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An infrared image based methodology for breast lesions screening

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HIGHLIGHTS

- We introduce a structured procedure for breast lesions screening.
- Infrared imaging temperature measurements are utilized.
- A normalized conjugate gradients methodology is tested.
- 101 individuals in control group and 47 breast cancer patients.
- 96% of the cases were detected.

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ABSTRACT

The objective of this paper is to evaluate the potential of utilizing a structured methodology for breast lesions screening, based on infrared imaging temperature measurements of a healthy control group to establish expected normality ranges, and of breast cancer patients, previously diagnosed through biopsies of the affected regions. An analysis of the systematic error of the infrared camera skin temperature measurements was conducted in several different regions of the body, by direct comparison to high precision thermistor temperature measurements, showing that infrared camera temperatures are consistently around 2 °C above the thermistor temperatures. Therefore, a method of conjugated gradients is proposed to eliminate the infrared camera direct temperature measurement imprecision, by calculating the temperature difference between two points to cancel out the error. The method takes into account the human body approximate bilateral symmetry, and compares measured dimensionless temperature difference values ($\Delta\bar{\theta}$) between two symmetric regions of the patient's breast, that takes into account the breast region, the surrounding ambient and the individual core temperatures, and doing so, the results interpretation for different individuals become simple and non subjective. The range of normal whole breast average dimensionless temperature differences for 101 healthy individuals was determined, and admitting that the breasts temperatures exhibit a unimodal normal distribution, the healthy normal range for each region was considered to be the dimensionless temperature difference plus/minus twice the standard deviation of the measurements, $\overline{\Delta\bar{\theta}} + 2\sigma_{\overline{\Delta\bar{\theta}}}$, in order to represent 95% of the population. Forty-seven patients with previously diagnosed breast cancer through biopsies were examined with the method, which was capable of detecting breast abnormalities in 45 cases (96%). Therefore, the conjugated gradients method was considered effective in breast lesions screening through infrared imaging in order to recommend a biopsy, even with the use of a low optical resolution camera (160 × 120 pixels) and a thermal resolution of 0.1 °C, whose results were compared to the results of a higher resolution camera (320 × 240 pixels). The main conclusion is that the results demonstrate that the method has potential for utilization as a noninvasive screening exam for individuals with breast complaints, indicating whether the patient should be submitted to a biopsy or not.

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Nomenclature

A_{Ω}	area of the affected region (m^2)
B_a	bias limit of quantity a
BI-RADS	Breast Imaging-Reporting and Data System
CASA III	UFPR Health Care Center
CEP	Brazilian Human Research Committee
CI	confidence interval
CT	computerized tomography
HC	Hospital of Clinics at UFPR
INCA	Brazilian National Cancer Institute
MLO	oblique midlateral position
MRI	magnetic resonance imaging
n	number of individuals in the sample
N_p	patient number
NPDEAS	Center for Sustainable Energy Research and Development
p	probability in a Student distribution
P_a	precision limit of quantity a
PET	positron emission tomography
R	resistance (Ω)
SPECT	photon emission computerized tomography
SQP	sequential quadratic programming
t	Student distribution test
T	temperature (°C)
U_a	uncertainty of quantity a
x, y	cartesian coordinates (m)
$\bar{x}$	sample mean
z	desired number of standard deviations

Greek symbols

α	body region
ΔT	temperature difference (°C)
$\Delta\bar{\theta}$	average dimensionless temperature difference of a skin region
$\overline{\Delta\bar{\theta}}$	the mean of all $\Delta\bar{\theta}$ in group ii (control)
ε	calculated error
θ	dimensionless temperature difference on a point
λ	normality range
μ	population mean
σ_a	standard deviation of quantity a
Ω	affected region domain, Fig. 1

Subscripts

b	body
c	infrared camera
FLIR	infrared camera FLIR E60
max	maximum value of a region in one individual
min	minimum value of a region in one individual
SAT	infrared camera SAT-S160
t	high precision thermistor
∞	ambient

Superscript

–	average value

1. Introduction

Most breast tumors are invasive, i.e., they could infiltrate in other tissues. They start in the breast lobules or ducts, but as the duct breaks, the breast surrounding tissues are invaded. The invasive breast cancer malignancy is strongly influenced by the sickness stage, i.e., the cancer extension or dissemination when it is diagnosed for the first time, thus early stage diagnosis becomes vital for a good prognosis [1].

The incidence of breast cancer new cases in the United States was 145.6/100,000 individuals, while in Brazil was 66.8/100,000 individuals in 2012. In the same year, the breast cancer mortality rate in the United States was 27.5/100,000 and 16.3/100,000 in Brazil, respectively [2]. The current breast cancer mortality rates remain high, most likely because the disease is still diagnosed in advanced stages. The Brazilian National Cancer Institute (INCA), and the Brazilian Ministry of Health estimated that 576,000 new cases of cancer would occur in 2014, from which breast cancer comprised 57,000 new cases, the most common among women of different listed types of cancer [3].

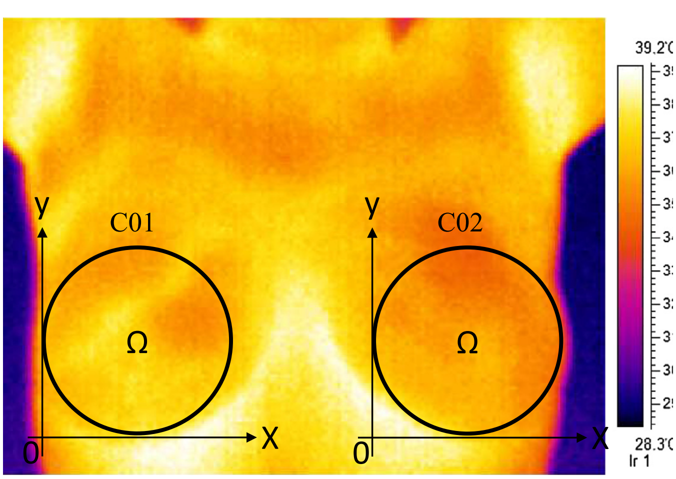

Fig. 1. Regions of interest.

Based on such facts, there is a need for the development of non-invasive methods to improve early diagnosis and screening of suspicious breast lesions [4–6]. One possible direction is the use of infrared imaging.

The human body skin temperature is a good health indicator although the temperature differences between a healthy and a sick individual are only marginal [7]. In the case of cancer, the cells are bigger than the normal cells, thus the cells need more energy, causing an increase in local irrigation and in skin temperature, i.e., there are more blood vessels to provide the necessary extra energy for them, that could be detected by the infrared camera [8,9]. Also, the ambient temperature, the individual metabolism and calibration parameters of the infrared camera are factors that affect the infrared imaging results [10].

Several non invasive diagnosis strategies for breast related diseases have been proposed in recent years, but no infrared imaging technique has achieved the status of possibly conducting patient screening before recommending a biopsy. Commonly used imaging modalities include mammography, ultrasonography, magnetic resonance imaging (MRI), scintimammography, single photon emission computerized tomography (SPECT) and positron emission tomography (PET) [11].

The mammography is considered the main breast cancer diagnosis method at the initial stage, capable of detecting small growths still non perceptible to the hand touch, and therefore favoring early treatment, effective, and non aggressive, with good aesthetic results, and few adverse events. The exam reveals small