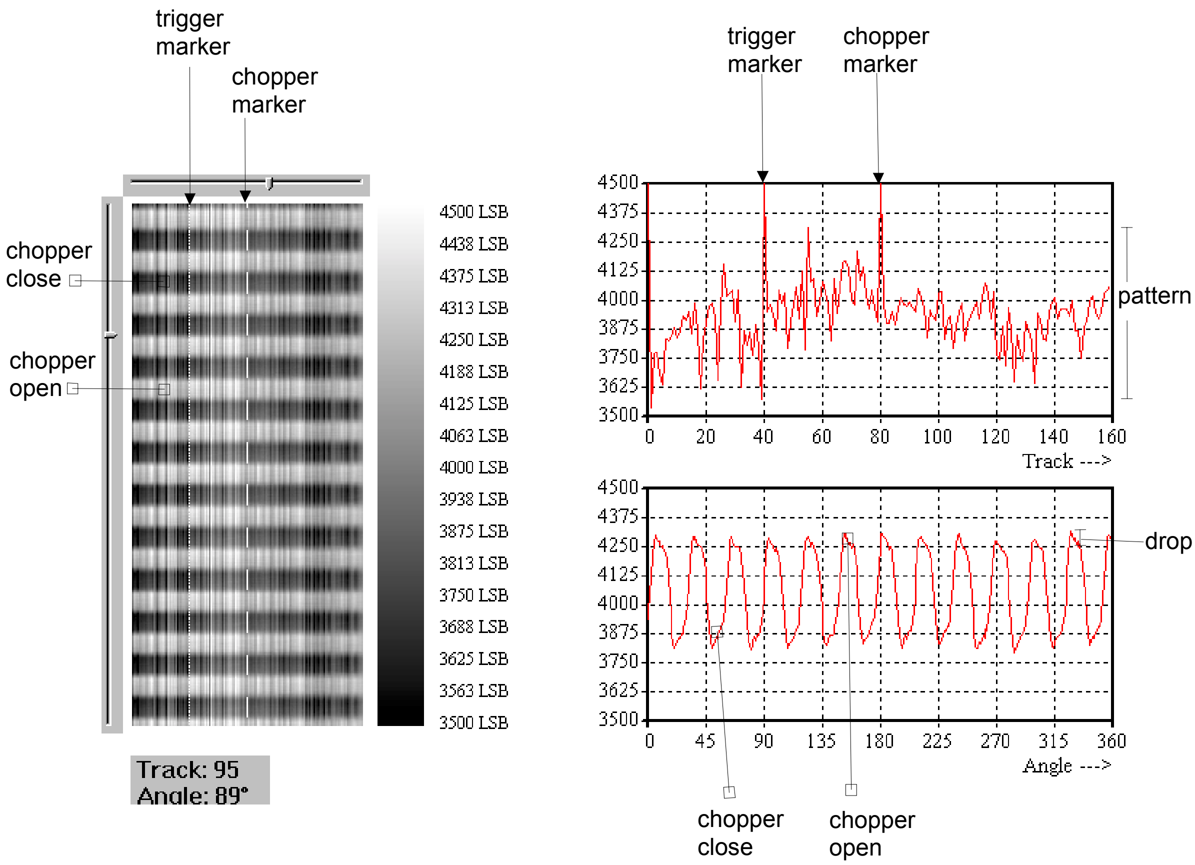

Figure 5: Representation of the input signal

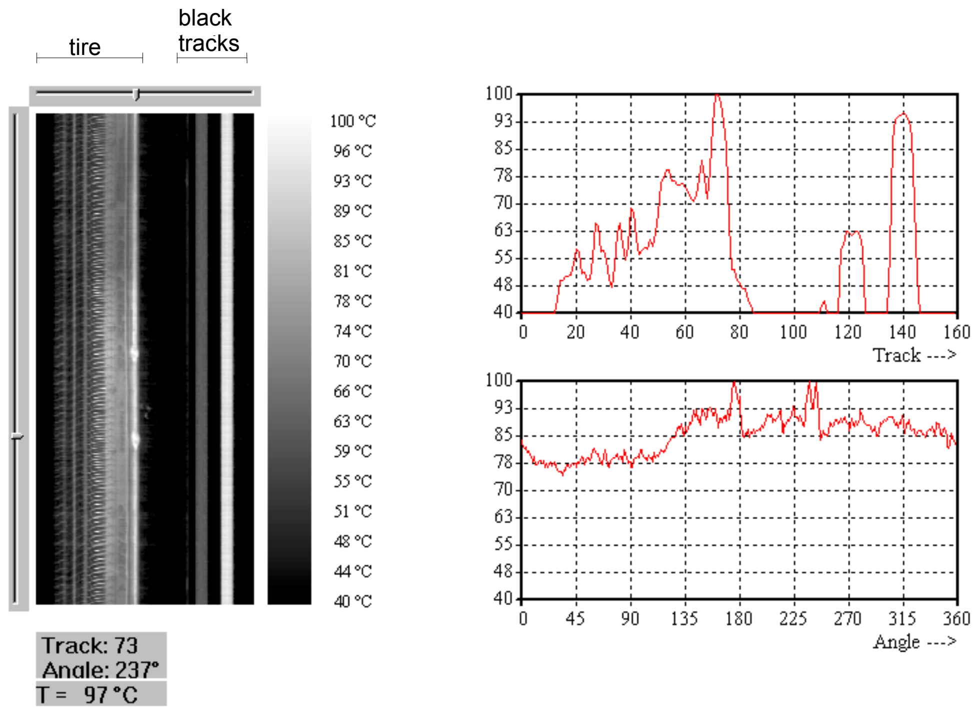

Figure 6: Tire unrolled footprint by 280 km/h with 2 hot spots

7 Conclusion

The high-speed IR line camera is designed for stationary use in industrial environments. For protection under harsh conditions the camera head comes with robust housing with optional air flushing and water-cooling.

The software realises a triggered measurement value recording at real time. At high speed tire testing system it is possible to detect smallest temperature changes and to make an automatic online processing control even at 450 km/h. Figure 2 shows an example of a tire testing system. Figure 6 shows a tire profile at 280 km/h.

Some software features are: online control of measurement points, zones, tracks and so on, alarm/threshold control, data recording with history and recording of types, date, time and additional information, automatic temperature calibration.

In conclusion some important technical information are described:

Temperature range	50…80 °C
Spectral range	3…5 µm
Sensor	PbSe 160-element sensor with CMOS-multiplexer
Field of View	29,7° x 0,13°
Temperature accuracy	± 2 K ± 2 % from measurement (°C)
Line Scan frequency	Max. 18 kHz
Standard Software	Controlling/evaluation software in Visual C++ (Windows NT) – camera control – trigger signal processing – temperature correction – averaging of real time pictures – visualisation – recording function – online threshold-control and hot spot detection