Optical Filters' Influence on Digital Image Quality in High Temperature Measurements of Surface Properties

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Abstract

This paper is concerned with high temperature image quantitative analysis systems. Particular attention is paid to computerised system for surface properties (wetting angle and surface tension) determination. A brief description of the system is given. The specificity of the performed measurements based on images presenting heat-emitting objects is considered. Moreover, the significance of optical filters' usage is explained. Infrared and neutral density filters are regarded. Influence of these filters on digital image quality is deliberated. Especially image noise presence is considered. The detailed analysis of noise properties change due filters usage is carried out. Finally, results of the analysis are presented and discussed.

Key words: digital image processing, image quality, optical filters, image quantitative analysis, image noise.

1 Introduction

Computer vision systems have become very popular nowadays. They are of great importance in almost every field of science, engineering and industry. Due to usage of appropriate digital image processing and analysis algorithms, vision systems are able to determine features and parameters characteristic to the given application.

Characteristic problems are connected with each application of vision system. For example, while high temperature measurements, sources emitting intense thermal radiation have to be viewed. In such cases it is necessary to use optical filters. In particular infrared (IR) and neutral density (ND) filters should be applied. IR filters stop non-visible infrared wavelengths. ND filters decrease light intensity. Usage of these filters affects with object visibility improvement. Moreover, vision system is protected from damage. However, it should be also underlined that optical filters' usage can seriously affect digital image quality.

In the following part of this paper, the problem of digital image degradation due to optical filters' usage is considered.

2 The experimental set up

The paper presents results of a research that were provided by analysis of images acquired from computerized system for high temperature measurements of surface properties (wetting angle and surface tension) of liquid and solid in contact. The system named "THERMO-WET" is property of Computer Engineering Department of Technical University of Lodz and is capable of measuring the surface tension of a liquid and the wetting angle of a solid by a liquid over a wide range of temperatures (up to 1800°C).

2.1 "THERMO-WET" measurement system

General view of "TERMO-WET" system is presented in Figure 1. The apparatus consists of:

1. vision unit;
2. specimen insertion mechanism;
3. technological gases supply system and system for the precise temperature measurement and control;
4. computer for controlling all stages of the measurement process;
5. high-temperature (up to 1800°C) electric furnace with a protective atmosphere.

Block diagram of "THERMO-WET" can be seen on Figure 2. For more detailed description of the measurement system, [6, 7] should be checked.

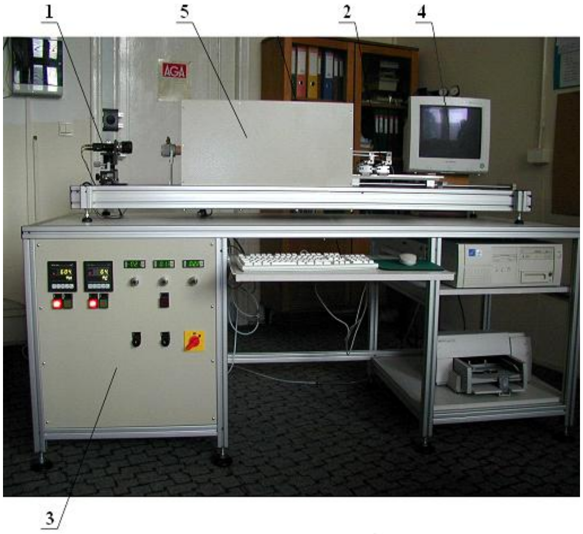

Figure 1. The measurement system.

The measurement process starts from placing specimen of investigated material inside the furnace. In order to do so insertion mechanism is used. The specimen under investigation is then heated to the temperature higher than the melting point. When it becomes drop, image segmentation is proceeded. The next step of the measurement process is concerned with surface properties determination.

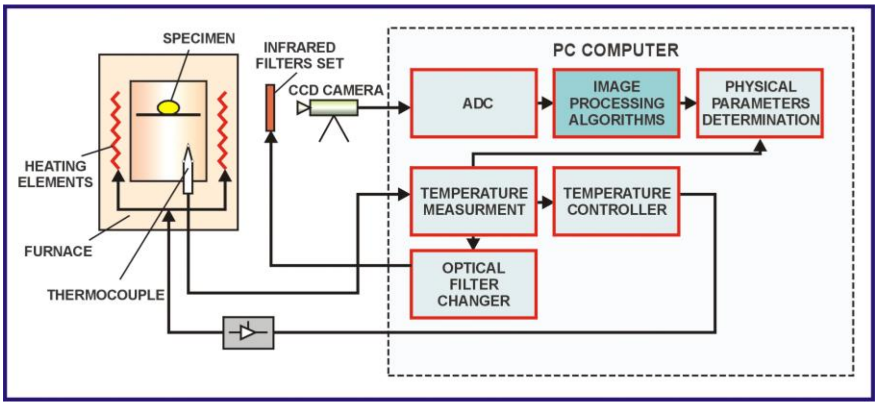

Figure 2. Block diagram of the “THERMO-WET” measurement system.

2.2 Vision unit

The measurement process crucial tasks are connected with vision unit of "THERMO-WET" (fig.3) which consists of:

– miniature monochromatic CCD camera;
– lens;
– optical filters with algorithm of their automatic changes.

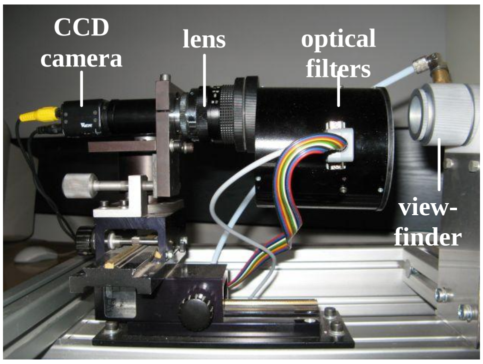

Figure 3. "THERMO-WET" vision unit.

The unit is responsible for the following operations:

– acquisition and conversion of an image into a digital representation;
– preliminary processing of the image including its segmentation;
– image analysis, localisation of the specimen and evaluation of its geometrical attributes (fig.4);
– determination of surface properties of the specimen using Porter's formula [6, 7].

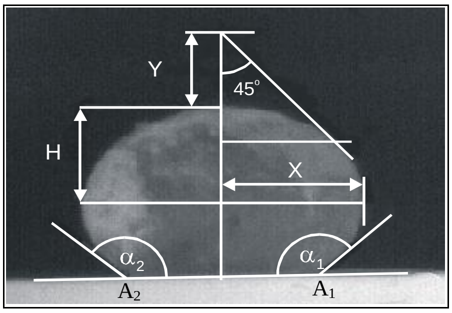

Figure 4. The exemplary specimen with important geometric parameters marked.

Selection of digital processing and analysis algorithms is not accidental. They enable automatic measurement of different materials' superficial properties. Due to optical filters usage measurements are possible to perform for a wide range of temperature and in consequence for different lighting conditions (connected with high-temperature specimen illumination).

3 Optical filters

The specificity of measurements performed using "THERMO-WET" dictates necessity of infrared filters usage. It is a consequence of specimen high-temperature illumination. Specimen heated to a high temperature emits light in a visible part of the spectrum. The illumination causes saturation of CCD camera photosensitive elements. The problem has been illustrated in Figure 5a. Optical filters usage makes specimen under investigation visible and protect vision system from damage. Especially infrared (IR) and neutral density (ND) filters are used. IR filters diminish mid-infrared wavelengths (thermal radiation). ND filers reduce the intensity of light. However, it is not possible to completely remove "aura" surrounding the specimen and blurring its edges (fig. 5bcd).

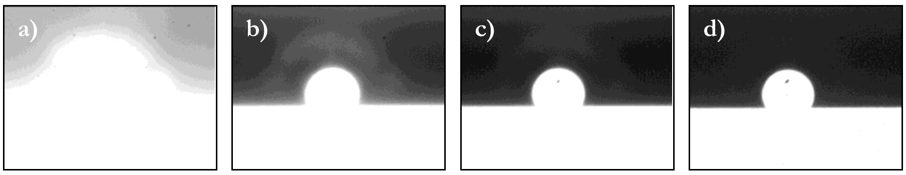

Figure 5. Aura phenomena – infrared filters selection influence. High temperature images of palladium 1564°C (a-no filters, b,c- incorrect infra-red filters selection, d-proper filters selection).

Infrared and natural density filters make specimen emitting thermal radiation visible. However, filters can also negatively influence the quality of the hot-object images. Experiments carried out based upon images acquired from "THERMO-WET" led to conclusion, that usage of optical filters increased noise level.

The following part of this paper presents analysis of optical filters influence on image noise level.

4 The Methodology of Noise Analysis

Each digital image L has two main components: a stable signal S and a random noise N [4, 5] in accordance with equation:

$$L(x,y) = S(x,y) + N(x,y) \tag{1}$$

where:

x,y - pixel coordinates.

Image of noise can be simply assigned from equation (1) and described as follows:

$$N(x,y) = L(x,y) - S(x,y) \tag{2}$$

It means that image of the noise can be obtain after subtracting "signal-only" image from the exemplary output image.

It is impossible to obtain "signal-only" image. However in accordance with literature [1, 4, 5] in case of multiple exposures the signal component of the image remains the same but the noise component differs from one image to another. Due to random noise canceling while summation, "signal-only" image can be approximated by an average of *K* images (input frames) of the same view-field in accordance with equation:

$$\tilde{S} = \frac{1}{K}\sum_{j=1}^{K} L_j \tag{3}$$

where:

$\tilde{S}$ - approximation of "signal-only" image;

L_j - j -th input frame.

In consequence, approximation of the noise N_j in each input frame L_j can be expressed by equation:

$$N_j = L_j - \tilde{S} \tag{4}$$

In case of noise-free images equation (4) should result with blank frame (i.e. frame of only zero pixels). In consequence, in case of noisy images, pixels of non-zero values in frames N_j correspond to pixels corrupted by noise in input frames L_j. Zero pixels are not considered as a noise.

It should be also pointed out, that noise either increases or decreases corrupted pixel intensity. In consequence noise levels can be either positive or negative. They are considered as pixel intensity change due to noise presence.

Noise distribution h_j in each input frame L_j can be described as follows:

$$h_j(L_{j_k})_{k \neq 0} = n_{j_k} \tag{5}$$

where:

L_{j_k} - noise level (pixel intensity change due to noise presence);

n_{j_k} - number of pixels corrupted by noise of level L_{j_k}.

Because of random character of investigated noise, one input frame cannot be used to extract authoritative conclusions about noise properties. Only an average noise distribution $\overline{h}_j$ computed in accordance with equation (6) can give such information.

$$\overline{h}_j = \overline{n}_{j_k} = \frac{1}{K}\sum_{j=1}^{K} n_{j_k} \tag{6}$$

Information about average of each noise level can be supplemented by its standard deviation value computed in accordance with equation:

$$\sigma_{j_k} = \sqrt{\frac{\sum_{j=1}^{K}(\overline{n}_{j_k} - n_{j_k})^2}{K-1}} \tag{7}$$

Finally, based upon noise average distribution $\overline{h}_j$, its average level $\overline{N}_j$ and standard deviation σ_{N_j} can be computed in accordance with equations (8) and (9) respectively.

$$\overline{N}_j = \frac{1}{K}\sum_{j_k} n_{j_k} \tag{8}$$

$$\sigma_{N_j} = \sqrt{\frac{\sum_{j_k}\left(\overline{N}_j - n_{j_k}\right)^2}{K-1}} \tag{9}$$

It should be underlined that single noise level is indivisible. In consequence all achieved values should be rounded to the closest integer value.

5 Results and discussion

This section presents results of analysis of noise contained in images acquired using different optical filters. The analysis was based on sets of input frames presenting images of uniformly illuminated surfaces (i.e. flat fields). Images were acquired using different filters. Set of 50 input frames was considered for each filter. The following configurations of filters from “THERMO-WET” vision unit were considered:

– no filter (filter 0);
– NG4 2,5 mm (filter 1);
– combination of NG4 5,0 mm and BG38 1,0 mm (filter 2).

NG4 is infrared filter [2]. BG38 is infrared and neutral density filter [3].

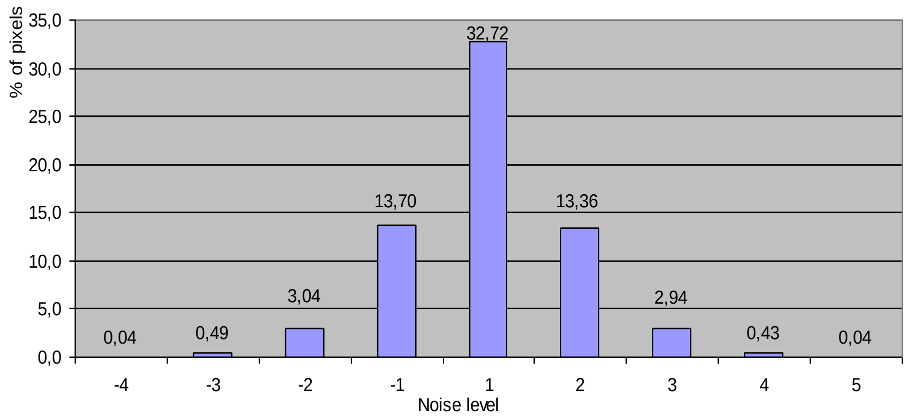

Figure 6. Noise distribution in images acquired without filter usage (filter 0).

Average percentage noise distribution in images acquired using above-mentioned configurations of filters is presented on Figures 6-8. Used filter is indicated in each figure caption. Noise main properties depending on type of filter used are presented in Table 1.

Analysis of histograms presented in this section leads to conclusions that optical filters’ usage influences digital image quality. Especially noise level increase (defined by means of percent of noisy pixels) can be observed.

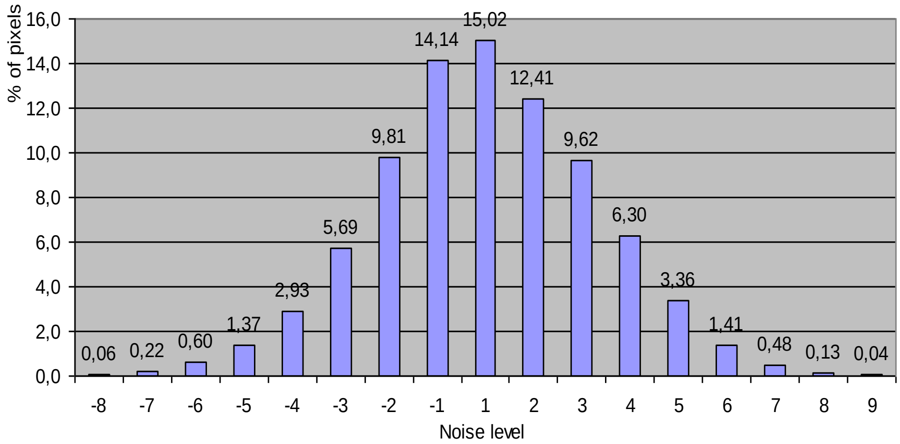

Figure 7. Noise distribution in images acquired using NG4 2,5 mm filter (filter 1).

Table 1. Noise properties depending on filter used.

	Filter 0	Filter 1	Filter 2
Percent of noisy pixels	66,76%	83,61%	85,49%
Average noise value	1	1	1
Noise standard deviation	4	7	7
Max/Min noise level	6/-5	11/-11	14/-6

In case of both tested filters noise increase exceed 25%. Moreover diversification of present noise levels (expressed by its standard deviation and extreme values) appears.

Infrared filters usage also changes type of noise distribution. Noise distribution in no-filter images is symmetrical. Filters make noise distribution skew.

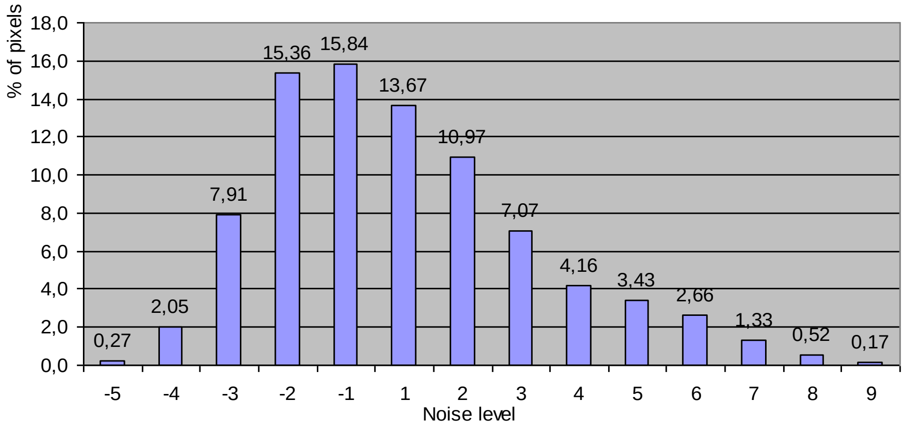

Figure 8. Noise distribution in images acquired using combination of NG4 5,0 mm and BG38 1,0mm filters (filter 2).

It should be underlined that Gaussian distribution characterizes noise presence in images acquired without any filter (fig.6). The effect is according with known literature [1, 4, 5]. This confirms that used methodology of noise analysis is authoritative.

6 Feature works

Feature works will be concerned with removal of noise introduced to images by optical filters. For each optical filter, appropriate algorithm will be constructed. The algorithm will take into account properties of noise.

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