Ultrasonics 53 (2013) 335–344

Contents lists available at SciVerse ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Target detection in diagnostic ultrasound: Evaluation of a method based on the CLEAN algorithm

Hassan Masoom, Raviraj S. Adve, Richard S.C. Cobbold *

Institute of Biomaterials and Biomedical Engineering, Department of Electrical Engineering, University of Toronto, Toronto, Ontario, Canada M5S 3G9

ARTICLE INFO

Article history:
Received 26 March 2012
Received in revised form 13 June 2012
Accepted 26 June 2012
Available online 10 July 2012

Keywords:
Ultrasound
Medical imaging
Diagnostics
Computer aided detection
CLEAN

ABSTRACT

A technique is proposed for the detection of abnormalities (targets) in ultrasound images using little or no *a priori* information and requiring little operator intervention. The scheme is a combination of the CLEAN algorithm, originally proposed for radio astronomy, and constant false alarm rate (CFAR) processing, as developed for use in radar systems. The CLEAN algorithm identifies areas in the ultrasound image that stand out above a threshold in relation to the background; CFAR techniques allow for an adaptive, semi-automated, selection of the threshold. Neither appears to have been previously used for target detection in ultrasound images and never together in any context. As a first step towards assessing the potential of this method we used a widely used method of simulating B-mode images (Field II). We assumed the use of a 256 element linear array operating at 3.0 MHz into a water-like medium containing a density of point scatterers sufficient to simulate a background of fully developed speckle. Spherical targets with diameters ranging from 0.25 to 6.0 mm and contrasts ranging from 0 to 12 dB relative to the background were used as test objects. Using a contrast-detail analysis, the probability of detection curves indicate these targets can be consistently detected within a speckle background. Our results indicate that the method has considerable promise for the semi-automated detection of abnormalities with diameters greater than a few millimeters, depending on the contrast.

1. Introduction

Ultrasound imaging can be used in the detection of various cancers [1–3], quantitative bone density measurements [4] and for the velocity estimation of blood flow [5]. Because ionizing energy is not involved, ultrasound is a comparatively safer imaging modality for both the patient and operator. This intrinsic safety and the non-invasive nature of ultrasound imaging can be used to increase the rate of cancer detection [6] and be a safe replacement for biopsies. Further, it is a relatively inexpensive imaging modality which led to its recommendation as a breast cancer screening tool, especially for limited-resource countries [7].

Biomedical ultrasound images are commonly evaluated by health care workers. Although they have generally undergone an intensive training program in the interpretation of such images, the detection and classification of abnormalities remains a subjective task [8]. As a result, computer-aided diagnosis (CAD) systems, have been developed to assist health care workers in detecting abnormalities. Some CAD systems extend detection to classification, i.e., whether the detected abnormalities are benign or malignant and even the likelihood of either case [9]. Still, it is widely accepted that in the near future physicians will not be replaced by CAD systems—they are meant to remove operator dependency on ultrasound diagnosis and to augment radiologists' abilities in diagnosing patients.

A number of different approaches have been proposed and investigated for the detection of targets.[1] They can be divided into two categories: those based on signal processing methods and those based on image processing. Some signal processing systems use filtering [10,11] or wavelet transforms [12]. The aim of these approaches is image enhancement which could include speckle reduction, increasing contrast or edge preservation in ultrasound images. After processing, these enhanced images can either be reviewed by physicians or be used for further image processing. On the other hand segmentation algorithms, partition the ultrasound image so that radiologists can better differentiate anatomical and physiological aspects of the image. One approach is to compare the statistics of neighboring regions [13,14], another is an active contour model where regions grow to create an outline that distinguishes an anomaly from the background [15]. Other solutions such as Markov random fields [16,17] and neural networks [18], among others, have also been proposed [19]. These pattern matching algorithms often require training data or some *a priori* information about the object

---

* Corresponding author. Address: Institute of Biomaterials and Biomedical Engineering, Department of Electrical Engineering, University of Toronto, 164 College Street, Toronto, Canada M5S 3G9. Tel.: +1 416 978 6530.

E-mail address: cobbold@ecf.utoronto.ca (R.S.C. Cobbold).

[1] In this paper, the terms *abnormalities* and *targets* are used interchangeably.

0041-624X/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ultras.2012.06.016

being scanned. Others are limited in scope so that they cannot process the entire image and thus require some intervention or initial seeding by operators to produce reasonable results.

As an alternative to pattern matching algorithms, time reversal offers a way in which to automatically detect target scatters with little *a priori* information. Initial work reported that successive transmissions of the time reversed received acoustic waves resulted in focusing on the brightest scatterer [20]. Subsequent work by the same group introduced the DORT algorithm which requires determining eigenmodes of the so-called time reversal operator, a matrix that represents the received signal at each of the receive transducer array elements after a transmission by each individual transmit array element. These eigenmodes can then be used to focus on individual targets.

Although a promising approach, time reversal has several shortcomings. Because the DORT algorithm requires transmission by an individual array element, for successful target detection the algorithm appears to require that the target contrast be substantially greater than the background speckle. Some of these problems can be alleviated by the newer FDORT (Focused DORT) approach which uses focused transmissions by the entire transducer array [21]. However, the FDORT algorithm requires specification of the areas upon which to focus and is therefore not entirely independent of human intervention. Moreover, scatterers with the same reflectivity have similar eigenvalues and are thus hard to disambiguate.

This paper proposes a technique for the detection of targets in ultrasound images. Its goal is to use little or no *a priori* information and to require little operator intervention so as to reduce the dependence on human interaction. The approach proposed here combines the CLEAN algorithm with constant false alarm rate (CFAR) processing. Neither of these appear to have been previously used for target detection in ultrasound images and never together in any context.

The CLEAN[2] algorithm was originally developed for radio astronomy [22] to enhance celestial images and automatically identify regions of interest within an image. It was used to disambiguate true celestial scatters from ones that were falsely created by interference of side lobes between closely spaced scatterers. It was also used to suppress the appearance of background noise, usually a result of atmospheric effects. Without noise or interference, the resulting image is then simply the sum of the signals from the individual stars.

In addition to providing an image free of background noise, the CLEAN algorithm is often used to extract some information about each of the individual targets. This can then be used for further image processing or as a method for feature extraction in its own right. For example, for each located target, the algorithm returns the associated location and backscattered response from the input image. This feature has since allowed the CLEAN algorithm to be used in a number of different applications such as time series analysis [23] and wireless communication, where it has been used for channel estimation as well as multi-path propagation analysis for many independent signals [24].

Developing the CLEAN algorithm for ultrasound images requires modifications from what is available in the literature. As will be seen, the CLEAN algorithm depends heavily on a detection threshold which determines whether a potential target is part of the background or if it is a true target. Choice of the detection threshold requires some intuition and is thus somewhat subjective. In the field of radar, the CFAR series of algorithms have often been used to circumvent this limitation [25] by automating the choice of detection threshold based on a prescribed false alarm (false positive) rate. Thus, a variation of the CFAR algorithms is proposed here. It requires the user to specify a tolerable false alarm rate and it then calculates a threshold based on local statistics.

It is the goal of this work to differentiate between areas of medical interest (targets) and speckle in an ultrasound image. Specifically, the term "target" is used to describe a region whose contrast is greater than the background speckle. For the purposes of this work, contrast is defined as

$$C = \frac{S_{out} - S_{in}}{S_{out}} \tag{1}$$

where S_{out} is the mean signal magnitude outside of the target area and S_{in} is the mean signal magnitude inside of the target area [26].

The rest of this paper is organized as follows. Sections 2 and 3 introduce variations of the CLEAN and CFAR algorithms, respectively, as developed for ultrasound. To evaluate their efficacy, several simulations were performed. These are described in Section 4, along with the results and discussion. Some concluding remarks are given in Section 5. It should be noted some of the work reported in this paper are more fully described in Masoom [27].

2. The CLEAN algorithm

In this section we introduce the CLEAN algorithm, which we have adapted for use in ultrasound image analysis. We also present an example of the use of this algorithm. The goal of the algorithm is to remove, from the input signal, any noise or interference so that the output contains only the effects from the targets. Furthermore, the CLEAN algorithm can extract features from each of the targets including their location and the temporal response of the target to the transmitted signal. The algorithm terminates when it determines that there are no more targets within the image.

The CLEAN algorithm begins with the initial length-N input data vector $D_1[n]$, $n = 0,\ldots,N-1$, denoted by $\mathbf{D}_1$. For simplicity, assume that $\mathbf{D}_1$ is one dimensional: an assumption that will later be relaxed. In the case of ultrasound, this signal corresponds to the samples of the returned signal arranged in a vector. First, the maximum magnitude of the entries in D_1 is found. If this magnitude is below the detection threshold, T_{det}, the algorithm terminates and declares that there are no targets in the signal. Otherwise, the maximum magnitude's location is noted in υ_1 and its amplitude is noted in a_1, i.e.,

$$\upsilon_1 = \arg\max_n |D_1[n]|$$

$$\text{and} \quad a_1 = D_1[\upsilon_1].$$

This location, υ_1 is considered to be the location of a potential target signal. A portion of $\mathbf{D}_1$ around the location υ_1 is then decreased according to an attenuation function $G_1[n]$, $n = 0,\ldots,N-1$, equivalently a vector $\mathbf{G}_1$ and the result is stored in $\mathbf{D}_2$ for the next iteration of the algorithm. The process iterates with new target locations identified in every iteration and terminates when no more amplitudes are above the chosen threshold. Overall, the algorithm can be described by the following pseudo-code:

```
while $\max_n|D_i[n]| > T_{det}$ do
    $\upsilon_i = \arg\max_n|D_i[n]|$
    $a_i = D_i[\upsilon_i]$
    $D_{i+1}[n] = G_i[n]D_i[n]$ for $n = 0, \ldots, N - 1$
    $i = i + 1$
end while
return $\mathbf{v} = [\upsilon_1, \ldots, \upsilon_M]$, $\mathbf{a} = [a_1, \ldots, a_M]$
```

The attenuation function $\mathbf{G}_i$ is a windowing function which decreases the magnitude of $\mathbf{D}_i$ near the location of the found target.

---

[2] From the available literature, "CLEAN" is not an acronym, but refers to the "cleaning" of the image.