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Research paper

Computer aided thyroid nodule detection system using medical ultrasound images

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ABSTRACT

Thyroid nodule is one of the endocrine problem caused due to abnormal growth of cells. This survival rate can be enhanced by earlier detection of nodules. Thus, the accurate detection of nodule is of utmost importance in providing effective diagnosis to increase the survival rate. However, accuracy of nodule detection from ultrasound images is suffered due to speckle noise. It considerably deteriorates the image quality and makes the differentiation of fine details quite difficult. Most of the detection systems for the thyroid nodules are semi-automated entailing manual intervention to draw rough outline of the nodule at some level or require manual segmentation in training or testing phases that increase the inaccuracies and evaluation time. To handle this, a fully Computer-Aided Detection system is presented for speckle reduction and segmentation of nodules from thyroid ultrasound images. The proposed system has three components: speckle reduction to reduce speckle noise and preserve the diagnostic features of ultrasound image, automatic generation of Region of interest (ROI) that identifies suspicious regions and fully automatic segmentation of nodule in processed ROI image. The proposed segmentation method outperformed other methods by gaining high True Positive (TP) value ($95.92 \pm 3.70\%$), False Positive (FP) value ($7.04 \pm 4.21\%$), Dice Coefficient (DC) value ($93.88 \pm 2.59\%$), Overlap Metric (OM) (91.18 ± 7.04 pixels) and Hausdroff Distance (HD) (0.52 ± 0.20 pixels). This system can facilitate the endocrinologists by providing second opinion to improve diagnosis of nodules as benign or malignant.

1. Introduction

Nodule is the abnormal growth of cells (lumps) within the thyroid gland that may be benign (non-cancerous) or malignant (cancerous) [1,2]. In general, the occurrence of thyroid nodule among all the cancer cases is reported to be around 0.2% [34,30,37,29]. The prevalence of this type of cancer increases with the age and is one of the most common cancers among women [3]. According to American Cancer Society's estimates for thyroid cancer, out of 62,450 new cases of thyroid cancer, 6.7% were males and 20% were females and 1950 (1080 women and 870 men) estimated deaths were expected due to thyroid cancer for 2015 in United States [42]. As per these medical statistics, thyroid nodule is a severe disorder leading to high mortality rate. However, the mortality rate can be reduced if cases are detected and treated early by finding the initial symptoms of thyroid nodule [14].

Ultrasound is used as the most common imaging modality for early thyroid nodules detection. It is generally preferred due to its non-ionising radiation effects, inexpensive and painless scanning operations which provide diagnostically important information needed for medical diagnosis [22]. However, the key challenge in automated analysis in ultrasound images is to make accurate nodules segmentation within the thyroid gland. As these images are affected by speckle noise and intensity in-homogeneity that may appear as bright spots. Speckle noise can be described as a texture pattern that changes with the type of biological tissue. It deteriorates the image quality and makes the differentiation of fine details difficult. The major purpose of speckle reduction is to improve the image quality [19,15] for accurate segmentation of nodules. However, the removal of speckle noise is always a trade-off between edge preservation and noise suppression.

Doctors interpret the ultrasound images to provide effective treatment in order to identify the severity of several thyroid diseases. Occasionally, practitioners make perception and interpretation errors while performing the diagnosis [20]. Perception errors occur when anomalies remain undetected even when it is in sight and interpretation errors occur when a detected abnormality is incorrectly interpreted as benign or malignant. These errors can

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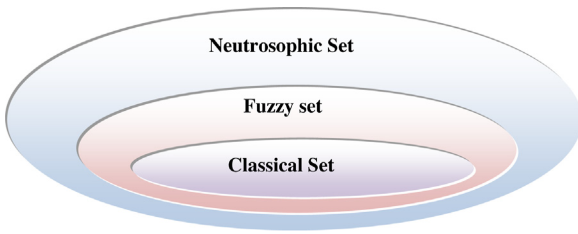

Fig. 1. Relationship among classical set, fuzzy set and neutrosophic set [39].

be due to distractions, endocrinologist exhaustions, Human Visual System (HVS) limitations and experience level. This uncertainty can be finally resolved by invasive procedures such as biopsies and Fine Needle Aspiration (FNA). The critical issue for an endocrinologist is to manually detect the accurate thyroid nodule in the ultrasound image and classify it as benign or malignant [16]. Therefore, Computer assisted detection systems are becoming popular which assist endocrinologists in accurate decision making for interpretation of huge amount of image data [22]. One of the key challenges to be considered in the design of fully Computer-Aided Detection system is to make accurate delineation of nodules with automatic extraction of Region of Interest (ROI) within the thyroid gland. The other challenges are speckle noise suppression in ultrasound images in some intuitive ways so that indeterminacy and fuzziness can be easily handled without using any prior information and human intervention. The goal is to preserve texture details which have high degree of indeterminacy due to resemblance to the speckle noise.

Fuzzy domain is most widely used by the researchers for handling fuzziness [7]. Fuzzy set (FS) is widely used in image processing applications [4]. FS can only deal with the membership degree but is not able to handle the indeterminacy degree of uncertain pixels [44–46]. Unlike fuzzy logic, neutrosophic logic introduces the extra domain *IM* that provides a more efficient way to handle higher degrees of indeterminacy that are very difficult to be handled by fuzzy logic. The relationship among classical set, fuzzy set and neutrosophic set is shown in Fig. 1. In case of classical set, *TM* and *FM* have either 0 or 1 values and $IM = \emptyset$. While in fuzzy set, $IM = \emptyset$ but *TM* and *FM* are real numbers $\in$ [0,1] and sum of *TM* and *FM* must be equal to 1. In neutrosophic set, there is no limit on the sum of *TM*, *IM* and *FM* that is *TM*, *IM*, *FM* $\in .]^{-}0,1^{+}[$. Statistically, *TM*, *IM* and *FM* are the membership subsets which depend on known and unknown aspects.

Recently, generalization of fuzzy set named as Neutrosophic Set (NS) is becoming popular in image processing applications [8,19,20,38,9,31,39,18]. Many researchers have used Neutrosophy in variety of applications like image denoising and segmentation which have shown that neutrosophic based methods yield good performance due to their indeterminacy handling capability [38,8,10,18]. Thus, this paper presented a Computer Aided Detection (CADe) system using neutrosophic based speckle removal method and segmentation method that can provide another opinion to endocrinologists for accurate nodule detection and reduction of unnecessary invasive biopsy operations and surgical complications.

The rest of paper is structured as: Section 2 discusses material and Computer aided detection system with speckle reduction and segmentation of thyroid nodules. Section 3 discusses the experiments and results while section 4 gives conclusion.

2. Material and methods

2.1. Material

2.1.1. Dataset

In this paper, two real ultrasound image datasets have been used to validate the efficacy of speckle reduction and segmentation methods. The first dataset of real thyroid ultrasound images is acquired from the Department of Radiology, Post Graduate Institute of Medical Education & Research, Chandigarh, India. It consists of 50 subjects, out of which, 20 were males and 30 were females, age from 15 to 70 years. The images were acquired with a 256 grey-level depth using IU22 Philips X Matrix with linear probe at a frequency of 17.5 MHz having 628 × 656 pixels. Each nodule is delineated by expert and the manual segmentation is served as ground truth for making comparison. The second dataset is obtained from open access Digital Database of Thyroid ultrasound Images (DDTI) from the website of Computer Imaging & Medical Applications Laboratory, Universidad Nacional de Colombia [36]. This dataset consists of 88 thyroid ultrasound images.

2.1.2. Performance measures

To investigate the performance of segmentation methods both area-based and boundary-based metrics have been used in this work. Area based error metrics such as True Positive (TP), False Positive (FP), Overlap Metric (OM) and Dice Coefficient (DC) are used to compute the number of pixels covered by the automated method correctly and wrongly. The boundary based error metrics such as Hausdroff Distance (HD) and Mean Absolute Distance (MAD) are used to determine the possible disagreement over two curves [6,43].

2.2. Methods

2.2.1. Neutrosophy

Smarandache introduced Neutrosophy to handle nature and scope of neutralities [40,41,17]. Neutrosophic theory gives a general framework to handle indeterminacy. Many researchers have explored several applications such as image de-noising and image segmentation. It generalizes fuzzy logic and handles the antitheses, antinomies, contradictions and paradoxes. The term '*Neutrosophy*', has appeared from the Latin term '*Neuter*' as neutral and Greek term '*Sophia*' as skill/wisdom [31,39]. Neutrosophy theory takes into account every concept, entity, or event $\langle A \rangle$ associated to its converse $\langle Anti–A \rangle$, the neutralities $\langle Neut–A \rangle$ and which is not *A* $\langle Non–A \rangle$ [39]. The three membership subsets are used to determine the truth degree, indeterminacy degree and falsity degree of $\langle A \rangle$.

Neutrosophic Set (NS) considers the nature, scope and origin of neutralities. In neutrosophic logic, three neutrosophic components: True Membership (*TM*), Indeterminate Membership (*IM*) and False Membership (*FM*) are defined to estimate the degree of truth, the degree of indeterminacy (neither true nor false) and the degree of falsity [40,41,17].

2.2.1.1. Neutrosophic image. An image in neutrosophic domain P_{NI} is considered as *TM*, *IM* and *FM* subsets [39]. A pixel in neutrosophic domain can be characterized as $P_{NI}\left\{t_m, i_m, f_m\right\}$, representing the pixel as t_m% true (nodule), i_m% indeterminate (nodule boundaries) and f_m% false (background), where $t_m TM \in$, $i_m IM \in$, and $f_m \in FM$ [32,33].

2.2.2. Proposed computer aided thyroid nodule detection system

Fig. 2 illustrates the block diagram of the proposed Computer-Aided Detection (CADe) system for thyroid nodules. The proposed CADe system consists of following phases: Speckle reduction, Region of Interest (ROI) extraction [24] and thyroid nodule segmentation. Firstly, speckle reduction method named as Neutrosophic Nakagami Total Variation (NNTV) is applied to remove speckle noise, then ROI is extracted automatically and finally proposed Neutrosophic Distance Regularized Level Set (NDRLS) method has been utilized for the segmentation of thyroid nodules.