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SOFTWARE FOR TEMPERATURE FIELDS ANALYSIS

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Abstract. Using holographic interferometry as quantitative measuring and contactless diagnostic method in basic and application research considerably depends on process of evaluation of interferograms. In the paper a programme solution is presented which will simplify time and labour consuming evaluation of holograms, it will increase accuracy of calculating and exclude subjective influences in evaluation. The programme states the temperature fields in holograms achieved at experiments. The interferential fringes occurred above heated wood sample are matched with the temperatures, which are possible to be used for further processing, e.g. to calculate the coefficients of thermal conductivity.

1. Holographic interferograms. Study of many physical processes could be much easier if they are visualised.

One of the possible applications of holographic interferometry [2, 7, 8] is visualisation of distribution of temperatures in testing combustibility of wood of different kinds of sample bodies in various anatomical directions, or different sample bodies. By evaluation of holographic interferogram we can receive the temperature profile above the examined sample, i.e. temperatures will be matched to individual parts of dark fringes.

Progress of the experiment is dynamic, individual patterns are changing relatively quickly, so it is advantageous to use a CCD camera, which operates immediately and records in form of bmp files.

In case there are photos of interferograms that had been recorded before computer technique came into interferogram analysis it is possible to use a scanner.

When the samples are charged with heat, the heat passes and gradual degradation of wood mass takes place. In heat charging of samples there heat transfer and gradual degradation of wood mass is arising. In images (*Fig. 1*) there are holographic interferograms of temperature field above heated samples recorded in the temperature of environment, 17 °C (290 K).

The heat passes through sample layer. In the images we can see gradual increase of thickness of heat limit layer. In longer distance from sample the chaotic distribution of interference fringes occurs which is caused by non-homogenous environment with wide-laid parameters. The images are characterised by clear borders of single interference fringes – the refraction index is changing. It is because the sample is gradually heated also in the upper side and as the temperature is higher, the more fringes occurs. It is possible to match the temperatures and individual fringes.

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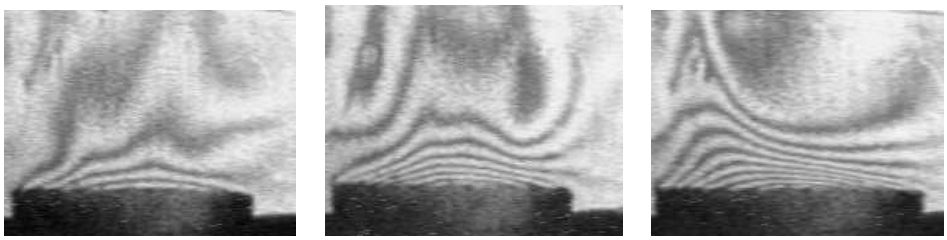


a) *b)* *c)*

FIG. 1 *Holographic interferogram of temperature field above heated spruce sample a) after 3 minutes b) after 7 minutes c) after 15 minutes*

1.1 Hologram analysis. Result of holographic interferograms analysis are numeric data of positions of interference fringes and calculated temperature profiles.

The process of interferograms evaluation itself can be divided into three parts. In the first part it is necessary to define positions of interference fringes, in the second part the temperatures are matched with individual fringes and in the third part there are done corrections of measured values.

The equation was applied to determine final functional temperature dependence on status quantities of the environment, on of length sample, light wavelength (it is included as a constant) and on the number of dark fringes [5]:

$$T(x,y) = \frac{T_\infty}{1 - 0{,}805.\frac{T_\infty}{l.p_\infty}.\left(s - \frac{1}{2}\right)}, \qquad 1)$$

where $T(x, y)$ – temperature distribution,
T_∞ – air temperature in the reference area,
p_∞ – pressure in the space,
s – interference index,
l – length of a sample.

Equation (1) is possible to use for He-Ne laser with a light wavelength $\lambda = 632$ nm (included as a constant).

2. Computer processing of image. Visualisation and its preparation, but especially animation is time-consuming especially in dependence on requested output quality [6]. In our case it means mainly work with plane graphics and images in grey scale.

2.1 Operating with histogram. It is possible to recieve various information from each image which could be consequently used to describe them. We can find the darkest and the lightest colour, edges, amount of noise, resolution, etc.

Histogram of image describes number and frequency of colours in the image. Histogram is a vector of absolute numbers of individual values participating in the image [9]. If the original image is a greyscale one then a histogram is a one-dimensional vector (this case).

Histogram quantifies brightness ratios in the image, but it doesn‘t carry any information of their area distribution. But despite this it contains important and valuable information.

The operations with a histogram are those adjustments which cause changes in the shape of histogram and may have also unwanted results, e.g. fusion of some brightness values and the image will be changed in an undesirable way.

We used the following operations:

- *Operations with a searching table*
  Searching table (LUT) is a discrete function that can assign the same functional value to several values from definition scale. It means that more brightness components could be substituted by one, so the brightness scale is restricted.

- *Thresholding*
  Operation **thresholding** is based on dividing the brightness scale according to the threshold into two parts and replacement of every part with a single value. Result contains maximum two values of brightness. The choice of threshold parameter is essential for quality of resulting image.

- *Equalisation of histogram*
  Equalisation of histogram is used to process images, where there are mainly either dark or light brightness components. Equalisation provides equal distribution of brightness components in an image and increases contrast and highlights details.
  Principle of histogram equalisation algorithm is finding such a searching table using which we will receive a histogram equalisation. If we have an image in resolution of $n \times m$ pixels of maximum intensity MAX, then ideally equalised histogram would include the same number of value $D = (n \times m) / \mathrm{MAX}$. But equalisation has also some undesirable effects. In some cases the noise can be emphasised by moving the noise into brighter part of intensity.

2.2 Noise removal. Noise shows as undesirable grain in the image. Removal of noise depends on the way of achieving the image, and characteristic of noise. If there are more samples of the same image and their source has no systematic error, resulting image is received as an average or median from pixels laying on the same co-ordinates in all images of the original. If there is available only one original, noise is removed according to characteristic of surrounding of every point.

In Fourier frequency spectrum the noise is demonstrated as high frequency. So noise blurring filters are often used to remove the noise. **Convolution kernels** can serve as filters.

Convolution kernel is a function which is defined mainly by matrix which states how the image will be changed using convolution. Convolution kernel is also called window (windowed function). Discrete convolution is realised when a „window“ of filtering function is laid on every pixel, from this a new value of the chosen pixel is calculated. Then this window is moved one step next and the value is calculated for next pixel.

To calculate result image $I'(x, y)$ adjusted by discrete convolution the following equation was used [9]:

$$I'(x, y) = I(x, y) * h(x, y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} I(x, y)h(x - i, y - j) \qquad (2)$$

where $I'(x, y)$ – resulting image,
$I(x, y)$ – original image,
$h(x, y)$ – convolution kernel.

Sum of the weights in the convolution kernel has to be always equal to one.

3. Analysis of problem. The analysis of the problem consists in several steps:

- modification of the holographic interferograms images received with CCD camera.
- stating of the interference index dependent on status quantities and wavelength of used light,
- determining the locations of minimums of interference fringes.
- calculating the temperatures for individual places of dark fringes from found data.
- drawing the graph describing temperature profile for calculated values.

In *Fig. 2* there is a detail cut from the holographic interferogram (from *Fig. 1 b*). It displays the specifying of position interference fringes and layout of interference indexes using the grey cut. The grey cut transforms individual colours to scale of black and white display. 0 belongs to black colour, 255 to white colour and between them there are levels of grey. In the right side of image there is a curve showing colour intensity of individual interference fringes related to the scale 0–255 grey levels.

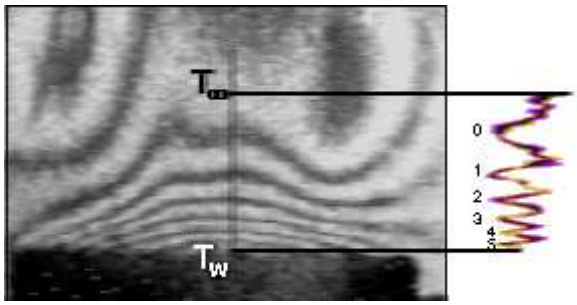


FIG. 2 *Specifying positions and interference indexes of holographic interferogram from Fig. 1 b, T_∞ – temperature of air in the reference area, T_w – temperature on surface of the board, 0, 1, … 5 – interference index,*

4. Algorithm design. From the algorithm design point of view the program consist of three basic parts [3]:

- algorithms for image adjustments,
- algorithms for data acquisition from images for another calculations,
- algorithms or procedures enabling a communication (typing messages, auxiliary objects drawing, graph drawing, tables, etc.).

To make the programme operation familiar we will present the principles of some of the algorithms from the first two parts.

4.1 Algorithms for image adjustments. *Removal of undesirable noise with use of convolution mask*

The algorithm removes undesirable pixels with higher brightness level. It uses the method of pixel blurring with help of a convolution kernel. In our case, the convolution mask is matrix of size 3 × 3 with following values:

$$h = \begin{pmatrix} 1/16 & 2/16 & 1/16 \\ 2/16 & 4/16 & 2/16 \\ 1/16 & 2/16 & 1/16 \end{pmatrix} \tag{3}$$

Image histogram creation

Algorithm creates image histogram, which is represented by one-dimensional array hist[i] with size of 256 elements. Each field index presents intensity of brightness in dependence from 0 (black) to 255 (white). The histogram expresses frequency of individual intensities.

Calculation of searching table LUT

Searching table serves to equalise histogram. The table is based on a principle similar to the one from histogram, i.e. each table index represents brightness component. The table will contain intensity values substituting intensity indexes defined by the table index. Ideally adjusted histogram would contain frequency value D, calculated as number of pixels in an image divided by maximum intensity. If a brightness component exceeds ideal value of D, it cannot be shortened with use of LUT. Using the algorithm we can distribute such a value. At first it is investigated into a what interval it is possible to divide the value, and undivided value is placed into the centre of the interval.

Displaying equalisation in a image

Algorithm provides projection of adjusted histogram with help of *LUT* table.

4.2 Algorithms for data acquisition from images for another calculations. *The position of interference fringes minimum finding*

Dark and light fringes are regularly changing above the board. The algorithm processes pixels between points from which it is measured, and surface of the board. The result of procedure are co-ordinates of pixels, in which interference fringe minimum were found.

Enlargement of a part of a image

This algorithm enlarges a part of the image which is defined as the distance of a point from which the measurement is realised and surface of the board (*Fig. 5*).

5. Program. If we want to indicate the importance of using computers in holography, it is necessary to emphasise their advantages. The advantage of digital recording and computer evaluation of interferograms there is especially the possibility of detectoscopy in real time, speed of saving and recalling of information. Computers are becoming a part of experimental equipment from the reasons of effective processing of measured characteristics [1].

Software, processing images recorded by CCD camera, was developed to process image data from holographic interferograms. It operates in maximum resolution of 384 × 288 pixels.

Program equipment enables receiving of quantitative data from the interference image, which is connected to a certain physical law (temperature).
Determining positions of interference fringes and determining distribution of interference indexes is one of the most important steps in processing of interferogram by computer. The next step is determination of refractive index itself and calculation of temperatures.

Designed software contains next functions to process holographic interferograms:

- setting entry parameters,
- brightness and contrasts setting,
- corrections of dark and light parts,
- measurement and calibration,
- RGB cuts of intensities,
- calculation of temperatures,
- displaying of graphical dependencies.

Program environment

Working area of the program is divided into seven independent parts (*Fig. 3*).

Input area

Input area enables choosing an image to process.

Co-ordinates area

This area consists of two independent windows: „Co-ordinates of the point of measurement“ and „Distance of the point of measurement from the left corner of the board“.
This menu is used when several holograms of the same body are processed, but measured in different time. Due to it the measurements can be performed at exactly the same place.

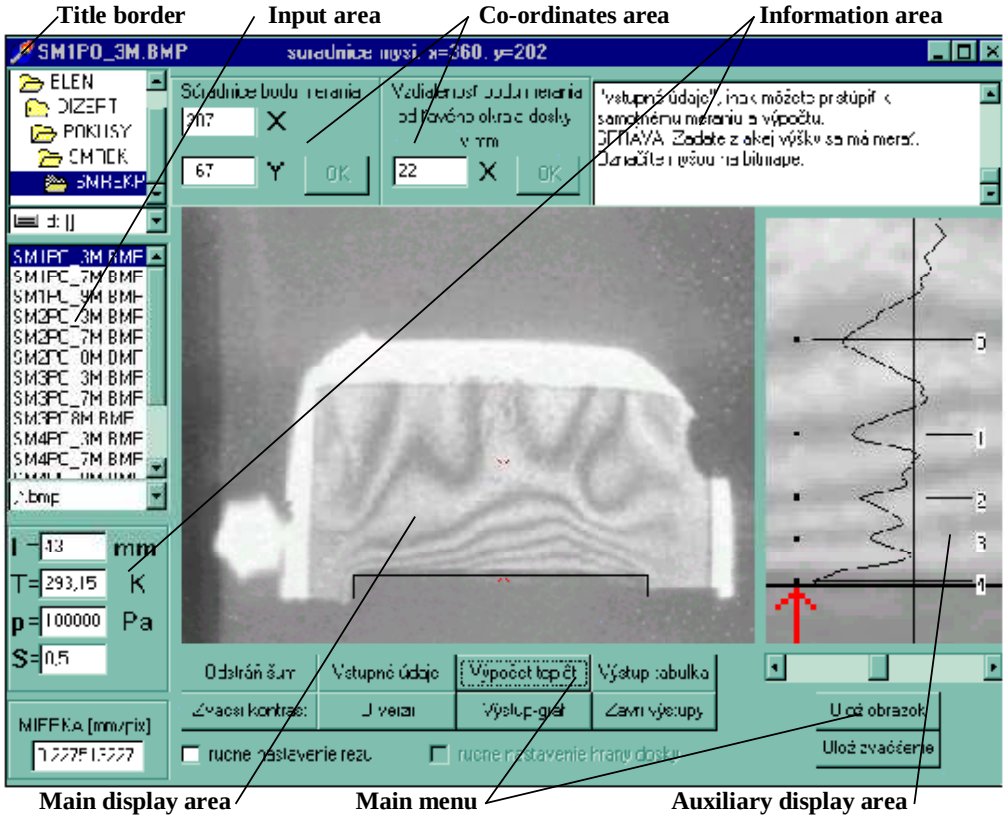


FIG. 3 *Program screen display with hologram recorded by CCD camera*

Main menu. Controlling menu or main menu is a basic tool of the program. It controls the core of the program – algorithms – transfers the information from a user and processes the information. The result is output information: visual – images, graphs or mathematical – numerical values.

Options of the main menu (*Fig. 3*):

- Remove noise
- Increase contrast
- Input data
- Information about the version
- Calculation of temperatures
- Output – table
- Output – graph
- Close outputs windows
- Save the image
- Save the enlarged image
- Manual setting of a cut
- Manual setting of a board edge

Information area. Information area has two independent parts. The first is in the right upper corner and is represented by a window with announcing and warning messages. The second part is placed in the left lower corner and has two windows. In the first current settings of input data (length, pressure...) are written and in the second the scale (mm/pixel) of current image is displayed.

Main display area. The image that is being processed and has been achieved by CCD camera in the form of bitmap file is shown in the main display area. Another entry data for further calculations (setting of board corners, setting of points for measurements) are entered through this area. Besides those, changes depending on adjustment of a bitmap image are demonstrated immediately. This area serves also to display graphical outputs (*Fig. 7*) and temperature table (*Fig. 6*).

Auxiliary display area. Auxiliary display area has several functions:

- it enlarges selected area of a cut,
- using of moveable cursor improves output data,
- it displays the curve, which determines intensity of colour of individual interference fringes and figures of the interference index.

6. Practical importance. As long as processing of holograph interferograms concerns a large amount of holograms, which is necessary to process and evaluate. Software replaces tedious process of manual evaluation of holograms for automatic calculation.

Generally known formulas from computer graphics and holographic interferometry were used in the algorithms.
Resulting source code was developed in development environment DELPHI4 [4] in programme language PASCAL.

The developed program belongs among programs with special orientation. It is not designed for wide users public but only for narrow group of experts, students and research teams. Program also can be used by students in creating of expert, term, diploma and dissertation works.

Visual method of holographic interferometry belongs to new methods in the area of experimental acquisition of physical properties. At present we do not know similar software of holograms processing.

Program is designed for holograms achieved by CCD camera in measurements performed on wood bodies. All the tests were made for this group of input images.

7. Practical utilization of the program. In the *Fig. 5 a)*, there is a holographic interferogram of temperature field above the heated sample body of beech wood in tangential direction in size of $43 \times 40 \times 10$ mm, which was recorded at the surrounding temperature of 25 °C (298,15 K). The record was made after 15 minutes of heating with a candle flame from the bottom side. The distance between the sample body and the source of heating was 18 mm. Hologram was

recorded at setting of interferometer for infinite width of interferential fringes in real time.

The interferential fringes represent isothermal curves of temperature field. The individual fringes are possible to match with the temperatures using the presented software.
To calculate the temperatures it is necessary to set entry data (*Fig. 4*).

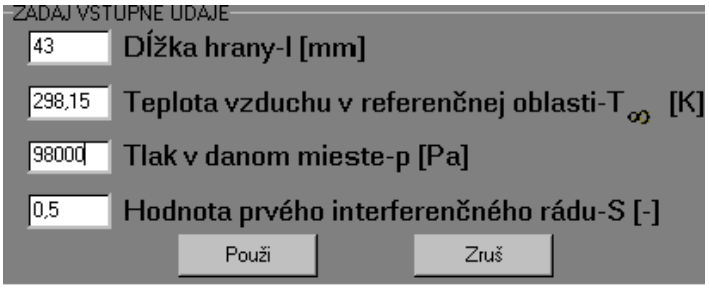
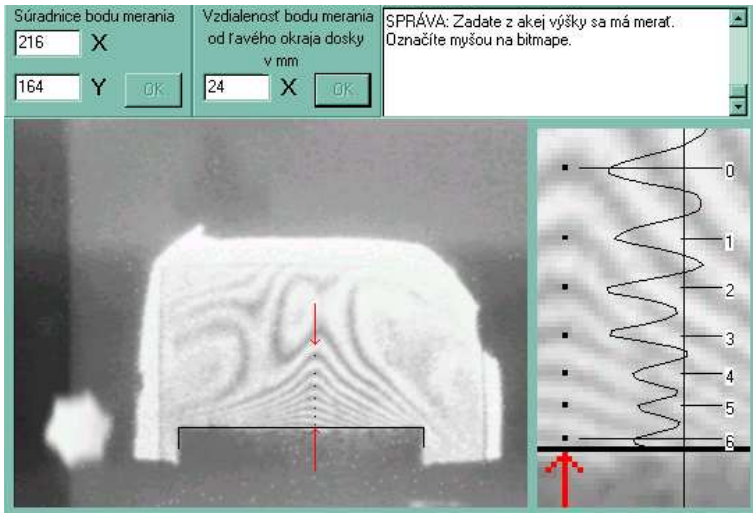


FIG. 4 *Entry data*
Dĺžka hrany – edge length,
Teplota vzduchu v referenčnej oblasti – temperature of air in the reference area,
Tlak v danom mieste – pressure in particular area,
Hodnota prvého interferenčného rádu – value of the first interference index

To be able to calculate the positions of minims of interference fringes it is necessary to set the distance between the point of measurement and the left edge of a sample. In our case the set distance was 24 mm. Based on this the program will calculate the position of the minima of interference fringes and will image them graphically (*Fig. 5*).



a) b)

FIG. 5 a) *Holographic interferogram of temperature field above a sample body of beech wood in tangential direction after 15 min. of heating*

FIG. 5 b) *Graphical image of minimal of interference fringes*

Based on entered data and calculated positions of minimal values of interference index „s“ are determined. The temperatures for individual fringes (*Fig. 6*) are calculated. The graphical dependence of temperature on distance from the surface of sample is plotted (*Fig. 7*).

BK2TA15M.BMP
The measurement was done in the distance of 24 mm
from the left edge of the board

s	y [mm]	T [K]
0	12.7	298
1	9.53	316
2	7.33	336
3	5.13	360
4	3.42	386
5	1.95	417
6	0.49	453

FIG. 6 *Display of calculated temperatures*

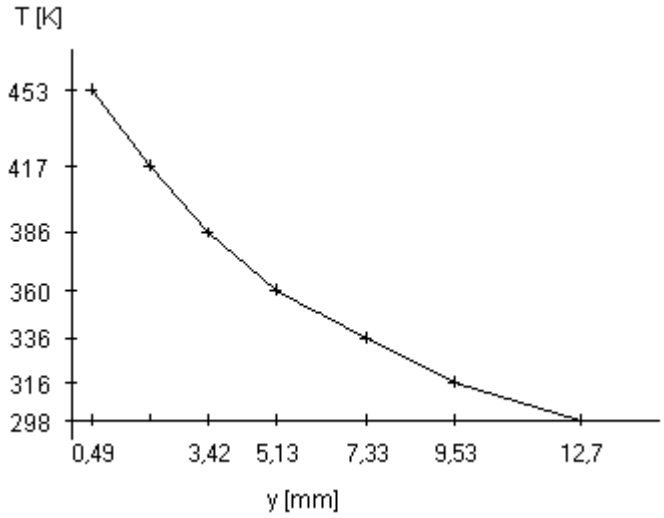


FIG. 7 *The graph (graphical dependence of temperature on height)*

Received values are possible to use for further processing, e.g. to calculate coefficients of thermal conductivity. Or it is possible to compare found values of samples in various anatomic directions, a sample with different heating times or values for various distances from left edge of a sample.

8. Conclusion. Using new untraditional optical methods in research of wood properties enables to specify many activities going on in the environment and at interface between material and this surrounding during heating. Along with using

new methods it was also necessary to design a new method for processing and evaluation of achieved data.

We tried to develop software for evaluation of temperature fields holograms achieved in experiments. Presented software enables to receive output data from holographic interferograms, put these data into suitable equations and so calculate individual temperatures. Thermal dependencies will be received when achieved values are drawn into graphs.

So combination of theory and experiment, mathematical and physical models can lead to improved knowing of activities that arise in heating and burning of wood.

Thanks to flexibility of program we can assume that after little corrections it is useable also in other branches where holographic interferometry is used.

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