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An Infrared Thermal Images Database and a New Technique for Thyroid Nodules Analysis

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Abstract

Thyroid nodules diseases are a common health problem and thyroidal cancer is becoming increasingly prevalent. They appear in the neck and bottom neck region, superficially over the trachea. Cancer tissues are characterized by higher temperatures than surrounding tissues. Thermography is a diagnostic tool increasingly used to detect cancer and abnormalities. Artificial intelligence is an approach which can be applied to thyroid nodules classification, but is necessary to have a proper number of cases with proven diagnosis. In this paper, a new database that contain infrared thermal images, clinical and physiological data is presented. The description of each nodule per patient, and the acquisition protocol (based on Dynamic Infrared Thermography approach) is considered as well. A semi-automatic method for image registration was implemented to pre-process the thermograms and a new method for the Region of Interest (ROI) extraction is proposed. Moreover, the obtained ROI results are confirmed by medical specialists and turned available for future comparison with other works.

Keywords:

Thyroid Nodule; Infrared Rays, Diagnosis; Thermography

Introduction

The thyroid is an endocrine gland located at the human neck, next to the thyroid cartilage and over the trachea. Thyroid nodules are a common clinical problem and differentiated thyroid cancer is becoming increasingly prevalent. Epidemiologic studies have shown the prevalence of palpable thyroid nodules to be approximately 5% in women and 1% in men living in iodine-sufficient parts of the world. In contrast, high-resolution ultrasound (US) can detect thyroid nodules in 19%–68% of randomly selected individuals, with higher frequencies in women and the elderly [1]. The clinical importance of thyroidal nodules investigation is for exclusion of thyroid cancer, which is prevalent in 7 to 15% of cases, depending of factors as age, sex, exposition to radiation, and familiar history [2].

The temperature distribution on the human skin can be measured by using infrared cameras and stored in a thermal image. These images represent a temperature pattern of the body, which is highly symmetric around the vertical axis of the sagital plane. Variations of this symmetry in a serial imaging can constitute a sign of abnormality. Thermal imaging is an inexpensive and non-invasive technology that has been applied in many fields, including sport medicine, forensic medicine, anesthesiology, peripheral vascular diseases, and cancer and breast diseases diagnosis [3]. Heat pattern measurement by thermography, is fast, non-contact and non-invasive [4].

A malignant tumor is related to abnormal growth of cells, invading tissues and spreading to other regions of the body. These tumors need nutrientes to grow and lead to the development of new blood vessels around them (angiogenesis) [5;6]. Due to increased blood flow, tumors frequently present higher temperature than the surrounding region, which can be acquired by thermography and used to aid in the diagnosis of malignant thyroids tumors [7]. In addition, toxic autonomous nodules tend to be large (>2.5 cm) and this may be increase the possibility of detection [10].

Thermography detects physiologic or functional changes on the surface of the skin and the Pennes´s equation [8] or artificial intelligent methods can be used for detect the possible internal cause of such thermal pattern. Thermograms are sensitive to environmental changes in temperature, humidity and air circulation. Moreover, they should follow the same acquisition protocol to standardize the process and minimize the intra and inter patient thermograms variations. Additionally, the thermograms must be preprocessed in a proper way to minimize possible errors. Discriminated features need be extracted for neck region (Regions of Interest, ROI) and used as input in algorithms for pattern recognition. This work proposes a protocol for infrared image acquisition; a database for thyroid study with infrared images and clinical data and a method for ROI autonomous identification and image registration of thyroid region.

Background

The thyroid nodule diagnosis using thermography has been studied in few works in the literature. A numerical analysis of the area by Finite Element Method is proposed by Helmy et al. [3, 9]. The authors also compare numerical simulation with a thermal image of the thyroid gland for the same patients [10].

Gavriloaia et al. [11;12] explain details of a system for infrared image acquisition to study thyroid nodules and analyze them by Penne`s equation. However, few infrared images are explored to find infrared signatures that can be used as descriptors of the thyroid tumors [11]. They use the ABCDE investigation method (based on Asymmetry, Border, Color, Diameter and Evolution of the contour) and affirm that their method can correctly identify 89.3% of the investigated patients with thyroid cancer. Moreover, they apply fractal analysis to quantify the irregularity in size and shape of thermal signatures of tumors and use self-similarity and laccunarity features [13]. Same authors purpose an improved method for IR image filtering [14] as well. This study is aimed at developing a numerical scheme which significantly reduces the computer time for thermal image denoising with edge preservation. This filter allows physicians to assess faster than using other anisotropic diffusion filters, the contour shape, to locate the outbreaks in ROIs. Other filtering types are used for improve the thermals images and for Empirical Mode Decomposition [15].

The results of thermography of thyroid dysfunctions are presented as an alternative clinical diagnostic technique considering 37 patients of Lagos University Hospital (Nigeria) with confirmed thyroid diseases and 16 volunteers as control [16]. Cytological methods were used for confirming the thyroid disease while the images of skin temperature maps were obtained using the FLIR Infrared Camera operated in self automatic calibrated mode. Thermograms were compared with ultrasound exams. The mean temperature ± standard deviation of 36.63 ± 0.56 °C was obtained for hyperthyroid, 34.93 ± 0.32 °C for hypothyroid, 35.76 ± 0.49 °C for control groups respectively. The variations in the mean skin temperatures of malignant are 37.63 ± 0.29 °C and of benign 36.21 ± 0.73 °C nodes. The results show that thermography could be relevant and if used in combination with other imaging modality, could play a vital role in the diagnosis of thyroid diseases. This study also confirmed that females are more susceptible to thyroid diseases than males and that hyperthyroidism is more frequent than hypothyroidism.

In [17], an automatic methodology to classify some thyroid disorders as hypothyroid or hyperthyroid is proposed. First the infrared images of neck of thyroid patients are taken by using a thermal camera, then a median filter is used, and the images are enhanced by equalization. Segmentation of the images and ROI extraction are done by using modified Otsu Technique. Texture features were extracted by using Gabor´s filters and wavelet. Contrast, Homogeneity, Entropy and Energy features from the gray level co-occurrence matrix are used as well. Classification is done by a Multilayer Perceptron Network (MLPN).

Other system to detect the thyroid gland disease using thermograph is proposed [18;19], where the patients' neck are captured by using a FLIR-E30 camera. These images were filtered by using median filter, and enhanced by histogram equalization. The segmentation of the images is done using Otsu's Technique, features are then extracted from region of interest: mean, variance of the low-low-frequency sub-band using the Haar Wavelet transform, Coefficient of Local Variation, difference between the number of pixels in a block and the ratio of the sum of pixel intensities in the block to the maximum in the block, Normalized Multi-Scale Intensity Difference (defined as the differences between the pixel pairs with horizontal, vertical, diagonal, and asymmetric-diagonal directions) , and the area occupied by the region of interest. Finally, the thyroid images are classified as hypothyroid, hyperthyroid or normal using a Bayesian Classifier [19].

Methods

Recent applications of thermography in medicine showed the effectiveness of Dynamic Infrared Thermography (DIT) in medical research. The DIT is a method for monitoring the dynamic response of the skin temperature after thermal stress in a period of time [20].

DIT Protocol for thyroids thermograms

We recommended that at least thirty minutes before the examination, the patient should avoid: alcohol, caffeine, physical exercise, nicotine, and should not apply any cream, oil or chemical substance to the neck region. Initially, the patient was asked to sit still in order to minimize the possible displacements; the distance from the camera to the patient was 0.5 to 0.6 meters. The relative humidity of air and room temperature were recorded and inserted as parameters in the camera. Room temperature was maintained between 22 ºC and 25 ºC, no doors and windows openings and with only fluorescent bulbs. Patients were requested to remove earrings, necklaces or any other accessory that can be seen in the thermal image and use a hair band. Body temperature was checked using a thermometer. Patients were seen in the room twenty minutes before starting the examination and were seated with their head tilted slightly back and looking up while capturing images. An air flow (electric fan) was directed to the patient, when the mean temperature of the skin decreases to 29 ºC, and this ventilation was stopped and the sequential acquisition was started. The cooling of the neck region improved the thermal contrast between healthy and unhealthy tissues. One image was captured every 15 seconds over five minutes, producing one sequence of twenty images.

Database

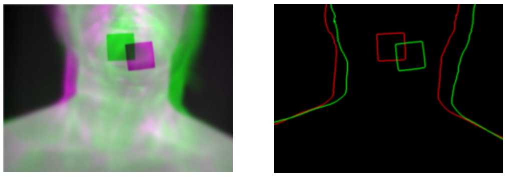
The database presents data and images from volunteers and patients of Federal Fluminense University Hospital (named Antonio Pedro University Hospital – HUAP - www.**uff**.br/**huap**/) in Niteroi, Rio de Janeiro, Brazil. In this work, we use data from 25 volunteers (twenty with benign thyroid nodules, and 5 healthy as control group). The average age was 54 and female was the predominant gender. A FLIR thermal camera model SC620 was used to capture the thermograms. The sensitivity of the camera was smaller than 0.04^{0}C and images had a dimension of 640x480 pixels. The image acquisition and their use for research was approved by the Ethical Committee of the HUAP and registered at the Brazilian Ministry of Health under number CAAE: 57078516.8.0000.5243. The database is accessible at http://visual.ic.uff.br/thyroid/.

Processing methods for patients classification

The proposed methodology for this is divided into four stages. First, the thermograms are registered to minimize the thermograms acquisition errors. Then, a neck and sub-neck region where thyroid nodules are located is segmented (the region of interest is segmented). Globals and locals features from ROI of each image are extracted to create few time series by patient. In the last stage, decision is performed by pattern classification of time series.

Image Registration

The protocol for image capture was designed to standarizate the process and minimize the errors that can ocurr during the thermograms captching process, but movements of patients can occur, causing misalignments between the images (Figure 1), and error in further processing.



a) b)

Figure 1 - Movements of a patient during the thermograms acquisition.

Two general types of movements can be identified: i) full-body modification, that include lateral movements to the left or right, to the top or bottom, or combinations of both; and ii) local modifications, that include movements related to perspective and distortion, such as tilts of the head to the back or front.

We use rigid transformation (translation and rotation) to correct the full-body modification. The first image is considered as reference or source, and each one of others as destination. At least two correspondent points are required to determinate the rigid transformation T (Equation 1) that maps the coordinates of the pixels $\mathrm{x} = (\mathrm{x}_1, \mathrm{x}_2, 1)$ of source image into a new coordinates $x' = (x_1', x_2', 1)$ of sensible image, where $x' = T \cdot x$.

$$T = \begin{bmatrix} cos\theta & -sin\theta & t_x \\ sin\theta & cos\theta & t_y \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The correspondence of points can be determined by algorithms or manually. In this work, the correspondence points are selected manually.

ROI extraction

After the registration process we extract the region of interest to focus the analysis in the neck region (thyroids). The ROI of the reference image (the first) is extracted using the algorithm proposed in this section. ROI is then identified for each of the other registered images.

The automatic algorithm proposed to ROI extraction is based on locating the neck region and the bottom neck area. The neck region is assumed be in the narrowest part of the patient body. In the algorithm, the left upper corner of image is considered the origin of coordinates and it is composed by six stages, as follow:

Algorithm

1. The image is transformed to black and white using the Otsu method [21].
2. Background points are removed. Pixels belonging to patient area are replaced by the temperature of the original image.
3. Determine the left L and right R edges of patient using left-to-right and right-to-left scanning and gray level information of pixels in the black and white image.

   The laterals limits of neck region are formed by the pixels $x \in L$ and $x' \in R$, with $x = (x_1, x_2)$ and $x' = (x_1', x_2')$ such that:

   $$(ANW - 0.1ANW) \leq abs(x_1 - x_1') \leq (ANW + 0.1ANW) \quad (2)$$

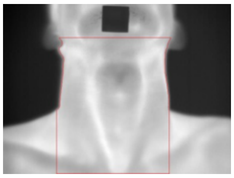
   and $x_2 = x_2'$.

   The ANW values is the neck average width of patient in the image, and is calculated from the N=80 minimal differences between all pixels $x \in L$ and $x' \in R$, with $x_2 = x_2'$:

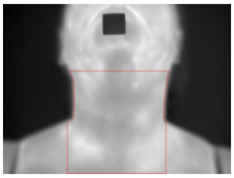
   $$ANW = \frac{1}{N}\sum abs(x_1 - x_1') \quad (3)$$

4. The upper limit of ROI is formed by de pixel row that link the start of left neck edge with the right neck edge.
5. The left (right) limit of bottom neck area is formed by the pixels in the same image column that the last one pixel in the left (right) neck boundary determinates in steep 5. The bottom limit of the bottom neck area is formed by the pixels in the last row of the image and into the left and right limits of bottom neck area.

In Figure 2 are shown in red line the ROIs result from two different patients.



a)



b)

Figure 2 - Automatic ROI segmentation.

Features extraction

Thermograms can be processed as time series of temperatures if errors during the acquisition process are minimized. A thermo gram is a two-dimensional map of temperature, and can be seen as a gray level image if scaled correctly. Moreover, methods of image analysis are applied to process the thermograms and descriptor features extraction, and artificial intelligence methods for classification. Features from ROI are necessary for the artificial intelligence methods of nodules diagnosis. These features must differentiate anomalous and normal patterns on unhealthy and healthy areas. Thermals patterns in the healthy human body are highly symmetric regarding the vertical axis of the sagital plane. To this end, the coefficient of asymmetric level is determined from all pixels of the ROI as bellow:

$$Assim(I) = \frac{1}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{\frac{n}{2}}\frac{min_{p,q=-1:1}|I(i,j)-I(i+p,n-j+q)|}{255} + \sum_{i=1}^{m}\sum_{j=\frac{n}{2}+1}^{n}\frac{min_{p,q=-1:1}|I(i,j)-I(i+p,n-j+q)|}{255}\right) \quad (4)$$

where m and n are the number of row and column of the ROI, and $I(i,j)$ is the gray level intensity value of pixel in the position i,j in the image. This feature is based on the similarity of gray level intensity value of each pixel in one vertical half of ROI and its most similar in the respective 3x3 window in the other vertical half.

It was observed that areas with nodules are characterized by high and constant temperatures in the recuperation phase to the thermal stress applied on the patient. On the other hand, temperatures in healthy areas were gradually increasing. Based on this statement, three features were selected from the ROI of each thermograms of the patient, as below: after binary thresholding of ROI using an empirical threshold T the hotter areas of the ROI were identified. These features are: Normalized Mean Intensity, Standard Deviation of Intensities and Normalized Maximum Intensity. Such features are considered as a time series of size 20. Then, each patient was represented as a pattern formed by four time series.

Classification

We employed the k-Nearest Neighbors (k-NN) [22] algorithm to perform a classification using the time series form extracted features. The quantity of neighbors k used was k=1. The Euclidean distance among time series was used to determine the similarity between the thermograms of two patients. The classification of a patient is performed to identify the most similar object, i.e. the patient described by the closest time series.

Results

A database was created for thyroid nodules research. This contains 25 cases with proven diagnosis. All cases were collected under the proposed protocol.

The pre-processing step of thermograms is very important to avoid further errors. In this case, an algorithm based on rigid transformation to images registration is implemented and evaluated. Ninety-one percent (91%) of images were correctly registered, but it is important to consider evaluate non-rigid methods as well, because the method can fail in images with locals deformations.

A new method for neck and sub-neck ROI image segmentation was developed. All images and used data can be found in http://visual.ic.uff.br/thyroid/. These results are confirmed by physicians. ROI were extracted correctly in the majority of used images.

Conclusions

This work performs an overall analysis of thermography images, focusing on thyroid infrared image acquisition, processing and analysis, with is a new field of study. We analyze data critically in order to extract relevant information that can help in artificial intelligence conclusion related to cancer diagnosis by using such images.

A new database was created and published for researches on thyroid nodules diagnosis. We proposed an autonomous ROI identification method, which is based on very simple fundamentals of computers vision.

As continuation of this work we will consider: (1) developing a automatic algorithm for selecting reference points (based on anatomical identification of the patients´ neck to been used as correspondent points in image transformations in the registration process); (2) analyzing non-rigid methods for the image registration process; (3) include others features to be used in the classification and (4) promoting a classification step by using data mining algorithm.

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