The Use of Multi-scale Monogenic Signal on Structure Orientation Identification and Segmentation

Xiao-Bo Pan[1], Michael Brady[2], Ralph Highnam[1], and Jérôme Declerck[1]

[1] Siemens Molecular Imaging Limited, Oxford, UK
[2] University of Oxford, Oxford, UK
bo.pan@mirada-solutions.com

Abstract. A method of extracting salient image features in mammograms at multiple scales using the monogenic signal is presented. The derived local phase provides structure information (such as edge, ridge etc.) while the local amplitude encodes the local brightness and contrast information. Together with the simultaneously computed orientation, these three pieces of information can be used for mammogram segmentation including locating the inner breast edge which is important for quantitative breast density assessment. Due to the contrast invariant property of the local phase, the algorithm proves to be very reliable on an extensive datasets of images obtained from various sources and digitized by different scanners.

1 Background

Medical image processing often involves identifying structures of several different types (edge – of a mass, or of the breast, ridge – e.g. ducts, etc.) as a basis for segmentation in complex images such as mammograms, and a great deal of effort has been expended on making those algorithms scale, intensity and contrast invariant.

When dealing with digitized mammograms, due to variations in X-ray acquisition protocols, breast density and digitizing scanners, there can be large differences in both the image intensity range and contrast. This poses a considerable challenge to developing fully automated algorithms without prior knowledge about the scanner and imaging protocol. In this paper, we describe a novel segmentation algorithm which can effectively handle mammogram images from various sources and which are digitized using different scanners.

It is well known that a 1D signal can be split into local amplitude and local phase using the analytic signal, in which the local phase provides the structural information and the local amplitude encodes the brightness and contrast information [1-3]. The split into these two independent and complementary kinds of information makes the local phase brightness and contrast invariant. The monogenic signal, introduced by Felsberg et al [4], is an extension of the analytic signal to 2D/3D/4D, where, in the case of 2D images, three pieces of information are extracted: the local amplitude, local phase, and local (image) orientation.

We have developed a multi-scale strategy to apply the monogenic signal to images, and extract distinct structure, orientation and contrast information. This information is of interest for a range of applications (e.g. mass detection, breast density quantification,

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detection of curvilinear structures or the pectoral muscle boundary), and particularly for differentiation of structures in an image. In this paper we demonstrate its utility in segmenting a range of structures in the same mammogram such as the film area, the breast and the inner breast edge.

Many methods have been developed for mammogram segmentation and these have been based on the intensity histogram [5], the intensity gradient [6-8], polynomial modeling [9, 10], or active contours [11, 12]. Many of these methods require manually adjustment of parameters, inevitably limiting the range of images that the algorithm can be applied to automatically, that is, without supervision or intervention.

Our method aims to solve the problem automatically and deals with the following difficulties: varying brightness and contrast; the skin-air breast boundary, which has low contrast to background, and sometimes has been cut off due to limited sensitivity of the digitizer; the background intensity and noise, which vary considerably; the images obtained from various scanners (CCD and laser based): CCD based scanners (e.g. Canon) are usually noisier and less sensitive than laser based scanners (e.g. Lumisys, Array, DBA).

2 Method

The method essentially relies on the exploitation of properties of the monogenic signal extracted from the image. In this section, we recall some of these properties and explain how they were exploited to create an application specific algorithm for mammogram segmentation.

2.1 Definition of Local Amplitude, Local Phase and Local Orientation

Hilbert transform, 1D analytic signal

To extract the structure and local amplitude information of a 1D signal f(x), the is convolved with its Hilbert transform $f_H(x) = h(x) \otimes f(x)$, where the transfer function of Hilbert transform is defined as [**1**]:

$$H(\omega) == i\text{sign}(\omega) = i \ \ (\omega{>}0)\ ,\ 0\ (\omega = 0),\ -i\ (\omega < 0) \tag{1}$$

And *h(x)* is the spatial representation of the frequency representation *H(ω)*. The analytic signal is formed as $f_A(x) = f(x) - if_H(x)$. The local amplitude *A(x)* and the local phase *φ(x)* are derived from $f_A(x)$ as:

$$A(x) = \left\| f_A(x) \right\| = \sqrt{f^2(x) + f_H{}^2(x)} \tag{2}$$

$$\varphi(x) = arg(f_A(x)) = \arctan 2(f_H(x), f(x)),\ \ \varphi(x) \in [-\pi, \pi) \tag{1}$$

2D Monogenic signal

In the 2D case, Felsberg and Sommer used the Riesz transform to extend the Hilbert transform to 2D or arbitrarily higher dimensions. The Riesz transform in 2D is defined as: