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HIGH TEMPERATURE DIAGNOSIS WITH INFRARED CMOS CAMERA

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Abstract

The original setup for high temperature measurements, equipped with a high-class pyrometer and standard CMOS camera was described in this paper. The principles of operation, basic rules and physical fundamentals of temperature measurement were shown and discussed. Chosen research experimental results were presented.

Keywords: *infrared radiation, temperature, CMOS camera, diagnosis*

1. Introduction

Many different kinds of technological processes are accompanied by the occurring of high temperatures. This can take place e.g.: in cutting and grinding - especially - superhard materials, welding processes, mould die techniques. Temperature rating is essential symptom for the proper conduct of the process state. For example; the temperature rise of the cutting edge can be a symptom of tool wear. Actually, there are various measuring techniques, ensuring the assessment process temperature, using both methods (contact or contactless). Particularly important are the non-contact methods of temperature assessment. These methods can be applied to both point measurements and the temperature distribution evaluating. Contactless measurement is based on the infrared radiation analysis, emitted by the surface at a specific temperature. The infrared radiation shall be adopted in the range: 0.76 ÷ 1000 μm, and for visible radiation: in the range 0.4 ÷ 0.76 μm. Any body with a temperature greater than absolute 0K emits electromagnetic radiation, including the infrared one. Spectral distribution of blackbody radiated energy (emitting best) describes the Planck's law [4]:

$$m_{cc,\lambda} = \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1}, \tag{1}$$

where:

$m_{cc,\lambda}$ - monochromatic emittance energy of a blackbody for the wavelength λ,

$c_1 = 3.7418 \times 10^{-16}$, W/m^2,

c_2 = 1.43879 x 10^2, mK,
T - temperature, K.

This law can be applied both for sources and receivers of radiation.

With increasing temperature of the radiating body, a maximum radiation intensity moves towards lower wavelengths - the law specifies Viena [4]:

$$\lambda_{\max} T = 2896\,\mu\text{mK}. \tag{2}$$

It refers to black and gray bodies. After integration, Planck's law for all wavelengths can be described by the Stefan-Boltzmann law [4], for total power radiated by a object at a temperature T:

$$W = ST_{cc}^4, \tag{3}$$

where:
S - Stefan-Boltzman constant: 5.67032 * 10^{-8} W/m^2-T,
T_{cc} - the absolute temperature blackbody K.

For real bodies the right takes form:

$$W = ST_{cr}^4. \tag{4}$$

The principle of operation of commonly used devices for contactless surface measurements is based on the use of previously described physical basis. Real bodies' infrared radiation, compared with ideal blackbody radiation is lower. This can be determined by emissivity coefficient:

$$\varepsilon_\lambda = \frac{W_{cc\lambda}}{W_{cr\lambda}}\ , \tag{5}$$

where:
$W_{cc\lambda}$ - ideal blackbody spectral density power radiation,
$W_{cr\lambda}$ - real-body spectral density power radiation.

The value of emissivity coefficient ε depend on temperature and surface conditions [8], e.g.:

- polished aluminum, at T = 50 ÷ 100 °C, ε = 0.04 to 0.06,
- galvanized sheet metal, at T = 50 °C, ε = 0.2,
- porous red brick, at T = 50 °C, ε = 0.9,
- crystal ice, at T =- 10 °C, ε = 0.98,
- polished copper, at T = 50 ÷ 100 °C, ε = 0.02.

In specially designed, non-contact measuring devices bolometrical infrared radiation detectors [10] are used most often. Determined, using them, temperatures are modified by the emissivity coefficient. Both infrared cameras and pyrometers (for the point measurements) work, basing on this principle [10].

Another technique, based on the CCD cameras use, [1,2,3] with no IR filter is also used. This technique allows the assessment of temperature distribution, basing on the relationship between the energy of infrared object surface radiation at a specific temperature and emissivity. Furthermore, there are dependencies between photometric and electric signal on CCD matrix [7]. Special patterns of black body radiation emission at a specific temperature and emissivity are mostly used for contactless devices for temperature measurements calibration [9]. CMOS camera application for surface temperature distribution test and experimental results are presented in this article.

2. Test stand

The research goal of this study was to evaluate the possibility of using a USB camera with a CMOS sensor, equipped with a filter, for the diagnosis of objects radiation at a visible range in high temperatures. Tests in the first stage consisted object pictures of known ceramic heater temperature. The heater temperature was adjusted by changing the voltage. Tests were performed in the voltage range from 100V to 230V. In addition, the setting– camera's exposure time was changed in range from 20% to 100%. Tests were repeated over the entire voltage of the heater. Original test stand was constructed - Fig. 1.

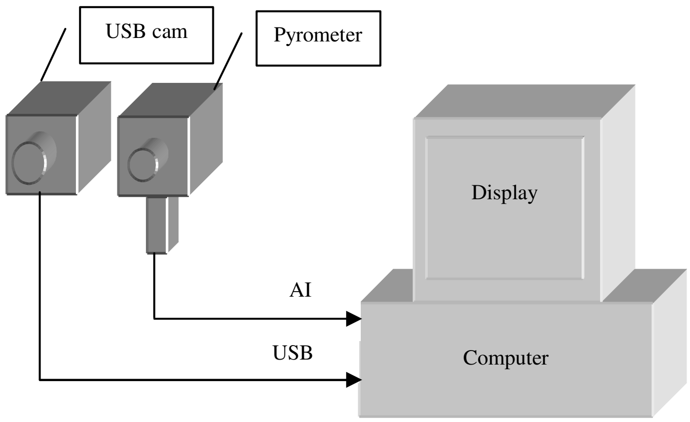

Fig. 1. Test stand diagram

Fig. 2. Minolta/Land Cyclops 152A pyrometer

USB camera was equipped with a visible light permeable filter for infrared radiation of wavelengths above 720 nm. Camera with a filter was directed at a heat source (electric heater). Heater supply voltage was controlled by the autotransformer at U = 100 ÷ 230V.

Fig. 3. 'TermoCapture' panel view

Heater temperature at a specific location was measured by Minolta / Land Cyclops 152A pyrometer (range: 550 ÷ 3300°C, spectral range 1 μm, measured area ϕ 5mm for 1m distance, accuracy: 0.25%, measuring modes: instantaneous value, maximum value, minimum value) – Fig. 2. Images from the camera were captured and recorded in grayscale, using original, made in VB6 program 'TermoCapture' – Fig. 3.

Designed program allowed determining of pixels brightness in the selected section of the image. Temperature measurements were conducted in parallel with the radiation sources images recording. Pyrometer, connected through an interface PCLD 8141 with analog input measurement card Advantech PCL-818L was used to record object temperature. VB object, associated with the program 'TermoCapture' was used for temperature measurements. Images were recorded for various camera sensitivity settings (25, 50, 75). Reduced camera resolution; 160 x 120 pixels and 60 s exposure time were used. The program allowed for capture object images capture at specified intervals (60 seconds was used).

3. Results and analysis

Heater temperature measurements results for different transformer settings are presented in the diagram - Fig. 4. Roughly linear relationship between voltage and heater temperature was found. Voltage 110 V was specified as a border value for further tests, due to the pyrometer measure range (550 ÷ 3200 °C).

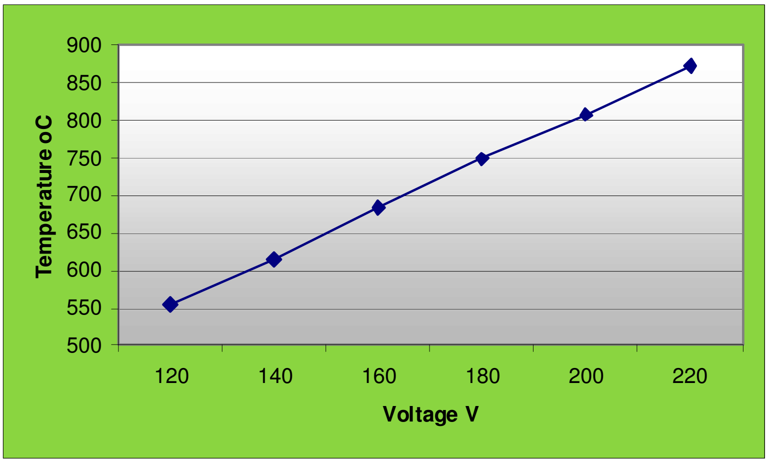

Fig. 4 The surface temperature and the heater voltage dependence graph

Sample, grayscale image of the heater surface obtained by the camera is shown in Fig. 5.

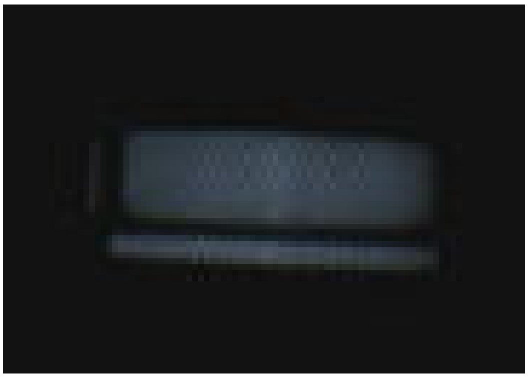

Fig. 5. Heater surface grayscale picture

Image data for measure and visualization of image points the brightness were sent to the graphics program – Fig.6. and Fig. 7. This technique allows for the surface temperatures spatial distribution, registered in the camera, visualization.

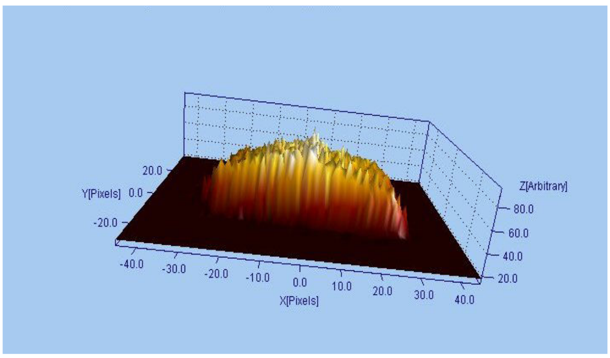

Fig. 6. Picture of the heater surface, processed by the graphic program, taking into account the pixel brightness (U = 180V, sensitivity 25%)

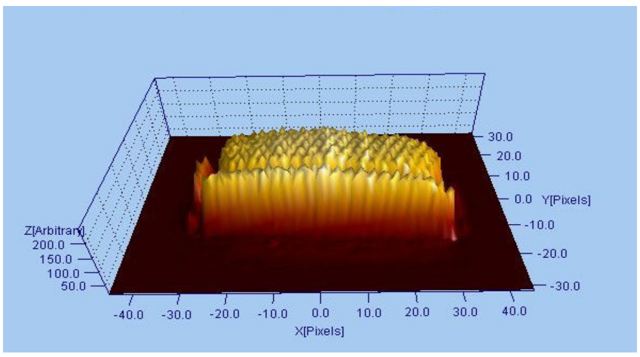

Fig. 7. Picture of the heater surface processed by the graphic program, taking into account the pixel brightness (U = 180V, sensitivity 75%)

Research results indicate a relationship between the object temperature and pixels brightness, recorded using USB camera with a CMOS sensor. At the same time, it was found that the registration process affects the pixels brightness of obtained image. Those results indicate a linear -

under certain test conditions - the relationship between the temperature of the object, and the brightness of pixels, recorded with infrared sensitive USB camera with a CMOS sensor - Fig. 8.

Linear dependence occurs in the range of pixels brightness from 50 to 220. At the same time, it was found that the camera settings (exposure time) affects the image pixels. This indicates the possibility of controlling the camera's sensitivity and allows determination of camera calibration relationships.

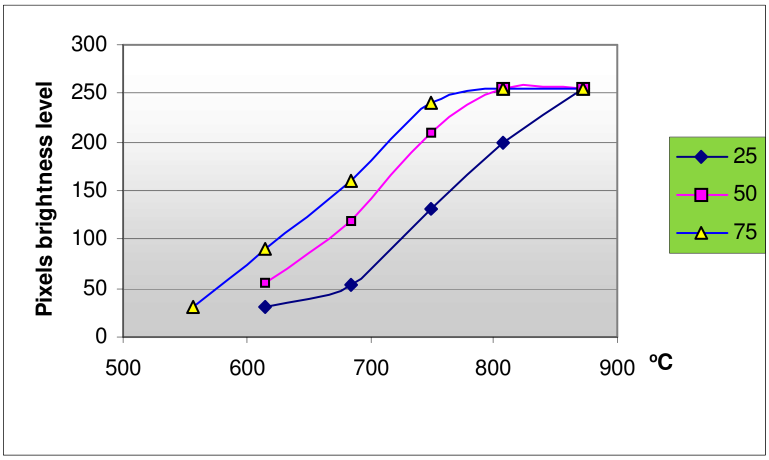

Fig. 8. Surface temperature dependence on image pixels brightness for various sensitivity levels: 25, 50 and 75%

Radiation detection system was saturated at higher temperatures. For this (upper) temperature range smaller exposure set-up time should be used. This indicates the possibility of extending the scope of the camera to determine the temperature of the object by using the maximum exposure time for reduced temperatures ranging from 550°C and the use of reduced exposure time to the possibility of temperature readings using a camera for higher temperatures - Fig. 8. This chart indicates that the effect of exposure time is nonlinear.

The test stand calibration requires further work, but the result of previous work indicates the possibility of using this system for diagnosing the temperature distribution in range above 550°C. It is possible to observe and record objects pictures in visible light by removing filter.

4. Conclusions

The following conclusions were formulated, on the basis of literature and the experimental results:

- ✓ camera with infrared sensitive CMOS sensor, with visible light filter, is useful for visualizing the distribution of surface temperatures in the range above 550°C,
- ✓ range of visible light filter coincides with the pyrometer used for tests,
- ✓ CMOS cameras with visible light filter are suitable for field temperature testing at a specified emissivity,
- ✓ temperatures in the range from 550°C to 880°C were recorded with various camera settings under tests conditions,
- ✓ the camera exposure time can be used to change the camera measuring range, reducing the exposure time allows the evaluation of the surface at higher temperatures,
- ✓ it is advisable to conduct further research on the developed method in the field of different applications, including the possibility of cutting process temperature measurement [5],

- ✓ it is appropriate to develop an image analysis procedure for the direct determination of the analyzed surface temperature,
- ✓ an important advantage of the described diagnostic method for high temperatures is the ability to use one camera to observe the test object in visible light (visible radiation without a filter) and in the infrared range.

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