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An automated diagnostic system of polycystic ovary syndrome based on object growing

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ABSTRACT

Objective: Polycystic ovary syndrome (PCOS) is a complex endocrine disorder that seriously affects women's health. The disorder is characterized by the formation of many follicles in the ovary. Currently the predominant diagnosis is to manually count the number of follicles, which may lead to inter-observer and intra-observer variability and low efficiency. A computer-aided PCOS diagnostic system may overcome these problems. However the methods reported in recently published literature are not very effective and often need human interaction. To overcome these problems, we propose an automated PCOS diagnostic system based on ultrasound images.

Methods and materials: The proposed system consists of two major functional blocks: preprocessing phase and follicle identification based on object growing. In the preprocessing phase, speckle noise in the input image is removed by an adaptive morphological filter, then contours of objects are extracted using an enhanced labeled watershed algorithm, and finally the region of interest is automatically selected. The object growing algorithm for follicle identification first computes a cost map to distinguish between the ovary and its external region and assigns each object a cost function based on the cost map. The object growing algorithm initially selects several objects that are likely to be follicles with very high probabilities and dynamically update the set of possible follicles based on their cost functions. The proposed method was applied to 31 real PCOS ultrasound images obtained from patients and its performance was compared with those of three other methods, including level set method, boundary vector field (BVF) method and the fuzzy support vector machine (FSVM) classifier.

Results: Based on the judgment of subject matter experts, the proposed diagnostic system achieved 89.4% recognition rate (RR) and 7.45% misidentification rate (MR) while the RR and MR of the level set method, the BVF method and the FSVM classifier are around 65.3% and 2.11%, 76.1% and 4.53%, and 84.0% and 16.3%, respectively. The proposed diagnostic system also achieved better performance than those reported in recently published literature.

Conclusion: The paper proposed an automated diagnostic system for the PCOS using ultrasound images, which consists of two major functional blocks: preprocessing phase and follicle identification based on object growing. Experimental results showed that the proposed system is very effective in follicle identification for PCOS diagnosis.

1. Introduction

Polycystic ovary syndrome (PCOS), also known as Stein–Leventhal syndrome or functional ovarian hyperandrogenism, is a complex endocrine disorder associated with a long-term lack of ovulation and excessive androgens [1]. The disorder is characterized by the formation of many follicles in the ovary, a process related to the ovary's failure to release an ovum [1]. PCOS is one of the most common causes of infertility. Symptoms may include various menstrual problems, hirsutism, endocrine abnormalities, acne, obesity, infertility, and diabetes with insulin resistance or hyperinsulinemia. Even if it may not cause an immediate problem, PCOS can have significant long-term effects, including diabetes, heart disease, and endometrial or breast cancer [2]. Accurate early diagnosis of PCOS is very important for its treatment.

Currently the prevalent method used by doctors for the PCOS diagnosis is to manually identify follicles and count the number in ovary ultrasound images, which is then used as a critical criterion

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to determine the PCOS diagnosis. However, manually identifying follicles may cause several problems, such as inter-observer and intra-observer variability and low efficiency. The tedious and time-consuming nature of manual operations for doctors may cause the inaccuracy of the PCOS diagnosis, which could seriously affect the women's health. These problems can be overcome by an intelligent PCOS diagnostic system which automatically identifies follicles and then counts the number of follicles. Nonetheless, to automatically detect follicles in ovary ultrasound images is not an easy task and several issues must be addressed in order to develop an automated PCOS diagnosis system.

Speckle noise is the major source of contamination in ultrasound images [3], which is characterized by a granular pattern of abrupt change of pixel intensity [4]. The extensive presence of speckle noise in ultrasound images makes it difficult to segment the image into different regions, which is critical in automatic follicle detection. In addition, different structures in ovary ultrasound images are not totally distinct and as a result the boundaries between them are neither clear nor continuous. Only a few approaches were proposed before for ovarian follicle analysis using computer-aided methods. Muzzolini et al. segmented one follicle in ultrasound images using multi-resolution textures [5]. Pierson et al. analyzed the responses of the ovary and individual follicles to different medicine stimuli by manually tracing follicular boundaries [6]. Sarty et al. developed a semi-automated method for follicle segmentation, where manual tracing was often required [7]. Krivanek and Sonka segmented the follicle using the watershed segmentation technique [8]. These methods mainly focused on the segmentation of one single follicle. They also required relatively high quality ovary ultrasound images and involved manual operations.

Potočnik and Zazula proposed an automated ovarian follicle segmentation method [9], which first extracted candidates of follicles by region growing and then identified follicles according to four empirical criteria. This method's recognition rate (RR) was reported as around 88% [9]. Although this method was completely automatic, it relied on parameters that were determined empirically. Potočnik and Zazula later improved their method [10,11] and developed several approaches to estimate parameters used for region growing and introduced a sequence of images to identify follicles based on a Kalman filter. Although the new method was more automated or computerized than their previous one, its recognition rate reduced to around 78%. Cigale and Zazula developed an approach for automatic ovarian follicle segmentation based on cellular neural networks [12]. Although this approach had lower computational complexity than previous methods, its recognition rate was merely 60%.

The major difficulty of automated follicle segmentation in ovary ultrasound images is to exactly identify real follicles under the interference of heavy speckle noise in ultrasound images. Various segmentation methods have been developed to extract the contours of objects in ultrasound medical images [13–15]. These segmentation methods were mainly based on boundary or region energy minimization. A straightforward attempt for follicle detection would be to extract the ovary boundary first using these segmentation methods [13–15]. However, the ovary boundaries in ultrasound images usually are not salient and follicles also appear as local minima, making these segmentation methods unsuitable for the purpose of follicle detection. Since follicles may appear as different features in ovary ultrasound images, another attempt for follicle detection would be to design a classifier [16,17] based on these features. However, our experimental results showed that a single follicle is not clearly discriminable from other local minima based on these features. These classification based methods did not take into account the characteristics of the ovary region and the connectivity or neighborhood between follicles. To achieve better results for follicle identification, it is needed to have a method that simultaneously considers the properties of follicles, the boundary information of the ovary and the different region information in the ovary ultrasound image.

In this paper we propose a novel, effective and automated method for the computer-aided diagnosis of PCOS using ovary ultrasound images. The proposed method is based on the fact that follicles always appear as low-echo local minimum areas inside the contour of the ovary. It consists of two major functional blocks: preprocessing phase and follicle identification based on object growing. The preprocessing phase automatically selects the region of interest and extracts the local minima as possible follicle candidates. Then a cost map is computed to distinguish between the ovary and its external region and each object (local minimum) is assigned a cost function based on the cost map. The object growing algorithm initially selects several objects that are likely to be follicles with very high probabilities and dynamically update the set of possible follicles based on their cost functions. The proposed method was applied to 31 ultrasound images obtained from PCOS patients and its results were compared with those of three other methods, including level set, boundary vector field (BVF), and fuzzy support vector machine (FSVM) classifier. Experimental results showed that the proposed method is very effective in follicle identification and achieved better performance than previously proposed ones.

The remainder of this paper is organized as follows. Section 2 describes in detail the proposed method, including the preprocessing phase and follicle identification based on object growing. Section 3 discusses the experimental results of the proposed method and compares its performance with those of three other methods. Some discussions are presented in Section 4 and finally conclusions are drawn in Section 5.

2. Methods

The proposed method consists of two major functional blocks: preprocessing phase and follicle identification based on object growing. The block diagram of the proposed method is shown in Fig. 1.

2.1. Preprocessing phase

The preprocessing phase performs three tasks: adaptive morphological filtering, local minimum extraction, and region of interest selection. First, the speckle noise in the input PCOS ultrasound image is reduced significantly using an adaptive morphological filter we developed recently [18]. Then an enhanced labeled watershed algorithm is proposed to extract local minima that are possible candidates for follicles. Finally the region of interest is computed iteratively based on the spectral residual approach [19]. The results of the preprocessing phase are then used by subsequent object growing for automatic follicle identification.

2.1.1. Adaptive morphological filtering

Speckle noise is characterized by a granular pattern of abrupt changes of pixel values [4] and it is the major source of contamination in ultrasound images [3]. Speckle noise reduces the contrast and obscures diagnostically important details. Various methods have been proposed to suppress speckle noise [20–22]. Among them, the adaptive morphological filter developed by the authors is an effective method for speckle reduction [18], which effectively depresses abrupt changes of pixel values due to the speckle [4] and facilitates subsequent image processing tasks such as segmentation. In this paper, the adaptive morphological filter is used to suppress speckle noise for extraction