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Automated breast-region segmentation in the axial breast MR images

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ABSTRACT

Purpose: The purpose of this study was to develop a robust breast-region segmentation method independent from the visible contrast between the breast region and surrounding chest wall and skin.
Materials and methods: A fully-automated method for segmentation of the breast region in the axial MR images is presented relying on the edge map (EM) obtained by applying a tunable Gabor filter which sets its parameters according to the local MR image characteristics to detect non-visible transitions between different tissues having a similar MRI signal intensity. The method applies the shortest-path search technique by incorporating a novel cost function using the EM information within the border-search area obtained based on the border information from the adjacent slice. It is validated on 52 MRI scans covering the full American College of Radiology Breast Imaging-Reporting and Data System (BI-RADS) breast-density range.
Results: The obtained results indicate that the method is robust and applicable for the challenging cases where a part of the fibroglandular tissue is connected to the chest wall and/or skin with no visible contrast, i.e. no fat presence, between them compared to the literature methods proposed for the axial MR images. The overall agreement between automatically- and manually-obtained breast-region segmentations is 96.1% in terms of the Dice Similarity Coefficient, and for the breast-chest wall and breast-skin border delineations it is 1.9 mm and 1.2 mm, respectively, in terms of the Mean-Deviation Distance.
Conclusion: The accuracy, robustness and applicability for the challenging cases of the proposed method show its potential to be incorporated into computer-aided analysis systems to support physicians in their decision making.

1. Introduction

Magnetic Resonance Imaging (MRI) is an invaluable tool in the clinical work-up of patients suspected of having breast cancer [1,2]. Moreover, the breast MRI is gaining popularity as a screening modality for patients with dense breasts or high-risk patients with BRCA 1 & 2 gene mutations (screened at a younger age when their breasts are dense) [3,4]. As the diagnostic efficiency is highly dependent on the level of experience of the radiologist [5,6], recent researches have focused on developing computer-aided analysis methods aimed at helping the radiologists in their diagnostic tasks, particularly those radiologists experienced in mammography reading but less experienced in interpreting the breast MRI [7].

The automated breast-region segmentation is required for performing a fully-automated computer-aided analysis of the breast MR images overcoming drawbacks of the manual and user-assisted segmentation which are impractical for processing large amounts of the MRI data being time consuming and biased by both the intra-observer and inter-observer variability. The breast-region segmentation refers to separation of the breast as an organ from other body parts in the MR images. The importance of the automated breast-region segmentation has recently been recognized in a number of applications for the breast MRI, such as the breast-density measurement [8] and tumour detection for the subsequent tumour classification [9]. It can also facilitate the pharmacokinetic-model calibration with respect to the reference tissues for improving the diagnostic performance of the dynamic contrast-enhancement breast tumours [10] where, for the purpose of calibration, the pectoral muscle (the most anterior chest-wall

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muscle) can be used given its properties [11]. This would require, among others, a precise breast-chest wall border determination which is a part of the breast-region segmentation.

To automatically segment the breast-region in the MR images, the segmentation algorithm needs to determine the breast-chest wall and breast-skin borders as well as the lateral-posterior breast ends. In the T1-weighted MR images – which are almost always included in the typical clinical breast MRI protocols for tumour analysis and used for the breast-density measurement – the fibroglandular tissue, skin and chest wall have a similar signal intensity. Therefore, for the challenging cases where a part of the fibroglandular tissue is connected to the chest wall and/or skin resulting in no visible contrast between them, automated breast-region segmentation is a highly demanding task. Moreover, the MRI signal intensity is usually affected by inhomogeneity, partial volume effect, aliasing, ghosting artefacts, etc., furtherly aggravating the breast-region segmentation.

There have been a few methods proposed in the literature to automatically segment the breast region from the MR images. The simplest ones are based on the intensity threshold usually followed by morphological operations [12,13]. The more advanced ones, such as fuzzy C-mean (FCM) clustering [14], sign of gradients [9,15], region growing [16,17], and Markov random field [18], use various connectivity rules between pixels. These methods are highly dependent on the visible contrast between the breast region and chest wall/skin, i.e. on the presence of the fat along the breast-region border, and therefore tend to fail in the challenging cases.

The performance of the model-based [19] and atlas-based [20,21] methods for the breast-region segmentation depends on the size and variety of the training database which is critical in achieving a reasonable accuracy. Moreover, the atlas-based segmentation techniques rely on an accurate intensity-based registration of the image to be segmented with the population atlas where the intensity-based registration assumes a similar grey-level distribution in the image compared to the atlas which it is impossible to account for the wide range of the clinical acquisition protocols (e.g., T1-weighted, T1-fat suppressed, T2-weighted), while it is impractical to create high-quality, expert-annotated atlases for every different acquisition protocol [19]. The absence of one or both breasts, as a result of the mastectomy surgery, might also challenge the model-based methods for the breast-region segmentation. Moreover, the previously proposed atlas-based methods have not been validated for the challenging cases while the proposed model-based method has failed in the cases when the contrast between the breast and chest wall is lower than the contrast between the chest wall and chest.

The edge-based methods [17,22,23] for the breast-chest wall border determination incorporate classical edge-detectors, such as Canny and Hessian, that are highly sensitive to the noise, low contrast and weak-textural edges affecting the accuracy of the breast-region segmentation. Moreover, the edge-based methods developed for the axial MR images [17,23] rely on the presence of the fat along the anterior side of the chest wall (according to their authors) and, therefore, they are not applicable for segmentation of the challenging cases.

In this paper we present a novel fully-automated method for segmenting the breast region in the axial MR images using a tunable Gabor filter which sets its parameters according to the local MR image characteristics to detect non-visible transitions between different tissues having a similar MRI signal intensity. The breast-chest wall border is determined using a multi-slice approach where the border information from the adjacent slice is used to specify the border-search area in the current slice due to the high similarity in the chest-wall morphology (shape and inner structure) between two adjacent breast MRI slices. The method applies the shortest-path search technique within the border-search area by incorporating a novel cost function using the edges obtained with a tunable Gabor filter and subsequent extension of the resulting path along the fat up to the lateral-posterior breast ends. The lateral-posterior breast ends are determined using the body-contour landmarks, while the breast-skin border is determined by incorporating the edge information of the tunable Gabor filter in a slice-wise manner. Validated on 52 MRI scans covering the full range of American College of Radiology Breast Imaging-Reporting and Data System (BI-RADS) breast-density categories, our method shows to be independent from the visible contrast between the breast-region and surrounding chest wall and skin, i.e., independent from the presence of the fat along the breast-region border.

Our paper is organized as follows. After presenting the aim of our research and overview of the works related to the breast-region segmentation in Section 1, Section 2 describes the clinical breast MRI scans used in our research. Section 3 provides a detailed explanation of the proposed method for the breast-region segmentation. Section 4 introduces the validation metrics used to measure the segmentation accuracy. Section 5 reports our experimental results. Section 6 discusses the main findings of our research, outlines its limitations and determines the areas of our future work. Finally, Section 7 draws conclusions of our research.

2. Materials

The used database of 52 pre-contrast MRI breast scans (i.e. volumes) was obtained from the Institute of Oncology, Ljubljana, Slovenia. These were all clinical cases of different patients where the screening MRI revealed a lesion suspected of being malignant. The age of the patients included in our database ranged from 28 to 67 years with an average of 46 years. The patients were scanned in a prone position.

The axial T1-weighted images were acquired using a 3D fast low-angle shot-pulse sequence (FLASH) through both breasts (TR/TE 7.8/4.72, flip angle 25°) at 1.5 T (Magnetom Avanto, Siemens, Erlangen, Germany) with a dedicated bilateral breast-surface coil in the prone position. The single-slice dimensions were 448×448, the field of view (FOV) was $340 \times 340\ \text{mm}^2$ and the in-plane resolution was $0.76 \times 0.76\ \text{mm}^2$ with the slice thickness of 1 mm. Each MRI scan counted 144 slices.

The database covers the full range of the BI-RADS breast-density categories. With a consensus of two radiologists experienced in interpreting the breast MRI, the breasts in our database were classified into four categories: I—extremely fatty, II—minimally dense, III—heterogeneously dense, and IV—extremely dense breast (I: $<25\%$; II: 25–50%; III: 51–75%; IV: $>75\%$). Our database contained 14, 15, 12, 11 cases of the BI-RADS density categories I, II, III, and IV, respectively. All the scans from category IV and some scans from category III from our database contain the slices where a part of the fibroglandular tissue is connected to the chest wall and/or to the skin with no visible contrast between them, however, the scans from category IV contain a considerably larger number of these slices compared to the scans from category III. The scans from category I and II do not contain such slices.

The manual segmentation of the breast region – considered as a gold standard (i.e., ground truth) – was performed by two experienced radiologists (K.H., 18 years of experience, and M.M., 15 years of experience) by using the MIPAV software version 7.0.1 [24], specifically utilizing the Draw polygon VOI tool making a sequence of the left-clicks with the mouse along the breast-chest wall and breast-skin border. MIPAV automatically connects the points along each border, thus forming two contours giving rise to a binary mask corresponding to both borders (the border binary mask). In order to accommodate the varying sizes of the breast in different slices and MRI scans, the radiologists use a varying