Automated Computer Diagnosis of IR medical imaging.

Marcos Leal Brioschi, Jorge Eduardo Fouto Matias, Manoel Jacobsen Teixeira, Jose Viriato Vargas.
Sao Paolo University Hospital – Neurology and Psychiatry Department. Parana Federal University – Mechanical Department and Surgery Post-Graduation Department. InfraredMed - Medical Infrared Imaging Diagnostic, Brazil. www.infraredmed.org

ABSTRACT
In order to improve infrared (IR) imaging diagnosis, application of computer software to the quantitative analysis of IR images has been studied by some investigators for years. The utilization of merely temperature alarms is not satisfactory for accurate diagnosis, it’s is necessary to work with thermal patterns tools, as example algorithms and fractals, to identify physiological abnormalities like fever and some diseases, adjusted with ambient and inner eye reference temperatures. The authors have developed an on-line IR image processing system with specialized algorithms to identify different diseases. Using a system of IR pattern recognition, digital geometry and signal processing was possible to create a diagnostic tool to increase the accuracy of risk analysis of breast cancer, diabetic foot ulcer, fibromyalgia thermoregulatory disturbance, knee osteoarthritis, hand/wrist rheumatoid arthritis, sleep disturbance, fever, and physiologic stress parameters. All the results were achieved from a data bank of FLIR images from the authors along 10 years of practice. From the results obtained, the quantitative diagnosis method by a computer was found to be a significant method. The overall accuracy of a computer diagnosis may vary more or less by different diseases assignments. The present processing system is being improved by the data bank.

INTRODUCTION
Some of the leading-edge processing currently under study includes automated target recognition (ATR), artificial neural networks (ANN), and threshold algorithms, to mention only a few. The uses of ATR and threshold algorithms are dependent on a reliable normative database. The images are processed based on what the system has learned as normal and compares the new image to that database. Unlike ATR and threshold algorithms, ANN uses data summation to produce pattern recognition. This is extremely important when it comes to the complex thermovascular patterns seen in infrared breast imaging. Ultimately, these advancements will lead to a decrease in operator dependence and a substantial increase in both objectivity and accuracy.

The identification of the asymmetry can be automated using image segmentation, feature extraction, and pattern recognition techniques. But one of the most common errors in applying this math processing is the fundamental and essential pre-normalization of the temperature readings first that will be elucidate in this paper.

Two objectives were sought in this work: (i) to suggest a normalized automated computer methodology for medical thermography diagnosis, and (ii) to test the methodology in different diseases.

METHOD
In an attempt to provide objective means to analyze skin surface temperature readings, Collins et al. (1974) developed the thermographic index to quantify infrared thermal imaging. The method was then utilized in several studies with different disorders. All studies showed the effect of medications on the thermographic index, which returned to basal levels with the symptoms remission. In general, the results established the concept of a stable environment as one of a number of essentials to reliable technique.

Other methods for medical infrared imaging quantification have been proposed, such as: (i) a heat distribution index (HDI), which consists of the average skin temperature at the affected region ± the standard deviation of the measurements, (ii) a compound thermographic index (CTI) in correlation with low density lymphocytes (LDL), (iii) a normalized thermographic index (DTn), which consists of the evaluation of the TI at the affected region minus the TI of a normal selected region, and (iv) a ds index (difference between temperatures of tissues of a breast tumor and normal tissues). Inoue et al. (1990) evaluated patients with rheumatoid arthritis
after 20 min of thermal stabilization in a room at 20°C showing that the HDI results correlated better with clinical observations than the TI.

The previously proposed methods for medical thermography (TI, HDI, CTI, DTn, ds, and skin-contact thermography) measure local temperatures that are significantly affected by ambient temperature and patient metabolism. A way to normalize temperature readings for any specific location would therefore be of much use in medical practice. Normalized infrared imaging could provide means for early and accurate detection of diseases and response to treatment.

The energy conservation principle states that, for any time interval, the variation of the energy of a system results from the exchange of matter and energy with the exterior, and the system energy variation is equal and opposite to the external world energy variation. Considering the system as a portion of an individual skin (the region of interest), its energy variation is a result of the exchange of matter and energy with the ambient and the rest of the individual’s body. Therefore, since energy is directly related to temperature, a general methodology to interpret the temperature readings obtained from an individual skin should consider the local environmental conditions and the individual metabolism.

An appropriate dimensionless variable was identified to interpret the infrared camera temperature readings. The variable is a well known dimensionless temperature in engineering heat transfer, and combines the locally measured temperature with the central body and ambient temperatures, as follows:

$$\theta = \frac{T - T_\infty}{T_b - T_\infty}$$

(1)

The results will range $0 \leq \theta \leq 1$ ($T_\infty = \text{ambient temperature}; T_b = \text{core temperature}$).

The dimensionless temperature defined by Eq. (1) is expected to deliver normalized temperature readings, independently of measuring units, for any particular skin location, whatever body and ambient temperatures are registered. The dimensionless temperature, as defined by Eq. (1), was first introduced in engineering by Pohlhausen (1921), who used it to present the normalized temperature profile solution to the thermal boundary layer problem of laminar forced convection on a flat plate.

In addition to the definition of a local measuring quantity, it is necessary to specify a representative quantity for the skin region of interest, namely, the affected region. Figure 1 shows a portion of the affected skin, in which a polygonal line defines a domain $X$ with respect to two Cartesian axes $x$ and $y$. The polygonal line should be appropriately specified to encompass the entire region of interest. Each region provides a dimensionless temperature field, which depends on $x$ and $y$, i.e., $\theta (x, y)$. Using the mean value theorem for integrals, the average dimensionless temperature for the entire region of interest is therefore evaluated by:

$$\bar{\theta} = \frac{1}{XY} \int_0^X \int_0^Y \theta (x, y) \, dx \, dy$$

(2)

Eq. (2) defines the quantity to be obtained through the infrared camera temperature readings in the entire selected region of interest, and through the measured central body and ambient temperatures.
Several authors have stressed the importance of establishing normal thermal patterns, but these have proved to be elusive. Throughout the literature, however, mention is made of ‘abnormal thermograms’ and of ‘hot spots’, but without prior definition of the normal.

Color images are seldom used in radiological images. Color, when used, is mostly for enhance visual appearance of features within this range. This may face legal issues because some information has been discarded or created (Figure 2).

It is imperative to solve this by using the same scale interval for all images by means of normalized temperature.
The skin temperature is affected by many internal (metabolic rate, core temperature, circadian rhythm, calorific intake, physical activity, emotional state) and external factors (atmospheric temperature and humidity). In particular, owing to the proximity of blood vessels to the skin in the extremities even small alterations in vascular tone will produce large changes in skin temperature. Many of these factors are uncontrollable.

If measurements of absolute skin temperature are made, this variation may lead to the suggestion of inflammation/tumor/ischemia where none is present and vice versa. In addition, the variation leads to difficulties in standardization and relating a single measurement to an arbitrary ‘normal’ temperature.

RESULTS

After analyzing our data bank was determined the dimensionless mean temperature of normal breast of 0.65 (\(\theta T=0.65\)). All the 365 women evaluated by the software had normal mammograms and ultrasound results and no complains. Mean age 35±25 years. Figure 3.

![Normal breast, grade I (TH1), symmetrical avascular. The dimensionless mean temperature of normal breast is 0.65 (\(\theta T=0.65\)).](image)

The breast cancer cases (n=235) had dimensionless mean temperature above 0.89 (\(\theta T>0.89\)). All had biopsies or surgery pathology exam confirmed (Figure 4). It was utilized the isotherm tool to identify automatically this cases and after to study the morphological distribution by mean of fractals. The accuracy to separate benign from malign cases with only this approach was more than 95% (p<0.001).

![R breast cancer (isotherm \(\theta T>0.89\)).](image)
R: Breast cancer (isotherm $T > 0.89$)
R: Ductal invasive carcinoma (isotherm $T > 0.89$)
R: Early breast infection, post-mastectomy, not cancer (isotherm $T < 0.86$)
R: Atypical hyperplasia, benign breast lesion (no isotherm alarm, $T < 0.89$)
R: Benign cyst (no isotherm alarm, $T < 0.89$)

2 cm Breast Cancer (isotherm $T > 0.89$)
Figure 4. Left column: thermograms before automatic computer analysis, some cases are with temperature scales and others with corrected dimensionless scale. Middle column: thermograms after automatic computer analysis. The breast cancer were identified by the isotherm alarm for dimensionless mean temperature above 0.89 ($\theta_T=0.89$) with 95% accuracy.

Figure 5. This is an illustrative case of breast grade II, classified as normal, but when compared with other parts of the body, it is possible to observe the high temperature of the breasts. This is a case of progesterone/estrogen hormonal imbalance. Dimensionless temperature avoid this common practice error indicating isotherm alarm above 0.77 ($\theta_T<0.77$).

For each area, $\theta(x,y)$, it is required to compute the normal reference dimensionless value. We started a hard project to determine some major areas and compare with classic illness (Figure 6, 7, 8).

R knee arthritis ($\theta_T=0.79$)
(normal reference knee=0.53)
<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacroiliitis</td>
<td>(θT&gt;0.83) (normal reference sacroiliac joint 0.54)</td>
</tr>
<tr>
<td>Myofascial pain syndrome</td>
<td>Trigger Points (isolated hot spots with θT&gt;0.79)</td>
</tr>
<tr>
<td>Fibromyalgia syndrome</td>
<td>(regional θT&gt;0.79, called mantle sign)</td>
</tr>
<tr>
<td>Fibromyalgia syndrome</td>
<td>(regional θT&gt;0.79, called mantle sign)</td>
</tr>
</tbody>
</table>
Sleep disturbance insomnia (palpebral θT>0.86, owl eyes)

Figure 6. Left column: thermograms before automatic computer analysis, some cases are with temperature scales and others with corrected dimensionless scale. Middle column: thermograms after automatic computer analysis with dimensionless isotherm pattern.

<table>
<thead>
<tr>
<th>No fever</th>
<th>Fever</th>
</tr>
</thead>
<tbody>
<tr>
<td>T max = 34.9°C</td>
<td>T max = 36.5°C</td>
</tr>
<tr>
<td>θT = 0.53</td>
<td>θT = 0.69</td>
</tr>
<tr>
<td>θT max = 0.81</td>
<td>θT max = 0.94</td>
</tr>
</tbody>
</table>

Figure 7. Left column: thermograms before automatic computer analysis with temperature scales. Middle column: thermograms after automatic computer analysis with dimensionless isotherm pattern comparing a normal face case with a fever case in the lower. It is possible to recognize easily the diffuse isotherm pattern, θT > 0.69.
Figure 8. A case of partial finger amputation after 1 month showed an ischemic awful visual aspect. By the isotherm pattern $\theta T < 0.86$ was simple to recognize the ischemic tissue limit and a good area of plenty blood perfusion for the tip of the finger. After 2 months monitoring, it was possible to see the tissue restoration without the need of finger amputation.

The normalized dimensionless temperature actually was improved with pattern recognition, digital geometry and signal processing using a system of IR. This software uses algorithms and fractals, to identify physiological abnormalities. The authors have developed an on-line IR image processing system with specialized algorithms to identify different diseases.

**SUMMARY**

This normalized temperature computer software allowed completely automated objective diagnosis with high accuracy, allowing studying far cases on-line by telemedicine. This will help an inter-centre image relationship and also a project of normal atlas with $\theta T$ IR reference diagnosis. Measurements of anti-inflammatory and other drugs action with thermography will be more reproducible. The challenges will be a full body analysis, fusion images with pattern description and IR imaging at outdoor environment for veterinary and pre-hospitalar trauma, emergency and clinic urgencies.

**REFERENCES**


ACKNOWLEDGEMENTS
The authors wish to thank Dr Francisco Nogueira and support of the Brazilian National Council of Scientific and Technological Development, CNPq for providing the resources to make this work possible.

ABOUT THE AUTHOR
Dr. Brioschi is graduated at Surgery from Universidade Federal do Paraná (1996), master’s at Medicine from Faculdade Evangélica do Paraná (2000) and PhD at Surgery from Universidade Federal do Paraná (2003). Post-doctoral at Faculdade de Medicina do Hospital de Clínicas da Universidade de São Paulo, Neurology Department. Has experience in Surgery, Legal Medicine and Clinical Thermology (infrared imaging, thermography), acting on the following subjects: pain management, breast cancer, angiology and surgery. Actually he is president of Brazilian Thermology Society and researcher of Brazilian National Counsel of Technological and Scientific Development for the study and implementation of medical thermography.