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Anisotropic diffusion filter based edge enhancement for segmentation of breast thermogram using level sets

S.S. Suganthi*, S. Ramakrishnan

Non Invasive Imaging and Diagnostics Laboratory, Biomedical Engineering Group, Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India

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ABSTRACT

Low signal to noise ratio and low contrast are the major limitations for segmentation, image analysis and interpretation of medical thermal images. In this work, an attempt has been made to improve and preserve the inter-regions edges by effectively removing the noise without blurring and hence, to extract the breast tissues from infrared images using level sets based on improved edge information. Gaussian filter is a linear, homogenous diffusion process that performs smoothing operation at each location that blurs the edge information resulting in difficulty of detection and localization of edges. To avoid smoothing across boundaries, an anisotropic diffusion based smoothing filter is used. This enables smoothing within the region by preserving sharp region boundaries. The performance improvement of the diffusion filter is verified and validated by extracting the breast tissues. The segmentation of regions of interests (ROIs) is performed by evolving the initial level set function based on this improved edge information. The extracted ROIs are compared with the corresponding four sets of ground truth images. The results show a good agreement of the segmented ROIs with ground truths. Further, the performance of the segmentation method is analyzed across inter person variations by calculating quantitative measures based on overlap and the statistics of regional similarities. It is observed that the segmentation method could able delineate the accurate regions of interest irrespective to the limitations of thermal images such as lack of clear edges. Average accuracy of 98% of regional similarity is obtained between segmented ROIs and ground truth images. Therefore, the enhanced edge detail seems to be useful to improve the performance of segmentation algorithm which could be used during breast cancer screening for early detection of tumor.

1. Introduction

Breast cancer is the most commonly diagnosed female cancer and it ranks second among other cancer types. It is predicted that number of diagnosed new cases will rise to 2.1 million by 2030 [1]. The survival rate among the diagnosed breast cancers is very less due to later stage diagnosis of the disease and lack of proper screening methods. The limitations of the current screening tool such as mammography are painful, exposure to radiation for longer duration, uncomfortable imaging procedures and high cost. The sensitivity of mammography mainly depends on physical presence of tumor and is very less for younger women with dense breast tissues [2]. Therefore, infrared imaging being a non-invasive, non-radiating, painless, low cost modality is widely used as an adjunct screening tool due to its high sensitivity and specificity [3].

The visual quality of the infrared (IR) images is often suffered by noise due to IR sensors used for acquisition and readout circuits of IR camera. It is further degraded by the ambient and atmospheric conditions [4]. To assist the physicians for proper diagnosis and interpretation, it is necessary to reduce the noise by preserving the important features such as edges that aids for segmentation and image analysis. Recently, partial differential equations (PDEs) based image processing have proved to be successful technique due to its several advantages. It is a best-founded mathematical technique performed in continuous space for shape simplification, structure preserving filtering and enhancement. PDE based smoothing technique considers the image as a diffusion process and extracts the filtered image by temporal evolution [5].

The most basic diffusion filters that are linear, homogenous diffusion processes have been proposed in the literature such as median filter, hybrid median filter, and Gaussian filter. At each location, the filter performs the same smoothing operation and hence, the important edges were blurred [5,6]. Several probabilistic based edge-preserving methods have also been proposed to estimate the denoised image from Gaussian corrupted images such as

* Corresponding author. Tel.: +91 44 22575065.
E-mail addresses: suganthiss@gmail.com, sramki@iitm.ac.in (S.S. Suganthi).

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the Bayesian estimate, maximum likelihood and maximum a posteriori estimators. These methods require the accurate knowledge of proper prior distribution of the noise free image [6–8].

Anisotropic filtering is a non-linear diffusion process that was first introduced by Perona and Malik for edge detection and scale space representation of images. It has been widely used for edge detection, image smoothing, image enhancement, image segmentation and restoration, defect detection and texture segmentation [5,6]. Smoothing operation was performed considering local gradient information so that the intra-regions in the image were smoothed and inter-region edges were preserved. The local gray-level variance and the gradient information were considered to preserve both edges and fine details and to filter out noise in the diffusion model proposed by Chao et al. [6]. Bilateral filtering and adaptive smoothing methods were pointed out to be the special cases of anisotropic diffusion [6].

The inherent limitations of the thermal images are low contrast, low signal to noise ratio [9], absence of clear edges and no definite shape. Therefore, accurate segmentation of breast tissue still remains as a difficult task [10]. High complexity is involved in extraction of the symmetrically separated breasts, lower breast boundaries and inframammary folds [11]. A recent survey has been carried out on image processing methods performed on breast thermography by Borchatt et al. [10]. It has been reported that the lateral and lower breast boundaries were detected using Hough transform and different edge detection techniques. They have reported that 96% of the computational time was due to execution of Hough transform. Gradient flow vector snake and conventional snake methods were failed in the detection of surface boundaries of thermal images [12].

Recently, a segmentation method using topological derivative has been reported by Machado et al. [11]. It was performed using average filter for smoothing, shape function to quantify ROI and quadratic uniform B splines to approximate the boundaries of breast tissues. In the method proposed by Marques [13], Otsu method and Laplacian filters were used for lateral and upper segmentation, thresholding, region growing and clustering techniques were used to detect the lower breast boundaries and uniform quadratic basis splines was used to smooth the initial set points. Motta et al. [14] proposed a segmentation method with several steps involved. First is to detect the infra mammary fold detection by automatic thresholding based on highest temperatures and morphological operations were performed to set the lower limit of the breast region. Second, Otsu threshold is applied for background segmentation. Using the results from second step, they found the upper limits of breast region. Arms and external objects were removed and finally, they searched for largest horizontal distance to fix the central axis as the half of the width of that distance aiming for symmetrical separation of both breasts. As this procedure does not succeeded for all images, they modeled the infra mammary folds using cubic splines interpolation technique. The results verification has been done visually. The drawback of this method is that the upper limit detection excluded the axillar region and regions of lymphatic nodes where both the regions may present cancer.

The segmentation reported in the work of EtehadTavakol et al. [15] incorporated with Canny edge detection, inner edge elimination, extraction of outer boundaries and extraction of two lower boundaries using landmark points whose locations were learned during training phase. The same author had compared K-means and fuzzy C means for color segmentation of infrared breast images and reported that the performance of fuzzy C means was comparatively good due to fuzzy nature of thermal images [16,17].

The method proposed by Ng et al. [12] had various steps such as image gradient, transition and gradient vector flow snake algorithm to improve the performance of the segmentation of breast tissues. Zhou et al. [9] performed blood vessel extraction from thermal images using level set method that used gradient magnitude and direction as edge information. Three or four randomly selected points within region of interest were used as initial points. A variational level set method was introduced by Li et al. [18] for geometric active contours that force the level set function toward the boundary by maintaining signed distance property and hence, the costly re-initialization procedure was completely eliminated. Later, distance regularized level set method [19] has been proposed in which periodic re-initialization was avoided and added with an external energy term to drive the LSF toward the desired location. In level set methods, the edge information was obtained as the gradient magnitude of Gaussian smoothed image and was used to evolve the level set function. Level sets are capable of capturing complex structures by using the proper edge indicator. Also they are potential enough to segment the breast tissues from the filtered and enhanced edges near lower breast boundaries and infra mammary folds.

Complex pre segmentation steps remain a problem due to the more intricate intensity field of breast thermograms. In this study, the main contribution is segmentation of breast tissues using an approach that integrates non-linear isotropic diffusion filter and level set method particularly from breast thermograms. This approach is to address the limitations of thermal images such as low contrast, low signal-to-noise ratio, and absence of clear edges. Hence, a unified framework of smoothing, edge enhancement and segmentation of breast tissue from infrared images is carried out. Anisotropic diffusion filter is used as a pre-processing tool for smoothing and enhancing the edge information. This is used as an edge map to evolve the initial contour using level set function without re-initialization. The segmented image is verified and validated against ground truth images using similarity and overlap measures.

2. Methodology

The breast thermograms are obtained from the online project database (http://visual.ic.uff.br/proeng/) [20] for this study. These images were captured using FLIR ThermaCam S45 Camera and was approved by Ethical committee of Federal University of Pernambuco. Thermograms were recorded at University Hospital and registered at Brazilian Ministry of health. This database images were taken from patients and volunteers older than 35 years. These images were corrected for relative humidity and temperature of the room and were acquired after requesting them to wait for 10 min in order to stabilize their metabolism. The corresponding ground truth images of extracted breast tissues that were manually segmented by radiologists and specially trained personnel's were also provided in the database [14]. 35 images are randomly selected for this work. The images are smoothed using anisotropic diffusion filter [21]. The gradient edge map is computed from the smoothed image. The initial seed points are given manually around the desired ROI. This initial contour is evolved using level set function based on this edge information to extract the ROI. For this the level set method without re-initialization proposed by Li et al. [18] is adopted.

2.1. Non-linear isotropic diffusion filter

In variational level set formulation using active contours without re-initialization proposed by Li et al. [18], the edge indicator function is obtained by taking inverse of gradient magnitude of Gaussian smoothed input image I. This linear homogenous diffusion filter blurs the image edges as the smoothing is performed in each location [22]. Therefore, to avoid smoothing across boundaries, a non-linear isotropic diffusion filter is adopted which performs