• High temperature IR-Imager with wide dynamic range for industrial process control

ABSTRACT

State of the art IR-Imager in the near infrared spectral range for monitoring high temperatures in industrial applications are characterized by a number of small measurement ranges. Scenes with a high temperature contrast require several measures switching between these range and result in pictures with under range and saturated parts. A newly developed high temperature IR-Imager with a spectral range in the near infrared provides for a wide dynamic range by utilizing specialized signal processing. A continuous temperature measurement range from 600°C up to 1500°C is realized with a resolution of 640x480 points and a measuring frequency of 25Hz. Each resulting image contains the full dynamic range and is transmitted via a Fast Ethernet interface in real time.

Keywords: IR-Imager, NIR, Thermal imager, wide temperature range, high dynamic range, industrial process control

1. INTRODUCTION

Some IR-imagers on the market today utilize video detectors in their basic design. A special window in front of the detector is typically used to select the specific spectral region of near infrared (NIR) from 0.8 … 1.1µm. A radiometric calibration of such a modified imager leads to a measurement device, much more sophisticated than a simple imager. The standard measurement range starts normally at 600°C (1112°F) object temperature and has a span of approximately 300K (e.g.: range from 600°C (1112°F) to 850°C (1562°F)). The limitation of small measurement ranges is mostly solved by using two or more ranges starting at different temperatures (e.g. 2nd range: from 800°C (1472°F) to 1150°C (2102°F). The range is selected manually or in an automatic mode by selecting the "best" range dependent on the observed scene. The disadvantage of this behavior is the appearance of under ranged and saturated images for scenes
With a higher temperature dynamic. There are some imagers with a "sequential operation mode"; in which a single measurement is taken from each measurement range and combined together with a composite image which then needs to be calculated to produce a single measurement. The prolongation of the over all exposure time due to this switching method between the different measurement modes, is the disadvantage of this image measurement technique. Even the resulted multi-range composite image has often some artifacts especially in the parts where the measurement ranges are overlapped.

There are two different ways to overcome the situation:

1. The use of a detector with a very high linear dynamic range or
2. Using a detector with non- linear signal processing.

The very high slew rate of the natural given characteristic between object temperature and emitted radiation makes the 1st method nearly impossible because it is very difficult to handle it in an adequate manner. The 2nd approach with the development of the customized detector and design of a camera was based on the various considerations and will be introduced here:

2. HIGH DYNAMIC RANGE DETECTOR

After various considerations (see above) a detector matching the main requirements for an IR-imager had to be designed. In cooperation with a local company the required detector was developed and manufactured. A patented pixel architecture was used to realize a non-linear characteristic to compensate the natural characteristic between object temperature and emitted radiation to an almost linear one. This design allows for a wide dynamic scene of over 120dB. To be covered. Even a linear operation mode is integrated for measurement jobs in a small temperature range. The detector dimensions including the pixel quantity are derived from the available optics: The detector array with 840 by 640 active elements uses only 640 by 480 elements.
The detector is made in a standard silicon CMOS technology and is designed for working in an extreme ambient

temperature range from -40 to 125°C (-40 to 257°F). An internal fixed pattern noise cancelation is built-in as numerous operational modes are used for almost any measurement task.

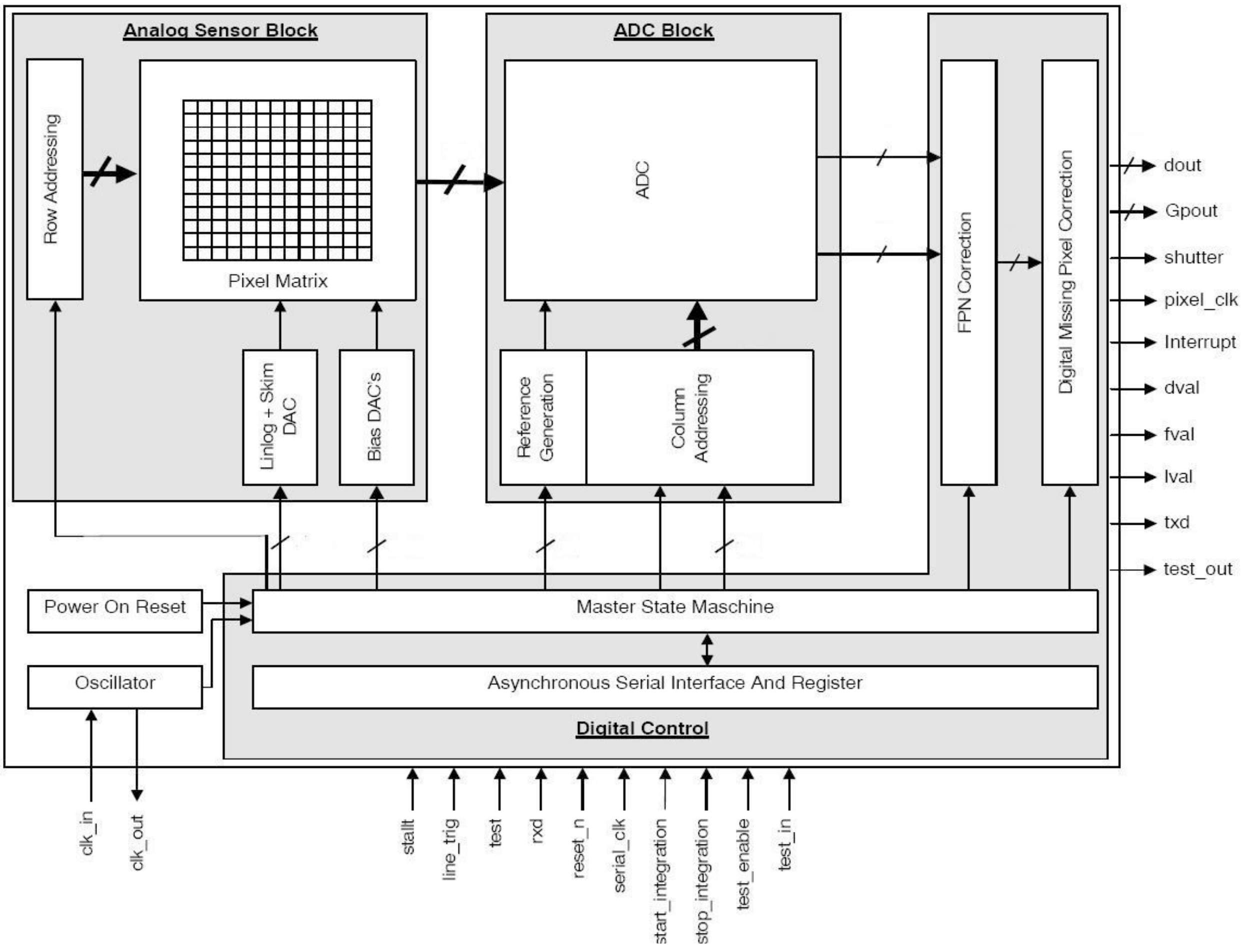

Fig. 1: Overview High Dynamic Range Detector

The development and manufacturing of the detector is a precondition to enable IR-imager to measure temperatures. Therefore many different jobs had to be accomplished:

- The adjustment of the operating point: There are many parameters influencing the properties of the detector. It was to find the right balance of all parameters to get the best compromise between measurement range, accuracy, noise equivalent temperature difference (NETD), stability, ambient temperature dependencies and other target values.
- The wide ambient temperature range of the detector is mostly welcomed but there was a dependency of the signal from the detector temperature! So a compensation algorithm had to be found and realized.
- The wide temperature range led to difficulties for handling the radiation-temperature characteristic in the same way as for standard devices. A new description of the characteristic was found and implemented in the measurement software. In connection with this fact the (re-)calculation of object temperatures dependent on the emissivity had to be adapted.
- A non-uniformity correction of the image was necessary to fulfill the requirements regarding the picture quality. Even here a new procedure was introduced to avoid the detector generated pattern especially for low signals.
- Development of a calibration method fulfilled both the requirements for accuracy and for a time saving procedure for the serial production.

The final detector was successfully evaluated and tested under numerous conditions. The imager based on it is described in the following section.

3. HIGH DYNAMIC IR-IMAGER

The design goal of the IR-imager to be created was to serve industrial applications. It results in two versions:

- A standard model in a classic camera design consisting of optics and camera body.
- A model with cooling jacket and air purging for the use in furnaces, utility boilers or kilns; any industrial applications where a wall separates the "hot" process from the environment.

A separate section will describe these versions (refer below).

1.1 Camera Body

The heart of the camera is the detector head covering the following functions:

- Providing the detector with all necessary voltages and clocks
- Data gathering inclusive averaging (user selectable)
- Signal processing: non-uniformity correction and ambient temperature compensation

Furthermore an independent signal evaluation is implemented. There is the possibility to define up to 8 different regions of interest (ROI), with selected shapes i.e. rectangles, circles, square etc., superimposed over the thermal image to provide the minimum, maximum or average temperature and up to two threshold temperatures for each region. The evaluation will be performed in real-time, the results of it can be linked to the camera outputs (digital, electrically isolated) directly. This kind of signal evaluation needs only one time programming (using a PC) and provides "stand alone" operation without the need for a connected computer.

1.2 Camera Data Interface

The data interface of an IR-camera must fulfill various requirements:

1. data transfer, able to transfer the native detector data rate
2. transport medium must be applicable in different environments (from lab to heavy industries)
3. transfer distance should be at least 50m with option to bridge much longer distances
4. use of a wide range of computers and operating systems
5. highly standardized protocol for avoiding installation trouble
6. high degree of reliability
7. possibility for camera maintenance (checking the camera, firmware update)
8. should be well introduced with an high acceptance world wide

The 1st three statements are "a must" but even the others are important with respect to the wanted functionality of the camera. There are only few solutions on the market, Ethernet met all requirements best. For this reason, the camera has a integrated Fast Ethernet data interface. Using the internet protocol (IP) family the camera can be easily connected to standard PCs using common network infrastructure and accessories. A loss free data compression is implemented to reduce the data rate to approximately 40 to 50 MBit/sec and allow the use of the well introduced 100 Mbit Fast Ethernet network.

Additional a tiny web-server resides inside the camera, enabling it to communicate with all known web-browsers. The web server delivers information about the camera, can be used for controlling and configuration purposes and is able to perform a firmware update easily.

1.3 Camera Housing and Lens

The housing contains all camera components except the lens. It is a rugged design and made from stainless steel. There are no external control elements like buttons, displays etc. only two connectors on the rear side of the camera, thus allowing for easy installation. A 12 pin connector provides the connection for the power supply and the digital inputs and outputs. A standardized M12D connector provides the industrial Fast Ethernet connection.

Fig. 2: High Temperature IR-Imager

The camera can be mounted inside a cooling tube in connection with a bore scope lens and an air purge nozzle. The bore scope lens keeps the camera away from the very hot end of the cooling tube and offers a wide field of view that can facilitate the inspection over a wide area within a furnace. The cooling tube has a very small hole (<=4mm diameter) in front of the bore scope lens, allowing the necessary radiation to enter it while maintaining a cooler environment for the IR camera. A slight overpressure inside the tube, provides a continuous air flow out through the hole and keeps it free of dust. For severe environments the hole can be designed as a nozzle (refer to fig. 4) to intensify the air purge. The cooling tube has got two connections for the cooling water (inlet, outlet).

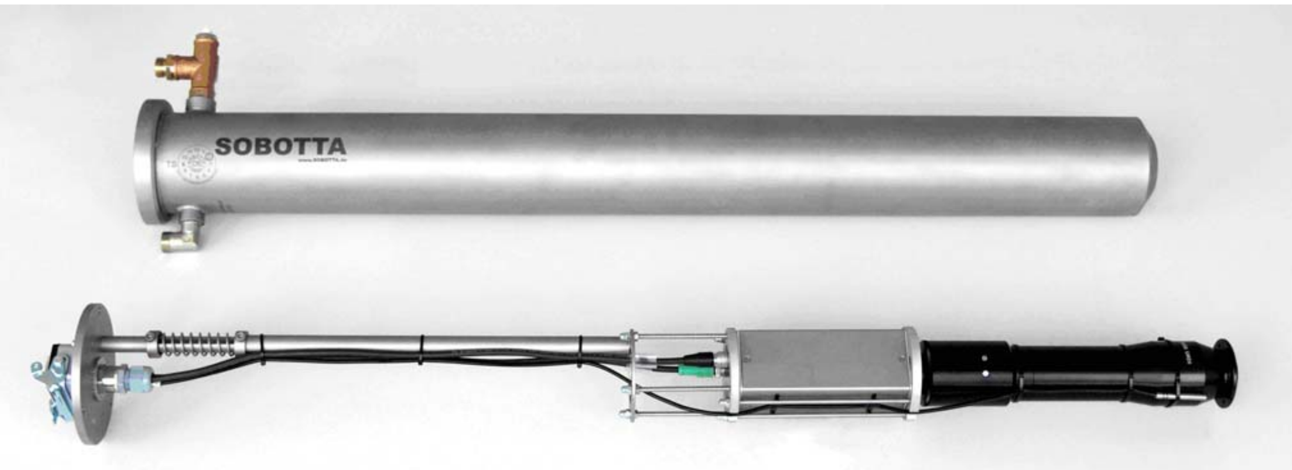

Fig. 3: Cooling tube with water connectors (up), Camera with bore scope lens, assembly pole, air and electrical connectors (down)

Fig. 4: Head of bore scope lens (left, foreground), Tip of the cooling tube with hole and air nozzle (right, background)

1.4 Technical data

The resulted camera meets the following technical specifications:

Spectral Range	0.8 m to 1.1 m
Temperature Measurement Range[1]	600 °C to 1500 °C, optional 2500 °C
Sensor	high dynamic 2D Si CMOS array (640 × 480 pixels)
Lens[1]	32° × 24°, spatial resolution 0.9 mrad, optional 46° × 35°, spatial resolution 1.3 mrad, optional 23° × 17°, spatial resolution 0.6 mrad, **optional bore scope lens 71° × 55°, spatial resolution 1.9 mrad**
Measurement Uncertainty[2]	0.5 % of the measured value in °C
Noise equivalent temperature difference[2]	<2 K (600 °C, 25 Hz)
Measurement Frequency	internal 25 Hz, selectable: 25 Hz, 12.5 Hz, 6.25 Hz, …
Response Time	internal 80 ms , selectable: 2 / measurement frequency
Interface	Fast Ethernet (real-time)
Digital Inputs	2 electrically isolated digital inputs (trigger)
Digital Outputs	2 electrically isolated digital outputs (alarm, error)
Connectors	round plug connector HR10A (12 pins, power supply, digital inputs and digital outputs), round plug connector M12-L (Ethernet)
Power Supply	10 V to 36 V DC, typical 3 VA
Housing	**60 mm × 60 mm × 160 mm (camera stainless steel housing without lens), optional** **With weatherproof housing or furnace probe lens with cooling jacket (IP65), incl.** **retract unit, auto-closure device, control and supply cabinet and other accessories**

Operating Temperature Range	–10 °C to 50 °C (without water-cooling), –25 °C to 150 °C (with water-cooling)
Storage Conditions	–20 °C to 70 °C, rel. humidity 95 % max
Software	Control and imaging software THERMALSOFT for Windows ®

Tab. 1: Technical data of the “High Temperature IR-Image with wide dynamic range

[1] Other available.

[2] Specification for black body reference and ambient temperature 25 °C.

4. APPLICATIONS

There are numerous well known applications in the steel industries. The new properties of the introduced IR-imager open up many new applications, two of them are illustrated below.

1.5 Vacuum Steel – Degasification

The vacuum degasification of molten steel is a common method to remove unwanted elements. It is especially used for producing high quality steel. The molten steel from the melting furnace is poured into a chamber where a vacuum will be generated (pressure 5mbar). The IR-imager is located in the hood of the chamber able to monitor the whole procedure from the early beginning up to the end. The main job is to control the degasification starting when the steel surface is covered completely with slag up to end of the process when all slag is gone. The monitoring of the chamber walls for damages and arising bubbles is the secondary task. Here are some characteristic images for the process:

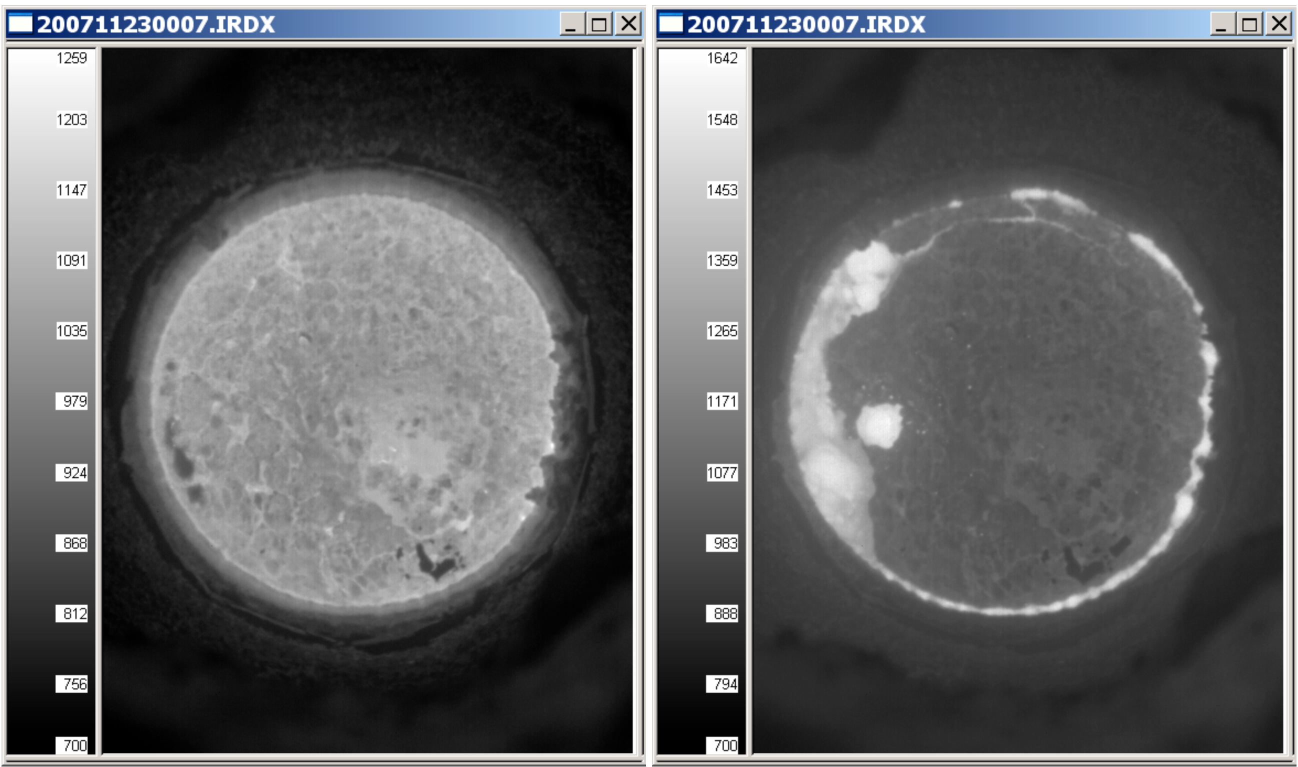

Fig. 5 + 6: The molten steel is completely covered with slag (left) respectively some areas are exposed (right)

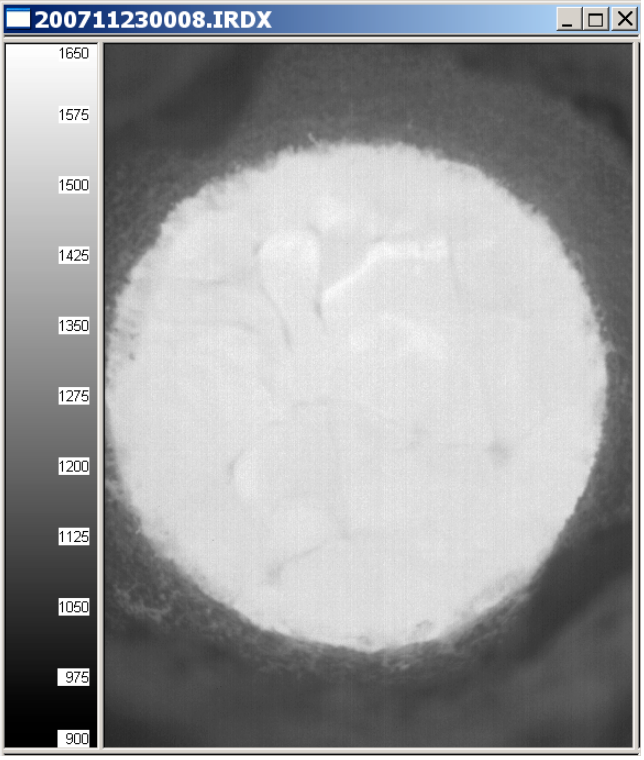

Fig. 7: Surface completely free, some bubbles are visible (left picture)

Fig. 8: Chamber hood with integrated camera (stub on top, left side) and steel chamber (preheated, right in the background); chamber is opened and separated

1.6 Cement Kiln Burning Zone monitoring /2/

The monitoring of a cement kiln shell is a well solved task for more than 20 years. Viewing inside the kiln was always made with TV-cameras and dual band pyrometers. It was always difficult to bring the information from the camera and pyrometer together but now, the introduced IR-imager can do this in a very simple way by replacing the TV-cam.

Fig. 9: IR-imager inserted through the cement kiln hood wall

Fig. 10: IR-image taken from the kiln hood, burner located on the right.

The IR-image shown above demonstrates the high dynamic range of the camera impressively: Both main objects in the scene the wall with the clearly visible tile structures (foreground left) and the very hot environment inside of the kiln (background, right) are measured without reaching the end of the measurement range. Please note that the gray scale in the above printed can not cover the full temperature range. In the colored image mode the full dynamic temperature range can be displayed.

5. SUMMARY

The newly introduced high temperature IR-Imager offers a wide dynamic range for a variety of industrial process measurement /control applications and is expanding very fast. Particularly, the camera with cooling tube and bore scope lens which are leading to a number of growing applications presenting new unexplored images and data that has never been previously realized.

SUPPORT

Process Sensors Corporation located in Franklin Lakes N.J., provides sales and technical support for clients located in the western hemisphere territory.

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