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Original Research Article

Discriminant analysis of neural style representations for breast lesion classification in ultrasound

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Ultrasound imaging is widely used for breast lesion differentiation. In this paper we propose a neural transfer learning method for breast lesion classification in ultrasound. As reported in several papers, the content and the style of a particular image can be separated with a convolutional neural network. The style, coded by the Gram matrix, can be used to perform neural transfer of artistic style. In this paper we extract the neural style representations of malignant and benign breast lesions using the VGG19 neural network. Next, the Fisher discriminant analysis is used to separate those neural style representations and perform classification. The proposed approach achieves good classification performance (AUC of 0.847). Our method is compared with another transfer learning technique based on extracting pooling layer features (AUC of 0.826). Moreover, we apply the Fisher discriminant analysis to differentiate breast lesions using ultrasound images (AUC of 0.758). Additionally, we extract the eigenimages related to malignant and benign breast lesions and show that these eigenimages present features commonly associated with lesion type, such as contour attributes or shadowing. The proposed techniques may be useful for the researchers interested in ultrasound breast lesion characterization.

1. Introduction

Breast cancer is one of the most common causes of death for women in the western world [1]. Ultrasound imaging plays an important role in breast lesion detection and diagnosis. This imaging modality is safe, low cost, widely available and can discriminate breast lesions with high accuracy. However, ultrasound imaging is highly operator dependent. Diagnosis of breast lesions by ultrasound imaging requires experienced

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radiologist who know how to operate ultrasound scanner and possess deep knowledge of characteristic image features related to lesion type [2]. This requirement results in high inter-observer variation rate among the radiologists. Moreover, low specificity of examination results in high number of unnecessary performed biopsies. To support the radiologists, computer-aided diagnosis (CADx) systems have been used to help differentiate benign and malignant breast lesions [3].

There are various approaches to breast lesion CADx system development [4,5]. Usually the features are extracted manually from ultrasound images and then the classification is performed with machine learning methods. In this case, the performance of a CADx system relies mainly on well-chosen handcrafted features developed by researchers. Those features are usually divided into texture and morphological features [4]. In the review paper [5] a large number of handcrafted features were evaluated for classifying breast lesions in ultrasound. The study demonstrated that the morphological features are the best for breast lesion classification. The aim of these features is to quantify shape and contour attributes of breast lesions [6–8]. Usually more regular and well-defined contours are expected in the case of benign lesions [9].

Nowadays, with the rise of the deep learning (DL) methods, CADx systems with automatic feature extraction have been proposed for classification of medical images [10,11]. These systems commonly use convolutional neural networks (CNNs) to transform input images into a single decision as output, which corresponds to the probability that the examined image contains pathology. However, datasets in medical imaging are usually too small to train a DL model from scratch. This issue makes the researchers turn to transfer learning methods for CADx system development [12,11]. In this case, a DL model pre-trained on a large dataset is used as a feature extractor for the task of interest. The performance of the pre-trained model relies on the similarity of the medical images at hand to those from the training dataset. In [13] the authors applied several transfer learning techniques to extract features for breast classification using the VGG19 neural network. In [14] the authors proposed to use a modified and fine-tunned version of the Inception neural network. Both studies reported good results and depicted the usefulness of transfer learning in breast lesion classification.

In this paper we combine two pattern recognition techniques to characterize breast lesions in ultrasound images. The first one is related to eigenfaces and Fisherfaces which have been used for human face recognition [15]. These methods of image decomposition relies on the idea of a template that match a specific object, e.g. the human face. Our first aim is to apply Fisher linear discriminant analysis (FLDA) to ultrasound images of malignant and benign lesions in a similar fashion as performed in face recognition. The second pattern recognition technique is related to the concept of neural transfer of artistic style [16]. As reported in several papers, DL models can be used to separate the content and the style of a particular image [17]. Neural style transferring has been applied to create appealing images that combine paintings of well-known artists with regular photos [16]. In this work, we extract the neural style representations corresponding to malignant and benign breast lesions. We assume, that there exist a universal style connected with the lesion type. Next, we apply the FLDA on these neural style representations for classification. It is presented that the decomposition of the style is much more effective for classification than the decomposition of ultrasound images. The proposed approach may serve as a general method of transfer learning.

This paper is organized in the following way. First we describe the dataset used in this study. Second, the concepts of Fisherimages and eigenimages are introduced. Next, we explain how the neural style representation can be extracted using a deep neural network. Our approach to analysis is described. The results are presented and discussed.

2. Materials and methods

2.1. Dataset

In this study we used the freely available breast lesion dataset, the OASBUD (Open Access Series of Breast Ultrasonic Data, https://doi.org/10.5281/zenodo.545928) [18]. The dataset contains raw ultrasound data recorded from breast focal lesions and was originally used to test quantitative ultrasound techniques [19,20]. It includes 52 and 48 scans from malignant and benign lesions, respectively. For each lesion, two orthogonal scans were acquired. Moreover, for each scan a region of interest (ROI) was determined by a radiologist to correctly indicate lesion area. The study protocol was approved by The Institutional Review Board. Additional informations about the dataset and the study can be found in the original paper [18].

To reconstruct the ultrasound B-mode images based on raw data, we employed the approach proposed by the authors [18]. First, the envelope of ultrasonic signals was calculated using the Hilbert transform. Lesion area was cropped using the ROI provided by the radiologist to contain the lesion plus 5 mm of the surrounding tissue area. Second, the envelope was log compressed to 40 dB dynamic range. Next, the data were resized using the bicubic interpolation to 224×224 and normalized.

2.2. Discriminant analysis

The eigenimages and the Fisherimages were extracted using the standard approach known from face recognition [15]. Each image was vectorized and the principal component analysis was applied to determine the eigenimages (eigenvectors) corresponding to malignant and benign breast lesions. The eigenimages are related to the directions with the greatest variance in the data. In comparison, the FLDA finds a direction, called the Fisherimage, that best separates the classes. This direction is expected to maximize the ratio of the variance between the classes to the variance within the classes. In the case of binary classification there is only one Fisherimage.

2.3. Neural style transfer

To build the style representation of an image we used the style transferring method proposed by Gatys [16]. This method utilizes the VGG19 CNN pre-trained on the ImageNet dataset

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