multiscale transformations,
complex wavelets, discrete wavelets,
directional local findings, mammogram

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MULTISCALE MODELING OF LOCAL DIRECTIONAL MAMMOGRAM FINDINGS

In this paper two multiresolution transforms (discrete 2D wavelets and complex wavelets) are compared for their capabilities to enhance local texture orientation of mammograms. The local orientation of image texture is useful feature to detect one of the typical types of abnormal findings in mammography - architectural distortions. Our research was directed to define an effective, more reliable directional model of local directional findings in mammograms. Computer-aided diagnosis was considered as a concept of accurate model application.

1. INTRODUCTION

1.1. MAMMOGRAPHY

Mammography is a method of examining women to early detect breast cancer. Necessity to review large number of mammograms in screening procedures and reality of limited diagnosis efficiency causes long-term intense research on computer assisted diagnosis. Interpretation process is significantly affected by image quality, conditioning of content assessment, individual radiologist knowledge and experience etc. affecting cognitive errors. Especially architectural distortions (ADs) are commonly misdiagnosed because of their subtlety and ambiguity in appearance.

1.2. ARCHITECTURAL DISTORTIONS

AD is a breast lesion in which the normal structure of the breast parenchyma is distorted as if being pulled into a central point, without a visible central density [1]. This is only one of the typical types of abnormal findings in mammography which has indefinite characteristic features, e.g. number of spicules, width and length of them or density of findings (Fig.1). Therefore, it is difficult to automatically detect ADs and consequently to increase breast cancer treatment and to decrease the survival rate by early detection. In screening mammography only 3% of detected by radiologists lesions are ADs, whereas 61% of detected findings are masses and 90% of lesions are microcalcifications. In comparison with the other pathologies in mammography the efficiency detection for ADs is unsatisfactory [3].

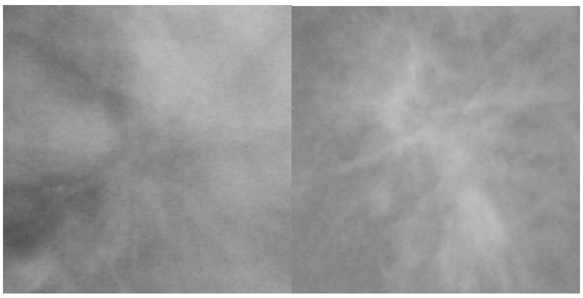

Fig. 1. The original ROIs containing architectural distortions [9].

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1.3. DETECTION METHODS OF ARCHITECTURAL DISTORTION

In image processing, AD is modeled as a group of line structures of different directionality. Bovik et al. [4] used filtering in the Radon domain as the extractor of texture orientation. Endo et al. [7] detected the suspect regions with ADs by concentration indexes of line structures. The indexes were extracted using mean curvature - areas with ADs corresponded to the high concentration regions. Ayres et al. [2] filtered mammograms with a bank of Gabor filters of different texture orientation angles to enhance texture orientations.

As the earlier result of our research [8], the ADs detection method called *ArDist* was proposed (Fig. 2).

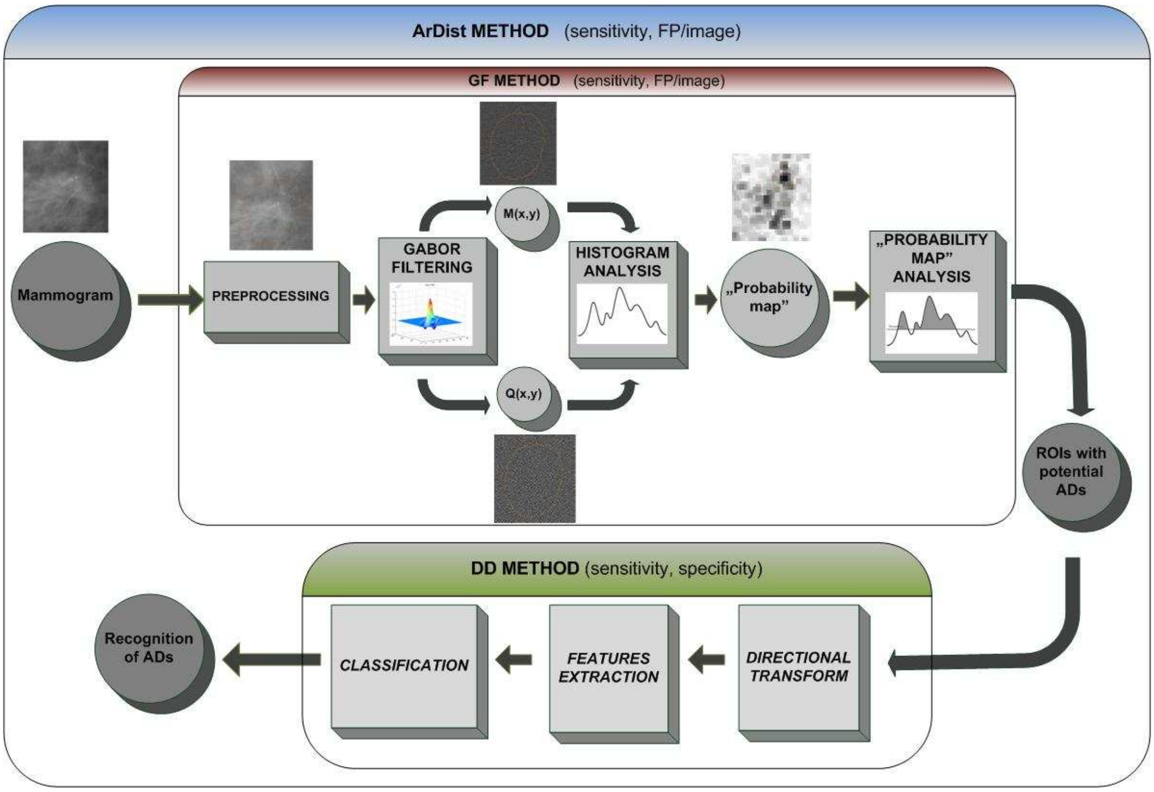

Fig. 2. Scheme of *ArDist method* which consists of two common step: *GF method* to extract ROIs with directional abnormalities and *DD method* to detect of potential ADs on selected in first step ROIs [8].

ArDist method consisted of two common steps, schematically:

- Regions of Interests (ROIs) detection with directional abnormalities (*GF method*):
  - preprocessing to reduce noise and enhance line structures,
  - Gabor filtering with 180 directional filters of adjusted impulse response,
  - calculating of “probability maps” based on histograms of Gabor maps,
  - analysis of the “probability map” to detect ROIs with abnormalities;
- recognition of potential ADs in selected ROIs (*DD method*):
  - directional transformation of 2D Fourier in polar coordinates,
  - feature extraction and reduction (extraction of image features and directional transform features of angular spectrum),
  - features classification to detect ADs.

We tested 33 images containing ADs. The sensitivity of *GF method* was achieved 79% (26 cases of ADs were detected) at the number of false positives per image FPI = 7.8 and for *DD method* the sensitivity was 86% by the specificity of 89% [8]. In order to increase the efficiency of ADs detection, considering especially detection of ROIs improvement, new directionality representatives should be approximated to differentiate normal and directionally abnormal breast tissue. The idea worth thinking is multiscale image transform extending Gabor filtering potential of directionality description. Gabor wavelets were omitted because of impractical complexity. We decided to consider other implementations of wavelets, especially complex wavelets with limited computational complexity and domain redundancy in order to choose effective directional model of local mammogram texture.

2. MULTISCALE MODELING OF LOCAL DIRECTIONAL FINDINGS

ADs have indefinite characteristic features, (e.g. number of spicules, distribution of spicules orientations, size of these findings), so some conditions of multiscale transforms is expected to be helpful in texture orientation extraction [11]. Image local representation should be successively approximated, with retained details of successive scales. The atoms of signal expansion bases should be representative to directional, small and elongated objects in both the spatial and the frequency domain with lack or small redundancy of domain. The expected result is enhanced directionality of texture signatures in both transform and reconstructed domain.

Considering potential of 2D real-valued discrete wavelet transform (DWT), only good isolation of the discontinuities at contour points is achievable [6]. The wavelet scheme is seen to slowly capture contours by isolated ”dots” (Fig. 3) but limitedly represent piecewise linear discontinuities along contour. In each scale, the number of significant coefficients describing contour is proportional to the contour length regardless of contour smoothness or regularity. Contour outline (Fig.4) is defined by numerous set of wavelet coefficients in different scale (by squares of different sizes). The problem is wavelet inability to adapt the diverse directions of geometrical structures because of square support of various sizes. There are only three enhanced directions: vertical, horizontal and diagonal directions and wavelets lacks phase information. Additional, disadvantages of the DWT is shift-variance, i.e. the fact that the wavelet coefficients behave unpredictably when the input signal is shifted. Significant fluctuations in the DWT coefficients energy make it difficult to model elongated, lineal structures from the coefficient values.

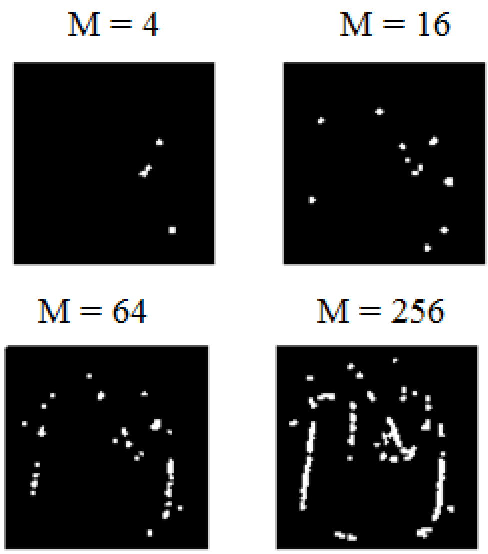

Fig. 3. Sequence of images showing the contour enhancement using the nonlinear approximation at the finest scale of the wavelet transform. M is the number of the most significant coefficients [6].

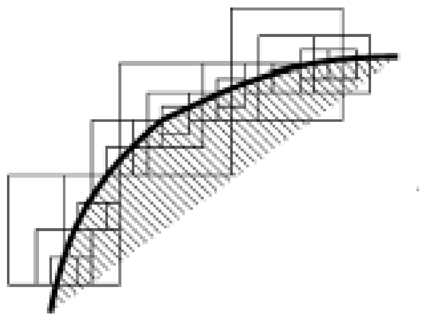

Fig. 4. Scheme of example contour are described by the wavelets coefficients [6].

The complex wavelet transformation (CWT) is useful to remedy these drawback of the DWT. However, many forms of complex wavelets are developed, the pragmatic meaning of dual-tree complex wavelets transform (DT CWT) is proved in lots of research efforts [5]. 1D DT CWT combines two orthogonal or biorthogonal wavelet bases (and associated filters) as ‘’real part’’ and ‘’imaginary part’’ of complex algebra [10] – see Fig.5. The 2D DT CWT is formed using 1D Hilbert transform of the usual 2D real DWT. Such complex transform provides near shift invariance, directional resolution improvement and phase information to linearly encode signal location. The 2D DT CWT has 4x redundant domain with six directional subbands.

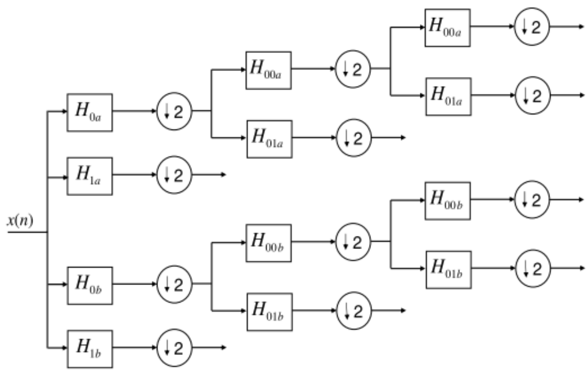

Fig. 5. The dual-tree of the complex wavelets [11].

3. RESULTS

Theoretical analysis of multiscale transform potential in contour description and enhancement shows wavelet bases and decomposition scheme dependence of the modeling results. The mammograms are kind of images with noise, irregular, complex and diverse texture of breast tissue. It is difficult to define that mammogram is image of piecewise smoothness or not. Therefore, it is not possible to affirm, based on theoretical analysis, which among multiscale transforms are more effective to model the ADs spicules. Additionally, indefinite characteristic features of ADs spicules make difficulties in creating the model of mammogram local texture directionality. In our research, two selected multiscale transforms (the DWT and the DT CWT) (Matlab implementation by Nick Kingsbury [10]) were tested to verify their texture orientations modeling capabilities. Simple AD phantoms were used to express fundamental features of spicules. According to earlier our research [9], we estimated that width of ADs spicules could be 9 pixels in average. Therefore, created phantoms of spicules have respondent size to real AD structure in mammograms (Fig.6).

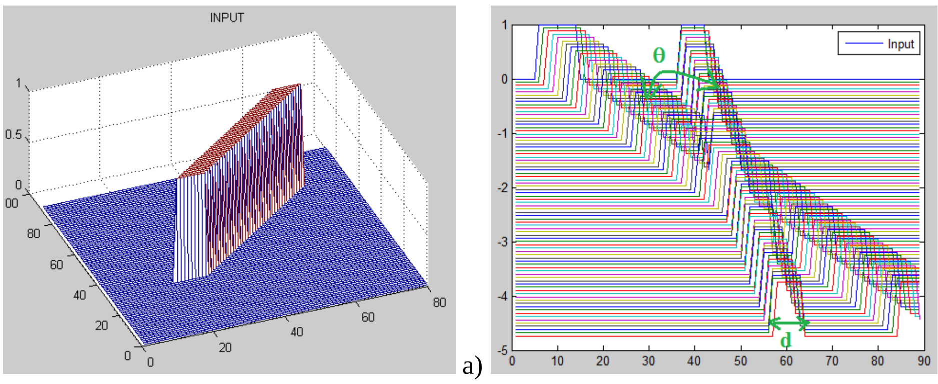

Fig. 6. The phantoms of AD spicules used in the simulations: (a) a single spicule of 9 pixels width, (b) two crossing spicules – width of spicules d = 9 and 6 pixels and angle between them θ = 15° or 30°.

First, we checked the undesirable influence of shift-variance of the DWT on spicule signatures in transform and reconstructed images. Small shift in input signal causes strongly variations in the amplitude of discrete wavelet coefficients. Single spicular structure after the wavelet transform (both discrete and complex) should be presented as two enhanced edges. However, in case of using the DWT it is difficult to catch two definite edges on reconstructed real signals (projections). Whereas, the DT CWT response are clearly much more consistent with shift (Fig.7, Fig.8). Visible effect of wavelet superposition results from the fact that width of spicule phanom is similar with filter size used in transforms.

To understand an additional preponderance of the DT CWT above the DWT in image processing, particularly in our research on ADs detection, phantom of two crossing spicules is used (Fig.6b). The reconstructed real image with gained adequate level and various angle between spicules were presented in Fig.9 and Fig.10. The signatures of close-lying linear spicules in reconstructed images of gained successive levels of the coefficients in both DWT and CWT cases are different. These differences are more perceptible for higher levels because of gained levels containing lower frequency, more compact in energy information. Owing of shift invariant the DT CWT allows to extract spicules orientations much better than the DWT (Fig.9). Enhancement of spicules orientations is additional disturbed by small angle between these spicules (Fig.10).

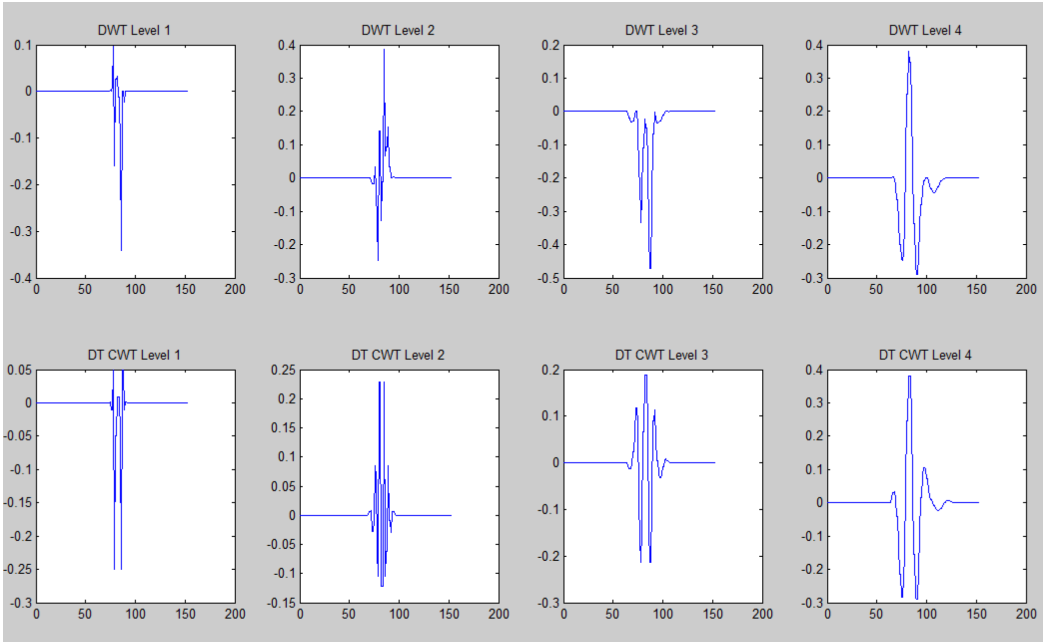

Fig. 7. Comparison of reconstructed real signal projections of input visible on Fig.6a with applied gain to respectively level which are achieved using the DWT and the DT CWT.

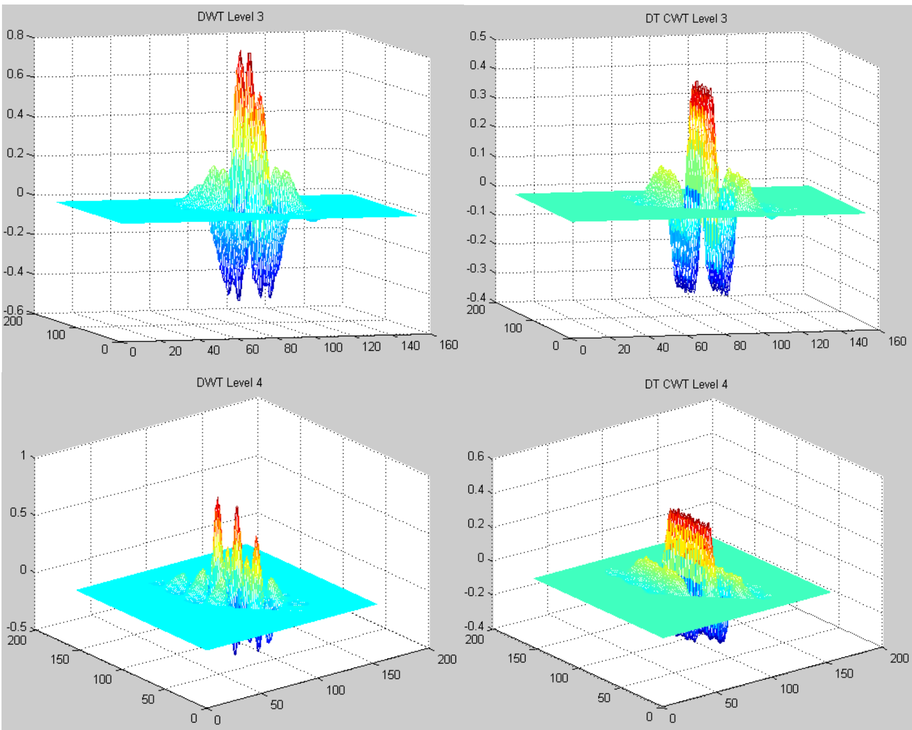

Fig. 8. Comparison of reconstructed real signal (all projections) of input visible on Fig.6a with applied gain to respectively level which are achieved using the DWT and the DT CWT.

Besides additional features reflecting elongated segment characteristics in multiscale domain, useful to recognize AD spicules, initial extracting of the spicules from the source image based on selective transform reconstructions was tested. Phantom of AD spicules with added noise was compared to its selective scale wavelet representatives – see Fig.11. Empowered linear structure in the DT CWT reconstruction enables simple AD spicule extraction or enhancement by simple thresholding procedure.

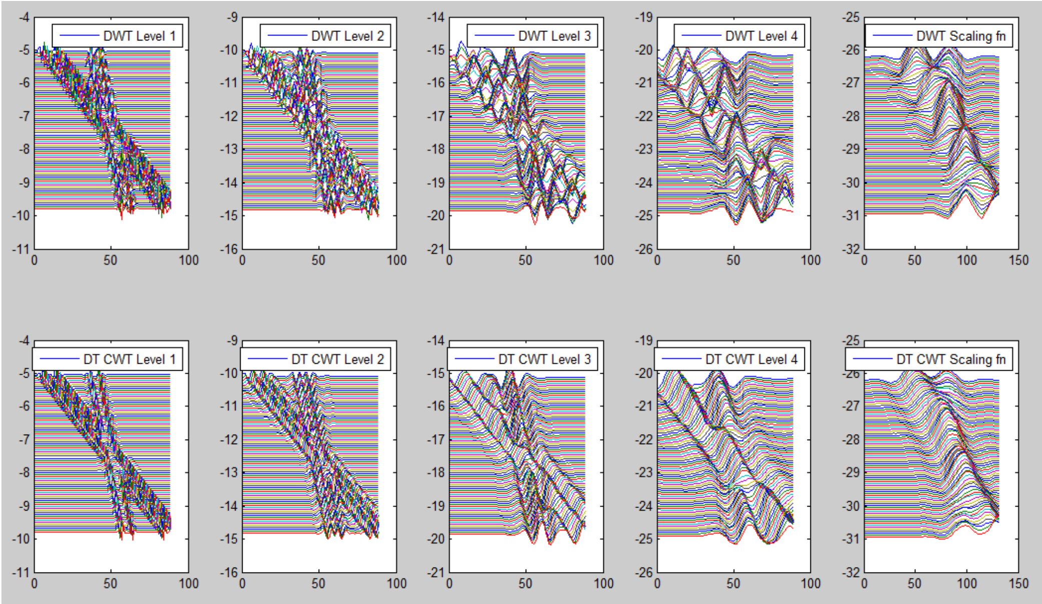

Fig. 9. Comparison of reconstructed real signals of input visible on Fig.6b (with angle θ = 30°) with applied gain to respectively level which are achieved using the DWT and the DT CWT.

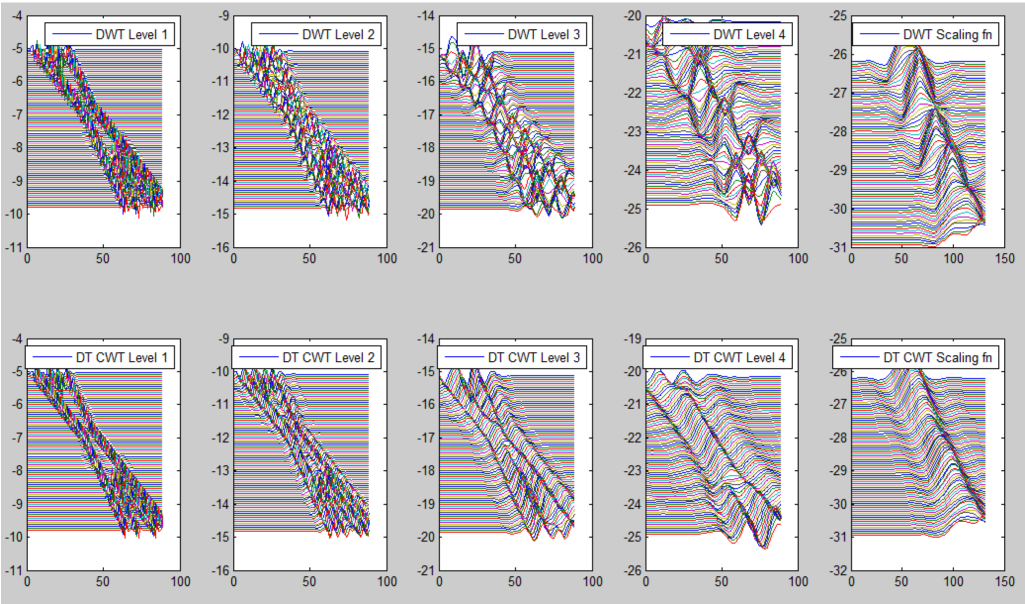

Fig. 10. Comparison of reconstructed real signals of input visible on Fig.6b (with angle θ = 15°) with applied gain to respectively levels which are achieved using the DWT and the DT CWT.

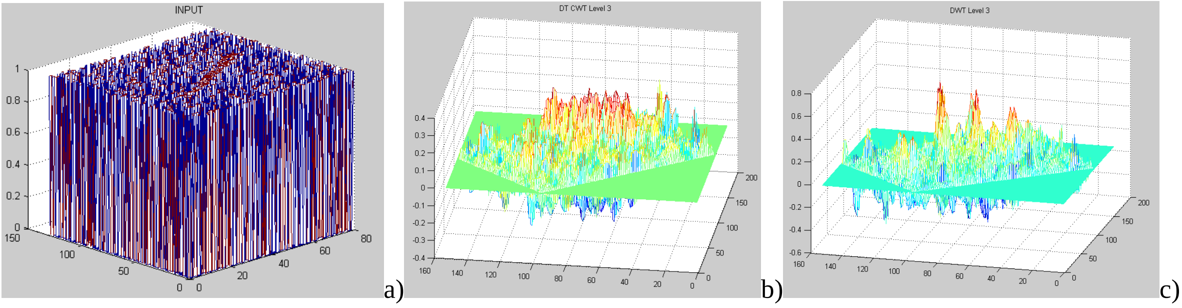

Fig. 11. Extraction of spicule from phantom containing added noise (a) in DT CWT reconstruction (b) compared to the DWT reconstruction (c) of respective levels.

4. CONCLUSIONS

Multiscale transform by the DT CWT was checked preliminarily as the extractor of the image structure orientations. Conditions of multiscale transform such as multiresolution, representation of basis elements presented in both the spatial and the frequency domain with lack or small redundancy of domain are helpful for effective modeling of image orientations, so they can be potentially useful for further ADs extraction on mammograms. It allows to enhance crossing spicules with small angle between them. Shift invariant, good directional selectivity in six different orientations are desirable in detection of ADs spicules on mammograms. Enhancement of local texture directionality, especially spicules represented by phantom following real spicules fundamental features, by the DT CWT is useful to improve image analysis and in consequences computer-aided detection of potential ADs.

In future, the effective directional features calculated on reconstructed images with gained respectively levels coefficients of complex wavaelets for differentiating ADs and normal breast tissue are searched.

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