MEASUREMENT OF IR TEMPERATURE DEVIATION IN BIO-MEDICINE

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Abstract

The modern thermographs converts 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 current research and development is software engine for colour graphical analyzes of the IR images, optimized for parallel execution in grid environment. The analyzes of IR images covers: the automatic colour palette recognition including determination of temperature deviations, generation of thermo-histogram for measuring the temperature levels, comparison of temperature deviation between two or more images within a range without geometrical parameters dependency and generation of 3D temperature deviation model.

This approach allows effectively and continuously to process different bio-medical objects including the workload monitoring of specialized micro electrical schemes in medical devices.

1. INTRODUCTION

Infrared (IR) thermography is a technique for remotely measuring the surface temperature. IR thermography exploits the correlation between the surface temperature and the infrared energy emitted by the surface. This relationship is described by Stefan-Boltzmann's Law as follows:

(1)

$$R(T) = \sigma . T^4$$

where *T* is the temperature of the surface and $\sigma = 5.67 \times 10^{-8}\ W/(m^2.K)$. The IR light is described in physics by Planck's law as a spectral radiance of electromagnetic radiation of black body at temperature *T*. As a function of wavelength λ = (speed of light *c* vs. Frequency *v*) the Planck's law representation is:

(2)

$$I(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

where *h* is Plank's constant, *k* is Boltzmann's constant. For the purposes of IR measurements the light must be described in terms of the *spectral energy density* and have to be digitized in wavelength units . After appropriate conversion the spectral energy density $u(\lambda,$ can be expressed as a function of wavelength, as follows:

(3)

$$u(\lambda, T).d\lambda = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} d\lambda$$

In practice the IR measurement precision is acceptable when the radiation from the surface can be fully detected by the camera sensors. However, with the increasing of the distance between the surface and the sensor, the atmosphere has strong detrimental and perceptible impact on the accuracy. Taking in consideration additional factors like high humidity, rain, fog, the absorption effects due to water vapour and

CO_2, the thermographs could report temperatures with significant error deviation.

In addition, the result of modern thermograph cameras is saved and compressed in popular graphical image formats like JPEG. However, in such file format we are observing loss of graphical information and increased noise of the images.

The current implementation allows the graphical information from thermographs to be analyzed from scratch using only external parameters, providing good precision and high performance image processing.

2. BACKGROUND

[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:

(4)

$$U_{source} = C.W(T_{source})$$

where C is a constant value. If the source is gray body with emittance ε, than the received radiation would consequently be εW_{source}. The total received power radiation W_{total} depends on three terms:

- Object emission
- Reflected emission
- Atmosphere emission

(5)

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

where:

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

In accordance with the Law of heat transmittance, the radiation power and temperature dependency can be represented by the fallowing formula:

(6)

$$W = \frac{S\gamma}{D}.T$$

where S is the heated surface, D is the transmitted distance from the object, γ is the specific temperature coefficient of transmittance, T is the temperature deviation. It can be considered that in the moment of thermal measurement for a short period of time the environment parameters remain unchanged. In that condition the fraction has a constant behaviour. It is obvious that the relationship between W and T is direct proportional – increasing T the value of W is increased also.

(7)

$$W = C_{source}.T_{source}$$

In accordance with above conditions and after appropriate substitutions in formula (4) and (5) we could represent the object temperature in terms of thermograph output signal as follows:

(7)

$$T_{obj} = \frac{1}{\varepsilon\tau}.T_{total} - \frac{(1-\varepsilon)}{\varepsilon}.T_{refl} - \frac{(1-\tau)}{\varepsilon\tau}.T_{atm}$$

The coefficients of object emittance ε and atmosphere transmittance τ may vary in diapason (0, 1].

The influence of the reflected emission is removed when ε = 1 (100% absorption of pure black body).

The influence of the atmosphere emission is removed when τ = 1 (vacuum).

The perfect conditions when measuring black body in vacuum the object temperature can be represented by:

(8)

$$T_{obj} = T_{total}$$

3. IMPLEMENTATION

The IR images temperature measurement is a complex procedure that solves the following five general tasks:

- Colour palette identification
- Colour transition approximation
- Colour pollution detection
- Temperature Range Calculation
- Statistical Aggregation

The above tasks are producing a result which could be summarised as follows:

- HSL (hue, saturation and luminance) image levels for each pixel
- Occurrence for each unique colour in the IR image
- Relative temperature levels

By combining the above information the current software engine generates:

A. Thermal histogram of the whole IR image.
B. Automatic generation of raw statistical data.
C. Comparison of temperature intensity between two or more temperature sub ranges.
D. Comparison of thermal histograms between two or more IR images

3.1. Colour Palette Identification

The colour palette identification is required in order to classify the full set of colour transitions that are necessary for the IR image analyses and temperature calculations. Normally the identification task looks simple and should be solved by applying one or more predefined standard palettes by choosing the most applicable one.

There are many colour systems that are measuring the distinction between the so called warm and cool colours. Such systems are: CIE 1931 Chromaticity Space, Geothe's Colour Wheel, Munsell's Colour System etc. Most certainly, the clearest and fully related to the energy density representation of Plank's law $u(\lambda,$ is Wien's Displacement Colour Temperature System [2]:

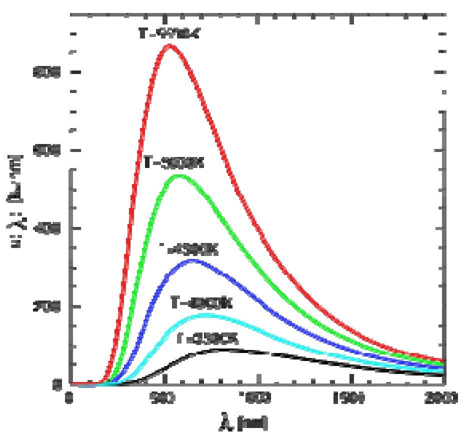

Figure 1. Black Body Spectrum

However in the practice, the thermographs are using custom defined colour palettes in order to generate IR images. For example in the Medicine it is accepted the coolest areas to be marked in black and most warm areas in white. In the heavy industry this selection is the opposite. However, even the intermediate colour transitions could be different.

Despite of the existence of several colour systems, it is obvious that direct comparison will take long time to process the entire image and would not cover cases when none of the standard palettes is applicable.

In order to avoid this weakness, the current implementation completely inverts the approach – what if the most applicable palette is hidden inside the IR image and can be generated directly from the source?

Such reverse-engineering is possible and it is a matter of appropriate colour selection and colour transition approximations. It is described in details in section 0.

3.2. Colour Transitions Engine

Because of the purposes of bio-medicine the current implementation accepts the Black colour to represent the coolest areas and the White colour to represent the warmest areas. In terms of thermographs this also means that any image information below the minimum temperature will be marked also in black. Respectively, anything above the maximum temperature will be marked in white.

The general concept of thermographs, in accordance with the Theory of Three Primary Colours, is to represent the temperature by colorizing the image in the visible spectrum [2].

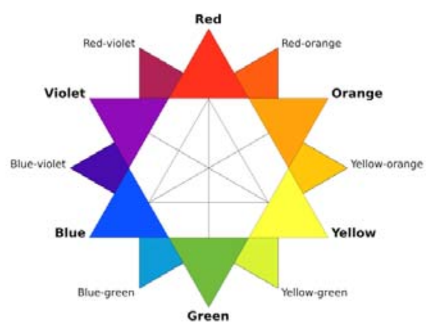

Figure 2. RGB Colour Star

The following colour chain can be identified: Black, Blue, Green, Yellow, Orange, Red, Violet and White. Therefore the possible colour transitions are 6. The algorithm preliminary accepts that any of those transitions are possible. It follows the rule of sequential natural colour transitions described in *Figure 2*.

The IR image is with 24-bit colour dept. Each of the colours is represented by 3 separate, 8-bit channels. The fluent transition from one colour to another is possible by reproducing the missing values by increasing or decreasing in range of 0 to 255 for each channel. The comparison of the colour is different for each transition because of the 3-channel digital encoding. Therefore it requires different logical approach. For example the comparison for the Black-Blue transition is represented by the following Boolean expression:

(9)

$$Res = \frac{C1.G + C1.R}{2} < \frac{C2.G + C2.R}{2}$$

Where *Res* is TRUE when *C1* (Colour 1) < *C2* (Colour 2). The green and red channels are represented as *G* and *R*. Comparison (9) is simple because Blue channel is always raising and because the digital representation of the Left transition colour (Black) is very simple – 0 (zero for each channel).

The complexity of comparisons for the rest of the transitions becomes polynomial.

The *Colour Transition Engine (CTE)* is a three pass algorithm:

- *Pass 1*: The pixels in the image are sorted in *transition groups*. Special evaluation function calculates the relative weight for each pixel in the groups;
- *Pass 2*: Groups are optimized by removing the duplicated colours;
- *Pass 3*: 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 process speed is significant: 500 000 pixels are fully analyzed for 1-5 seconds. The speed varies because of the number of the discovered duplications.

The purpose of CTE is to create a colour palette from the source image. But one problem remains – the *colour pollution*.

3.3. Colour Pollution

The colour pollution is natural part of image encoding. It can be produced by the thermograph sensor sensitivity, by the image colour compression, by previous image optimizations or modifications, by applying additional information on the image like titles, labels etc.

The pollution is a relative quantity. It measures those colours which should not be included in the image palette. It is based on the fluctuation of the colour values which are outside the "normal" transition function scope.

The CTE controls the pollution levels by managing separately the colour channels for each pixel. The pollution detection algorithm is a logical part of evaluation function used during the Pass 1. This means that for each *transition group* the pollution criteria is calculated individually, as follows:

- The pollution detection affects only those colour channels in the current transition group which define the *colour deviation*. For example in the Black-Blue transition group the pollution affects only Green and Red channels;
- The pollution affects only the variable part of the channel within the current transition group. This part represents 100% of values that could be removed from the palette;
- The pollution removal algorithm works only between 1% and 50% of the selected for removal values. Once selected it affects as percentage all respective colour channels simultaneously.

Example:

The Black-Blue transition group allows Green channel to be blended between 0 to 255 and Red to be blended in range from 0 to 128. If the pollution removal is set to 50% it will remove all colours with containing values of Green and Blue more than 128 for Green and 64 for Red.

The colour pollution removal value is set in CTE to 50% by default.

3.4. Temperature Calculation

Once created, the IR image palette contains two sequential ranges of unique colours:

- temperature operational range
- garbage colours range (all colours removed during the pollution detection)

Because of *CTE*, the temperature range is already sorted. The sub-ranges are set correctly one after another – the first unique colour from the IR palette is the coolest one, the last from the operational range is the warmest.

The temperature values are distributed for each *operational* colour from the palette by calculating a relative offset $C_{offset}(T)$:

(10)

$$C_{offset}(T) = \sum_{0}^{C_T - 1} \frac{abs(T_{max} - T_{min})}{C_T - 1}$$

Where $C_T = C -$, C is the count of all unique colour from the palette, C_G is the count of the garbage colours, T_{min} and T_{max} identify the absolute global temperature range for the selected IR image. The colour temperature C(T) is represented as follows:

(11)

$$C(T) = T_{min} + C_{offset}$$

There are three density modes of temperature calculation:

- High: per each pixel
- Medium: average temp. using aperture size 3x3
- Low: average temp. using aperture size 5x5

Medium and Low approximations automatically excludes any garbage colours detected inside the apertures.

3.5. Statistical Aggregation

During the Pass 2 of *CTE* the algorithm calculates the occurrence of each unique palette colour.

4. EXAMPLE

Using the mathematical model described in Chapter 2 and implementation approach described in Chapter 3, the following software development creates measurement technology for IR images in bio-medicine field:

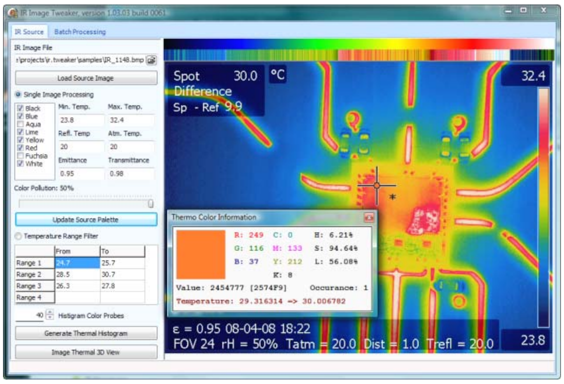

Figure 3. Colour Information provided by CTE

The IR image in *Figure 3* is captured with a standard thermo camera. Initially it was saved in JPEG file format and it was distributed as a raw BMP file format losing all camera information from the manufacturer. Taking in consideration the influence of the reflection power and the atmosphere transmittance, the image is processed with *CTE*. The calculated temperature of 29.31 °C is automatically corrected to 30.0 °C. This fully complies with the original temperature level captured by the thermograph.

The *CTE* helps to generate the image thermal histogram as it is shown in *Figure 4*. The occurrence of coldest and warmest colours is represented for the selected temperature range between 23.8 °C and 32.4 °C.

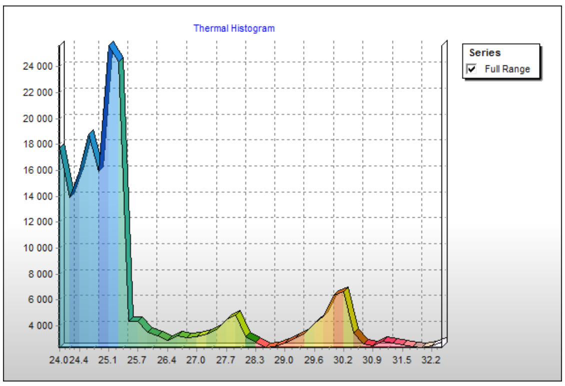

Figure 4. Example thermal histogram generated by *CTE*

5. CONCLUSION

The Colour Transition Engine 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.

6. ACKNOWLEDGMENTS

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