Software for Computerized Thermal Image Processing

Anna Andonova* Andrew Andreev
*Department of Microelectronics
Technical University
8, Kliment Ohridski, Sofia 1797, BULGARIA
**Centre of Biomedical Engineering "Prof. Iv. Daskalov"
Bulgarian Academy of Sciences
Bl.10, Acad.G.Bonchev str., 1113, BULGARIA
ava@ecad.tu-sofia.bg andrew.andreev@binnetix.com

Abstract: - The modern thermograph cameras are providing great opportunity to observe consequently surfaces. The generated image result can be processed for additional analytical purposes. The current research and development demonstrates how an independent digital image processing can identify the object temperature directly from the source without having specialized hardware. It shows also different techniques for image enhancements, three-dimensional representations and effective batch processing of operations for compression analyses.

Key-Words: - Image processing, Embedded Petri networks, Evolutionary computing, Applied thermography, NDT, 3D thermal model, Thermal histogram

1 Introduction

The problem of accomplish reliable and efficient safety systems thermal checks has received great attention in recent years. Recently, advances in a couple of related areas have pushed forward series of activities to reappraise the role of IR imaging in thermal management. These advances, including the development of the new-generation infrared technology and smart image processing algorithms, will provide a cost-effective and user-friendly approach to quantity monitoring and examination, as well as to assisting diagnosis [1, 2]. Infrared thermography (IRT) is non destructive (the temperature of the sample studied is usually low increasing), contactless (optics excitation and radiometric detection) and only one side of the sample needs to be accessible. These properties make the thermography, a method of analysis that is well adapted for industrial and medical use [3]. In this article is discussed the software implementation of the thermogram temperature measurement, aggregation of thermal histogram and 3D temperature model for different implementation of the thermovision studies.

2 Basic Principle in Thermography Measurements

IRT is aimed at the discovery of subsurface features (such as subsurface thermal properties, presence of subsurface anomalies/defects or overheating), thanks to relevant temperature differences observed on the surface with an infrared (IR) camera. Figure 1 illustrates the general concept. IRT is deployed along two schemes, passive and active. The passive scheme tests materials and structures which are naturally at different (often higher) temperature than ambient condition (under electrical or mechanical load) while in the case of the active scheme, an external stimulus is necessary to induce relevant thermal contrasts (which are not available otherwise, e.g. specimen at uniform temperature prior to testing).

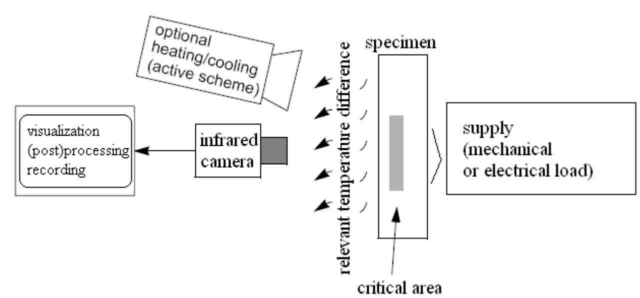

Fig.1.

The calculation of object temperature from the calibrated camera output depends on the received radiation power W from a black body source of temperature T_{source}. On short distance the thermograph generates output signal U_{source} that is proportional to the camera power input:

$$U_{source} = CW(T_{source}) . (1)$$

where C is a camera constant value. In theory the scanned object could be analyzed as a perfect black body in accordance with Plank's law. However in practice the object have to be represented as a gray body with a specific emittance coefficient ε. Consequently the received radiation power can be represented by the pair εW_{source}.

Generally speaking, the total received power radiation W_{total} captured by the thermo camera can be examined on three groups:

- Object radiation W_{obj}
- Reflected Radiation W_{refl}
- Atmosphere Radiation W_{atm}

Therefore:

$$W_{total} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau W_{refl} + (1-\tau)W_{atm}. \quad (2)$$

where [1]:

- $\varepsilon\tau W_{obj}$ is the emission from the object, ε is the object emittance; τ is the transmittance of the atmosphere. The object temperature is T_{obj}.
- $(1-\varepsilon)\tau W_{refl}$ is the reflected emission from ambient sources, (1-ε) represents the reflectance of the object. The ambient sources have the temperature T_{refl}.
- $(1-\tau)W_{atm}$ is the emission of the atmosphere. (1-τ) represents the emittance of the atmosphere.

3 Software for Thermogram Analyses

The modern thermograph cameras convert the information gathered during the scanning of the infrared spectrum into true colour graphical images. Temperature levels are represented by different colour palette in accordance to the practical needs. The general concept of thermographs, in accordance with the Theory of Three Primary Colors, is to represent the temperature by colorizing the image in the visible spectrum [1].

The fluent transition from one color to another is possible by reproducing the missing values for each color channel by increasing or decreasing in range of 0 to 255. The reverse-engineering process of the specific palette information requires color rearrangement for each recognized transition because of the 3-channel digital image encoding. Therefore it requires different logical approach. For example the comparison for the Black-Blue transition is represented by the following Boolean expression

$$Res = \frac{C1.G + C1R}{2} < \frac{C2.G + C2.R}{2}, \quad (3)$$

where where Res is TRUE when $C1$ (Color 1) < $C2$ (Color 2). The green and red channels are represented as G and R.. Comparison (3) is simple because Blue channel is always raising and because the digital representation of the Left transition color (Black) is very simple – 0 (zero for each channel). The complexity of comparisons for the rest of the transitions becomes polynomial.

The algorithm passes on three stages:

- The pixels in the image are sorted in *transition groups*. Special evaluation function calculates a relative weight for each pixel in for each group;
- Groups are optimized by removing the duplicated colors;
- Modified QuickSort algorithm is executed for each group using the calculated relative weight from Pass 1. Depending on the transition group this modification of QuickSort is working in ascending or descending mode.

The modern thermographs encode the temperature levels and the parameters of measurement while capturing the IR image. Normally the result is saved in specific to the camera file format. Later these files are distributed as a standard image file formats like JPEG (compressed) or BMP. However during this process the information necessary for any further analyses is lost, when should work without SDK. In this case the most important issue for the IR imaging is to restore the temperature information for each pixel in source image. In order to solve this issue the minimal T_{min} and maximal T_{max} temperature levels detected by the camera must be provided as external parameters.

When the palette is already sorted – the first unique color is the coolest one, the last color is the warmest.

The temperature value T_c is distributed for each unique color in the palette as follows:

$$T_c = T_{min} + \sum_{0}^{C_T-1} \frac{abs(T_{max} T_{min})}{C_T}. \quad (4)$$

where $C_T = C-$, C is the count of all unique colors from the palette, C_G is the count of the garbage colors. Temperature calibration can be performed in accordance with Formula (2) where T_{total} have to be replaced with T_c.

The full calculation process over 400000 pixels takes less than 10 second.

4 Thermal Histograms and Thermal 3D Models

From practical point of view the Histogram provides quantitative information how warm or cold is one IR image. The aggregation process of the histogram is a global operation and, therefore, does not depend on the IR image geometrical parameters. Consequently, the Thermal Histogram is an excellent tool to compare two different IR images. It helps also when analyzing the temperature changes on specific object.

The data required for the Histogram is acquired by calculating the occurrence of each pixel from the source image vs. each unique color from the thermal color palette (Figure 2and 3). The number of calculations could be significant if the algorithm is not working with color probes. These probes are selected automatically. The histogram color density values are approximated to the nearest color probe. For better view each probe is colorized in accordance with the thermal palette of the IR image. The Histogram preparation time is very fast – assuming that the thermal palette is already create over 400000 pixels then the Histogram is generated for a second.

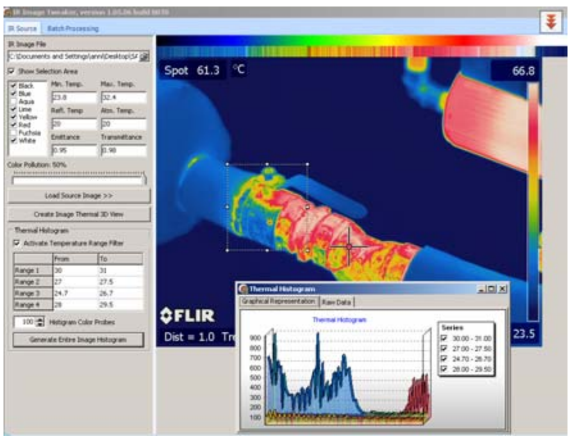

Fig.2

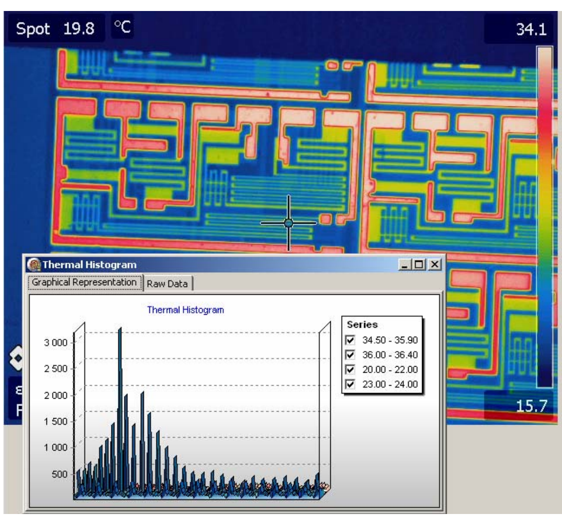

Fig.3

The thermal 3-Dimensional (x, y, z) model visualizes the flat IR image into as a function of the temperature, where:

- X-axis and Z-axis represent the 2D pixel matrix of the IR image
- Y-axis represents the temperature level

All “garbage colors” are kept in order to preserve the geometrical proportion of the image. Anyway, they are set as zero Y-axis value and are colorized in light gray.

Unlike the Thermal Histogram, the 3D model is geometrically dependent. Therefore it can be used to visualize and to magnify different intersections from the IR image. This option is very useful when hot and cold intersection areas have to be compared.

On the Figure 4 and 5 are given example of the 3D pictures god as result of thermography investigations in the field of building and medicine respectively.

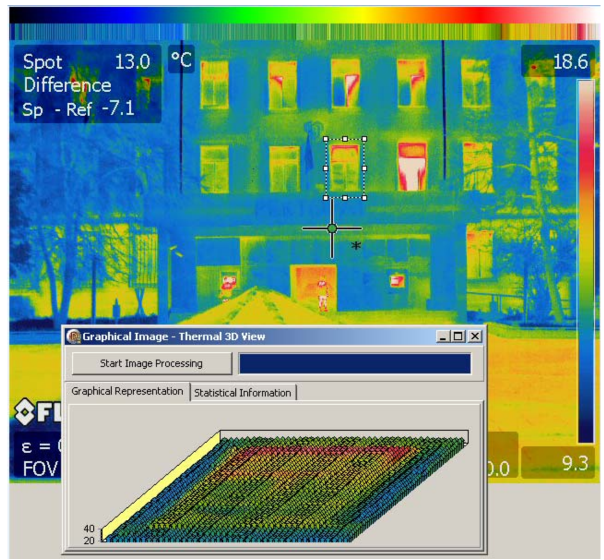

Fig. 4

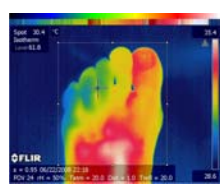
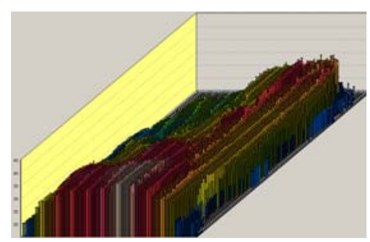

Fig.5

Previously we were clarified that the Thermal Histogram is geometrically independent and therefore could be extremely useful tool to compare two or more IR images.

Realized Batch Processing demonstrates the real behavior of the specimen (in Figure 6 and 7 are given results of a relay contacts wearing thermograph diagnostic used in Railway) which temperature is increased fluently for a certain period of time. This situation can be meet during the active scheme of the thermography. The Thermal Histogram calculation uses 10% of 200 serial images. Most of the object surface remains unchanged except those pixels marked in yellow.

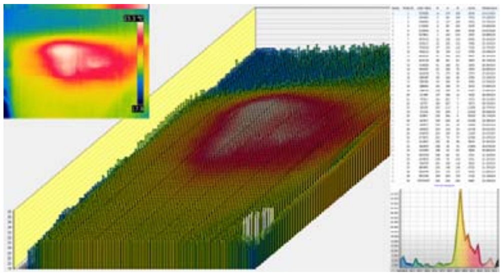

Fig.6

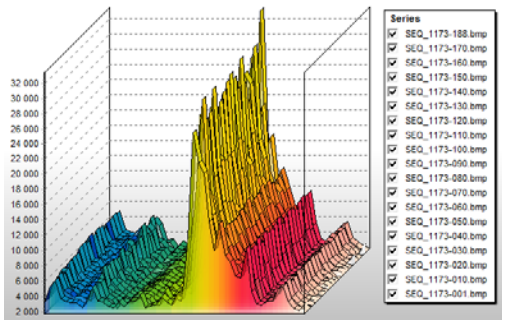

Fig.7

One of the many feasible realizations of a temperature information reconstruction program from thermograms in AEG is shown on the Figure 8.

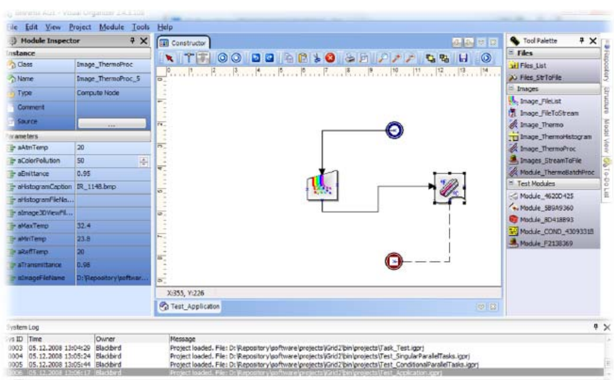

Fig.8

A FLIR IR camera model P640 (640x480 pixels) that detects the infrared radiation of the surface of the measured object in the range 7,5 – 13 μm and from –40^{0}C up to +2000^{0}C was used in our study.

IR images from different areas of application (transport, medicine, communication, electrical and mashinery industry) are collected and analyzed by the software for different schemes – active and passive thermography.

5 Conclusion

The main advantage of thermographic methods is related to the possibility of obtaining either time or space resolved analysis of the surface temperature of the whole sample.

The paper shows that the temperature information can be effectively restored using the IR image as the only source. This functionality helps IR images to be analyzed from different sources or camera's models. The image calculations are working fast with high precision and large amount of data. The maximal detected temperatures are limited only by the capabilities of the type of the used IR camera.

The calibration of color transition during thermal palette generation has to be improved in cases when the image color pollution is high or when there are too many color transitions gaps.

The Colour Transition Engine (CTE) works fast and very flexible with wide IR types of images. It allows being fully tuned-up by managing only few physical parameters. The CTE controls fluently the colour pollution and provides a great opportunity for direct processing of commercial images derived from thermographs produced by different manufacturers.

The CTE is designed as a thread-safe software library ready to be used in cell modules as a part of the parallel grid environments.

Acknowledgements

The authors would like to thank for the support of Bulgarian Ministry of Education – Scientific Investigations Fond under which contract 1-854/2007 "Thermal Management of Microelectronic Systems (MC) – TEMC", the present work was conducted.

References:

[1] Robert Fisher, Simon Perkins, Ashley Walker, Erik Wolfart. Digital Image Processing, HIPR2, John Wiley, 2004

[2] Docheva L., Al. Bekiarski ,I. Dochev, Analysis of Analog Neural Network Model With CMOS Multipliers, Proceedings of Czech and Slovak Technical Universities and URSI Committees, Journal Radioengineering, vol.16, №3, pp. 103-107, 2007.

[3] J. R. Keyserlingk, P. D. Ahlgren, E. Yu, N. Belliveau, M. Yassa. Functional infrared imaging of the breast. IEEE Engineering in Medicine and Biology, pages 30-41, May/June 2000.

[4] FLIR Systems, Technical Specification Issue, 1558550, Rev. a174, pp 243-244, 2005