Preface

Thermography or infrared (IR) imaging system is dependent on an accurate analysis of skin and tissue temperatures. Its diagnostic procedure allows practitioners to identify the locations of abnormal chemical and blood vessel activity such as angiogenesis in body tissue. It is a noninvasive approach by applying the technology of the infrared camera and state-of-the-art software. Nowadays available high-resolution digital infrared imaging technology benefits highly from enhanced image production, standardized image interpretation protocols, computerized comparison and storage, and sophisticated image enhancement and analysis.

We are interested here to provide latest update on chapters in recent application of infrared to biomedical sciences. More examples will be analyzed comprehensively and deeply in this book. This book certainly includes color images and tables. Since infrared imaging is a nonintrusive, contactless, safe and easy approach, it is very beneficial to medical field. Nowadays with new generation and advancement of sensor technology, image processing algorithms and sophisticated computers, infrared imaging is being paid more attention. For better and healthier society we need to look at a safe and noninvasive modality with early detection potential as an adjunctive method to detect health problem. The book covers wide-ranging topics as follows:

The book with 28 chapters has two parts. First part of the book covers six different chapters by us. Various methods and applications of IR as contributed by many IR experts are then discussed in second part of the book.

Thermography is a simple, noninvasive and reproducible test that can accurately reflect the inflammatory activity, and can be used safely and repeatedly, during biological course of inflammatory bowel disease. Chapter "Potential of Infrared Imaging in Assessing Digestive Disorders" presents the possibility of infrared imaging in assessing digestive disorders such as irritable bowel syndrome, diverticulitis, and Crohn's disease.

Pain has been a problem to be differentially diagnosed for years since it has been diagnosed subjectively. There is no test that can provide data indicating the accurate information regarding the location and amount of the pain. Hence clinicians count on the patient's own explanation of the location, form, and timing of the pain. Chapter

"Potential of Thermography in Pain Diagnosing and Treatment Monitoring" introduces pain and application of thermography for diagnosis of different pain categories as well as monitoring the treatments. Thermography can provide data of pain quantitatively as it reports detail and deep thermal variations. Indeed this method can be useful to diagnose pain objectively.

Nowadays there is a considerable appreciation of thermal physiology and the connection between superficial hotness and blood perfusion. Furthermore, the advantages of computer-aided digital imaging and the examination modality has considerably enhanced the trustworthiness of this technique in medical fields. The advantage of this new possibility and its applicability to medical determination of peripheral perfusion and liveliness of cells are shown by studies in diabetology. Researches demonstrate that routine checking up on foot temperature could terminate the occurrence of impairment conditions including foot ulcers and lower limb amputations. Thermography is identified as one of the potential techniques for temperature checking up on the feet and it can be employed as an adjunctive method for modern foot examinations in diabetes and systematically discussed in Chapter "Assessment of Foot Complications in Diabetic Patients Using Thermography: A Review". Researches indicate that routine checking up on foot temperature may terminate the occurrence of impairment conditions including foot ulcers and lower limb amputations.

In more than 30 years of IR breast cancer investigation, 800 peer-reviewed researches including more than 300,000 women contributors have exhibited thermography's potential for diagnosing breast cancer in very early stages. Identifying relationships between neo-angiogenesis, chemical mediators, and the neoplastic developments are the aim of current studies to investigate thermal feature of breast anatomy. Chapter "An Overview of Medical Infrared Imaging in Breast Abnormalities Detection" presents an overview of medical infrared imaging in breast abnormalities detection.

Chapter "Registration of Contralateral Breasts Thermograms by Shape Contexts Technique" reports that comparison of breast temperature in the contralateral breast is very helpful in breast cancer detection diagnosis. Asymmetrical temperature thermal diffusion might be a sign of early irregularity. Practically, most of the real breast thermograms do not possess symmetric borders. Consequently, a suitable registration is required for comparing temperature distribution of two breasts by investigating in contrast the extracted features. In this chapter, the proposed registration algorithm includes two steps. First, shape context, the technique as introduced by Belongie et al was used to register two breast borders. Second, a mapping function of boundary points was obtained and applied for mapping two breast interior points. Results are very encouraging. Boundary registration was accomplished perfectly for 28 out of the 32 cases.

Although it is controversial that with pseudocolored gray images more data can be allowed to the observer, but precisely produced pseudocolor image indeed is capable of tumor identification that is equivalent to the grayscale and upgrades accomplishment of other jobs like perception and judgment of a tumor. In Chapter "Color Segmentation of Breast Thermograms: A Comparative Study", three techniques for breast thermograms color segmentation (K-means, mean shift (MS), and fuzzy c-means (FCM)) were used with 60 breast thermograms. The FCM technique allows the two first hottest areas for each subject where convenient features are obtainable. There are some conveniences of breast thermograms color segmentation by FCM such as: identification of irregular subjects by contrasting the analogous clusters from the contralateral breasts (over the symmetrical line); determination of level of malignity with identifying the two first hottest areas and extracting them some useful features.

The use of artificial sources for cooling the skin has revealed new functional information that complements steady-state thermography findings. This autonomic cold challenge has also been used to identify a tumor's blood vessels. Recent numerical methods have investigated the effectiveness of dynamic breast thermography and revealed new parameters that are strongly correlated with tumor's depth. Chapter "Potentialities of Dynamic Breast Thermography" reviews the state of the art in dynamic thermography as it is applied to breast diagnosis and identify some of the potential information that could be provided about breast diseases.

Chapter "In Vivo Thermography-Based Image for Early Detection of Breast Cancer Using Two-Tier Segmentation Algorithm and Artificial Neural Network" proposes a technical framework for automatic segmentation and classification of abnormality on multiple in vivo thermography based images. A new two-tier automatic segmentation algorithm is developed using a series of thermography screening conducted on both pathological and healthy Sprague-Dawley rats. Features extracted shows that the mean values for temperature standard deviation and pixel intensity of the abnormal thermal images are distinctively higher when compared to normal thermal images and for classification, Artificial Neural Network system was developed and has produced a validation accuracy performance of 92.5% for thermal image abnormality detection. A large data set from both healthy and cancer patients is required as future clinical study in both thermal visual and data temperature point formats to confirm the efficacy of this method.

Detection of elevation in local surface temperature due to an underlying pathology (hot spots) from conventional breast thermograms is quite challenging, mainly due to incomplete image acquisition. Chapter "Detection of Breast Abnormality Using Rotational Thermography" explores a framework in developing a breast cancer screening system using thermograms acquired with rotational thermography in multiple views to locate the position of the tumor in correlation with ultrasound and biopsy findings, its ability for localization of abnormality has also been discussed. Image features are extracted from rotational thermograms in spatial, bispectral, and multi-resolution domains. Optimal features are identified using Genetic algorithm and automatic classification is performed using Support Vector Machine. In addition to screening, attempt has been made to characterize a detected abnormality as benign or malignant.

Chapter "Application of Infrared Images to Diagnosis and Modeling of Breast" reveals several approaches that have been implemented related to the use of IR images to breast modeling and diseases diagnosis; the authors consider many aspects of the process of diagnostic tool implementation: capture thermal matrix of patient body, storage and retrieval of images from a database, segmentation, 3D reconstruction, feature extraction and classification. The experiments and implementations were done by the Visual Lab group of the Fluminense Federal University in Niteroi, Rio de Janeiro, Brazil. The results support the statement that IR analysis is able to detect breast anomalies and to include the thermography in clinical routines for breast diseases examination and screening. When considering the dynamic protocol versus the static one, tools for diagnosis implemented using the dynamic protocol data always achieve better results even when very simple approaches are used like only the temporal series of data.

Chapter "A Semi-Analytical Heterogeneous Model for Thermal Analysis of Cancerous Breasts" studies a semi-analytical method for breast thermography through coupled stationary bioheat transfer equations. The theoretical and numerical modeling results indicate that the data parameter will influence the thermal distribution of the tumorous breast. The work provides a helpful framework for studying the thermal profile of breast cancerous tissues. It facilitates the understanding of the complex behavior of its surface temperature. In brief, thermography together with mathematical and computational modeling bring an appropriate methodology in order to allow the assessment of rapidly growing neoplasm.

Chapter "Dynamic Angiothermography (DATG)" develops Dynamic Angiothermography (DATG) for the noninvasive diagnosis of breast cancer. DATG consists of a thin plate with liquid crystals that changes color due to a change in temperature, consequently offering an image of breast vasculature. DATG is based on the angiogenesis (bioheat) theory on tumor initiation, development, and growth. A tumor needs new vessels. Therefore, by studying the changes in the pattern of vascular blood supply, it is also possible to diagnose neoplasms very early. In particular, it is shown that every human being has his or her own vascular pattern which, in the absence of disease, does not vary throughout the life time. By repeating DATG periodically, an efficient control of the onset of disease is possible, even in its early stages. This is not new, however, still only little-known technique which is a component of the overall diagnostic techniques for the study and prevention of breast cancer that serves to offer a complete clinical picture of the patient. The great advantages of DATG are: it does not use radiation; it is not invasive or painful; it is low-cost and can be repeated periodically and successfully with no drawbacks. The angiothermographic examination therefore makes it possible to visualize the breast vascularity pattern without using contrast medium. On the other hand, while highlighting changes in mammary vascularization, DATG is not able to indicate the size or depth of the tumor; even if recent researches (based on the approximated solution of the inverse Fourier heat equation) show the possibility to evaluate the depth of the tumor. In brief, DATG is affordable from the economic standpoint as it can play a very important role especially for young women and for those applicants who need frequent checks (follow-ups).

Considering the substantial increase in diabetics cases worldwide, a dedicated effort for early detection of diabetes is essential. Various studies reveal that infrared thermography is capable of the early detection of diabetic peripheral neuropathy and vascular disorders. Chapter "Infrared Thermography for Detection of Diabetic

Neuropathy and Vascular Disorder" highlights the studies on diabetic neuropathy and vascular disorder using IR thermography technique. The basics of IR thermography, classification of medical thermography techniques, details of various IR cameras available, ideal experimental conditions, data analysis, etc., along with typical case studies on the subjects are discussed. To recommend IRT as routine techniques for diagnosis of diabetic neuropathy and vascular disorder, more systematic case studies in large number of subjects from various continents and correlating the IRT results with clinical findings are a prerequisite. Further, refinement in the experimental protocols, automation, rapid and reliable data analysis approaches are to be developed. For example, diabetes mellitus (DM), lower extremity diseases (LED) include both diabetic peripheral neuropathy (DPN) and peripheral vascular disease (PVD). Other than focusing on the effect of autonomic neuropathy on the microcirculation causing atrial–venous shunting one should also look at the fundamentals that PVD itself, i.e., macroangiopathy manifesting as atherosclerosis is a separate disease progression among people with DM.

Chapter "Exploratory Thermal Imaging Assessments of the Feet in Patients with Lower Limb Peripheral Arterial Disease" introduces pilot study to explore the potential use of thermal imaging in identifying Peripheral arterial disease (PAD). Absolute, gradient, spatial, and bilateral skin temperature differences of the feet have been quantified in PAD and non-PAD legs and have found no significant differences overall. The pilot study indicates that thermal imaging from resting measurements is unlikely to be of diagnostic value in detecting significant PAD. Furthermore, the study also raises questions about the apparent misconception that in PAD the foot temperatures are always significantly reduced. Thus, reliable fast, noninvasive devices (in contrast to the ankle brachial pressure index tool) for the detection of PAD are still required to aid the diagnosis of this underdiagnosed but significant cardiovascular disease.

The feet of healthy individuals can be very variable in absolute temperature on different days but thermal symmetry is generally maintained. Characteristic thermal patterns seem to be consistent so there may be some diagnostic value in a change in pattern or symmetry. Thermal asymmetry due to transient changes during the study period need to be ruled out with repeated images. Chapter "Reproducibility of Thermal Images: Some Healthy Examples" permits a baseline understanding of thermal symmetry in the feet of healthy participants which can be used when interpreting the images of the feet of patients with diabetes and neuropathy. It concludes that when looking for significant thermal asymmetry it is important to rule out transient changes by repeated imaging and to refer to baseline images.

Chapter "Thermal Imaging for Increasing the Diagnostic Accuracy in Fetal Hypoxia: Concept and Practice Suggestions" develops a method for diagnosing fetal cerebral hypoxia with a thermal imaging camera. The method is based on the following detected principle: hypoxia and ischemia reduce the intensity of thermal radiation from tissues. Monitoring the dynamics of temperature in the central suture allows doctor to evaluate the oxygen supply to fetal brain cortex during delivery. In this context, if the temperature drop areas are not observed in fetal head skin during his passing through the birth canals, it indicates the possibility of giving birth to a healthy child. In its turn, the occurrence of local hypothermia over the central suture of the skull indicates the hypoxic and ischemic damage to the fetal brain cortex and requires immediate hyperoxygenation of the fetus blood.

Chapter "Active Dynamic Thermography in Medical Diagnostics" shows importance of still new in medicine visualization modality called ADT—Active Dynamic Thermography. Assuming that classical thermal imaging (TI) is already broadly accepted, what in fact is only partly true as some clinicians still remember that this technology in breast cancer diagnostics failed in early stage of development, the ADT increases the role of thermal imaging in medicine. To register static TI and dynamic ADT images the same IR camera is applied. Both modalities are supplementing each other as TI shows metabolic functional thermal images and ADT allows reconstruction of structural thermal properties adding to functional also structural diagnostic data. Therefore analysis and comparison of temperature distribution and images of ADT descriptors provide better understanding of diagnostic content and support multimodality concept of advanced diagnostics in medicine.

Respiratory rate is very important vital sign that should be measured and documented in many medical situations. Chapter "Evaluation of Respiration Rate Using Thermal Imaging in Mobile Conditions" analyzes respiration rate estimators that can be used to processed sequences of thermal images captured from small thermal camera modules embedded or connected to smart glasses for respiration waveforms derived from the regions of the nostrils or mouth in thermal video sequences. After calibration of thermal camera modules and using the algorithms to estimate pulse rate from video (recorded in visible light), additional vital signs can be estimated. This could allow obtaining three the most important vital signs: body temperature, pulse rate, and respiration rate. Using the intelligent patient identification such data can be automatically stored in the Hospital Information System or other system for the management of Electronic Health Records or Personal Health Records.

Infrared thermography (IRT), one of the most valuable tools, is used for non-contact, noninvasive, and rapid monitoring of body temperature; it has been used for mass screening of febrile travelers at places such as airport quarantine stations for over 10 years after the 2003 severe acute respiratory syndrome (SARS) outbreak. The usefulness of IRT for mass screening has been evaluated in many recent studies; its sensitivity varies from 40% to 89.4% under various circumstances. Chapter "Applications of Infrared Thermography for Noncontact and Noninvasive Mass Screening of Febrile International Travelers at Airport Quarantine Stations" performs IRT evaluations in detecting febrile international travelers entering Japan at Nagoya Airport, immediately after the SARS epidemic, from June 2003 to February 2004, and at Naha International Airport from April 2005 to March 2009. The correlation of body surface temperature measured via IRT with the axillary temperature was significant. Febrile individuals were detected with good accuracy and the detection accuracy was improved by corroborating surveillance with self-reporting questionnaires. However, there are several limitations associated with the use of IRT for fever screening. To solve the unreliability and obtain higher accuracy in mass screening, the authors have developed a novel infection screening system using multi-sensor data, i.e., heart and respiration rates are determined by microwave radar in non-contact manner and facial skin temperature is monitored through IRT. The detection accuracy of the system improved, which is notably higher compared to the conventional screening method using only IRT. In future work, one of the most promising approaches is to connect multiple infection screening systems, which enables information sharing between different systems. This will allow application of big data analysis techniques, which can be used to predict outbreaks of infectious diseases much earlier than the existing methods.

It is clinically important to detect tear instability in Dry Eye (DE) as the treatment may involve specific measures such as chronic eyelid warming therapy. To achieve this, a practical and rapid method to analyze the relevant features from different regions of the ocular surface in DE will be useful. In Chapter "Evaluation of Evaporative Dry Eye Disease Using Thermal Images of Ocular Surface Regions with DWT and Gabor Transform", efficiency of using the upper half and lower half regions of the ocular surface (cornea + conjunctiva) in the detection of evaporative dry eye is assessed using IRT images where the significance of limited ocular surface regions for the identification of DE is suggested by extracting Gabor transform features from DWT coefficients. The study shows that the lower half of the eye is superior to the upper half for the purpose of DE detection. The proposed algorithm is efficient, simple and may be employed in polyclinics or hospitals for faster DE assessment time without analyzing the entire ocular surface.

Skin, the largest organ of the human body, is essentially a temperature *mosaic* determined by the rate of blood flow through arterioles and capillaries adjacent to the skin. IR imaging has the potential to provide a robust method of surface temperature mapping in disease states where pathology disturbs the 'normal' distribution of blood flow to skin. Hierarchical clustering-based segmentation (HCS) has been used in Chapter "Infrared Thermal Mapping, Analysis and Interpretation in Biomedicine" to aid the interpretation of wound images and to identify variations in temperature clusters around and along the surgical wound for their clinical relevance in wound infection at levels not discernible by human visual processing.

Among the known and routinely used tomography methods, there is the thermal tomography, which seems to be still unappreciated. Certainly, it has some constrains, especially due to the limited depth of the body penetration by the heat waves, but on the other hand, it can be recommended for daily screening of skin tissues pathologies, burns during healing and superficial tumors. For medical thermal tomography, one proposes the cold provocation applied to the skin tissue and the measurements of body temperature recovery by IRT. Then, by applying the inverse thermal modeling of the tissue, the internal structure can be reconstructed. Inverse thermal modeling, however, requires the forward thermal models and the optimization. Both of these elements can be implemented today in a software to perform the screening since IR cameras are cheaper and widely available today. It makes possible to establish a new medical protocol for IRT screening. Chapter "Medical Thermal Tomography—Different Approaches" describes the different original approaches in medical thermal tomography developed by the authors recently and the presented protocols can be easily and fast adapted to the practical use in the medical diagnosis.

Water transformation process operated by evaporation can be considered as one of the most important causes of thermal disequilibrium in both living and nonliving objects (i.e., porous materials). Vapotranspiration fluxes taking place on surfaces of many kind of materials has been proved to be quantitatively defined measuring surface temperature of the object being studied. This value, at the equilibrium conditions among all terms of heat exchange occurring through the surface, shows to be strongly dependent on the vapor flux rate. Correlations between temperature and evaporation rate have been confirmed in Chapter "Vapotranspiration in Biological System by Thermal Imaging" on different type of materials such as leaves, plaster, brick and human skin, proving the strong correlation between temperature and evaporation rate, both in a thin system such as leaf, porous building, materials and human skin.

Chapter "Change in Local Temperature of Venous Blood and Venous Vessel Walls as a Basis for Imaging Superficial Veins During Infrared Phlebography Using Temperature-Induced Tissue Contrasting" demonstrates a possibility of fast, safe, and efficient imaging of superficial veins with an IR imager in experiments with pigs, in studies with healthy adult volunteers, and in clinical observations of adult patients when providing vital medical care in emergency situations. This chapter describes the original techniques for infrared veins imaging enabling the authors to lay the basis for infrared venography. In order to image superficial veins, it is recommended that infrared monitoring of local temperature dynamics in the selected part of the body surface under the conditions of artificial multidirectional changes in temperature of veins and/or surrounding tissues. The chapter also shows advantages of infrared phlebography over other radiology methods to address urgent and repeated imaging of superficial veins in critical situations to optimize intravascular access for sampling venous blood, its subsequent laboratory testing and intravenous injections of medications.

Anastomotic failure is the most serious complication following colorectal resection that can lead to reoperation, permanent stoma, and even death. The current practice of assessing blood perfusion at the anastomosis bowel ends by direct inspection of bowel pulsatility, bleeding, and tissue coloration has been demonstrated to lack predictive accuracy. In Chapter "Intraoperative Thermal and Laser Speckle Contrast Imaging Assessment of Bowel Perfusion in Two Cases of Colorectal Resection Surgery," two case studies which show the feasibility of performing thermal and laser speckle contrast imaging measurements intraoperatively for assessing bowel perfusion during colorectal resection surgery are reported. This experience could pave the way to a number of other applications for these technologies in the surgical arena.

Chapter "An Approach for Thyroid Nodule Analysis Using Thermographic Images" presents a small scale preliminary study conducted in order to evaluate the feasibility in time, cost, and effect of the use of an IR camera as a tool in detections of thyroid nodules in the ambulatory service of our university hospital. The authors perform an overall analysis of thermographic images, focusing on thyroid thermographic acquisition, processing and analysis, which is a new field of study. An autonomous region of interest (ROI) identification for the thyroid images is proposed, which is based on very simple fundamentals of computer vision. Future works will involve improving the described methodologies and analyzing the reported evidences in regard to a large scale of data.

Chapter "Modeling Thermal Infrared Imaging Data for Differential Diagnosis" introduces the two commonly used approaches for modeling thermal infrared data for differential diagnosis purposes: (i) Qualitative modeling approach based on using statistical and machine learning techniques, (ii) Quantitative modeling approach based on performing mathematical/analytical modeling of the thermoregulatory processes with three main techniques: (a) empirically using automatic control theory, (b) nonempirically using bioheat equations and (c) semi-empirically using both bioheat equations and automatic control theory. The authors summarize the advantages and disadvantages of each modeling approach. Such summarized information could serve as a guide for the IR researcher in selecting the appropriate modeling approach regarding his/her research scope and interest. However, it should be point out that it is important to take care when considering the assumptions and approximations in order to choose the suitable modeling method. Hence implementing such modeling approaches highly increase the potential ability of IR imaging to be a fascinating and promising complementary imaging tool to the gold standard medical imaging methods for differential diagnosis.

Three-dimensional thermography systems that combine 3D geometric data and 2D thermography data enable users to have a more accurate representation of the surface temperature distribution and aid in its interpretation. A system for 3D dynamic infrared thermography comprising two units is presented in Chapter "3D Dynamic Thermography System for Biomedical Applications"; each unit consists of an off-the-shelf depth camera rigidly mounted to an IR camera. The units are fixed on the arms of the device that allow their placement in desired positions near the subject. The developed 3D system provides a number of advantages in research for biomedical applications, such as the correct temperature measurements on curved surfaces, the possibility to select regions of interest by taking into account the shape of the subject and the possibility to use the 3D data to easily eliminate the background from 2D thermograms. As a future work, due to hardware limitations with the fact that a mannequin that used in the test is static, one should use a different 3D scanning technique and registration methods to improve this accuracy for implementing algorithm in living human beings, particularly when selecting ROIs of smaller parts of the body, such as the breast or the feet.

In summary, IRT is identified as one of the leading technologies in use today. It has potential for temperature monitoring of the skin and it can be used as an adjunctive method to current practices for surface temperature examinations in diabetes. Many esteemed authors have contributed generously and made this book possible by their diligent hard work and valuable time. We thank them wholeheartedly for their significant contributions. The book represents the latest infrared technologies and helps the potential readers to better appreciate their relevant mechanism and physics of the application and case studies are explored and investigated from different aspects with illustration in detail particularly from computer aided diagnosis with classifiers.

In this book, we have made an honest effort to present information and applied methodologies of Infrared technologies to help researchers, doctors, teachers, and students particularly in biomedical science and engineering.

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