# ULTRASOUND SPECKLE REDUCTION BY DIRECTIONAL MEDIAN FILTERING

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## ABSTRACT

This paper presents a novel adaptation of the median filter to the problem of boundary-preserving speckle reduction in ultrasonic imaging. The technique involves applying a bank of oriented one-dimensional median filters to the image, and retaining at each point the largest value among all the filter bank outputs. The result is an operator which suppresses speckle noise while retaining the structure of the image, particularly the thin bright streaks, which tend to occur along boundaries between tissue layers. The technique is compared to a block median filter and an algorithm discussed by Loupas *et al.*, and is shown to be far superior to the median filter, and noticeably better than the Loupas filter at enhancing thin lines.

## 1. THE ULTRASOUND SPECKLE PHENOMENON

Ultrasound speckle is a quasi-random phenomenon which occurs when acoustic pulses of coherent phase are used to image soft tissue, and are non-coherently detected to form an image. Many biological tissues contain densely spaced unresolvable ultrasound scatterers as well as larger tissue discontinuities (targets) whose surfaces are rough on the scale of a typical ultrasound wavelength. Thus, ultrasound speckle is similar in origin to laser or radar speckle.

Speckle is often modeled as a multiplicative process [1], because fully developed speckle has the property of constant signal-to-noise ratio. This is a result of the physical mechanism which gives rise to speckle, the constructive and destructive interference of pulse reflections from different parts of a rough surface [2, 3]. Thus, the speckle fluctuations in the signal will be proportional in magnitude to the signal strength, and the resulting image will have significant noise even in very bright regions.

## 2. THE USE OF "STICKS" IN ULTRASOUND IMAGERY

A useful idea in analyzing and processing ultrasonic images is that a set of "sticks," line segments of constant length and variable orientation, can locally approximate certain image features. In particular, tissue boundaries have the appearance of straight or gently curving line segments because they are cross-sectional views of the surfaces between tissue layers. The boundaries are smooth on the scale of the spacing between scan lines and generally define closed convex shapes. However, in many cases they are discontinuous, for example, at locations where a boundary lies parallel to the beam axis.

We have found the use of sticks as templates to be very successful in automatically identifying boundaries in an unsupervised setting. In [4], we presented an image enhancement technique involving local projections of image pixels onto the set of sticks. That algorithm produces an enhanced image by plotting at every point the maximum value obtained by summing pixels along a stick passing through the point, and varying the orientation of the stick. In [5], we formulated the problem of boundary detection as a composite hypothesis testing problem, and compared the stick projection technique in [4] to several other algorithms for detecting stick-like line segments in simulated ultrasound speckle.

Linear and linear-quadratic operations for line detection can offer good performance under certain conditions if the signal and noise are modeled exactly. However, if the detection scenario deviates from the assumed statistical model, the performance of the schemes in [5] is significantly degraded [6]. Simple schemes such as [4] are far more robust than those which make more detailed assumptions about the noise statistics. With this in mind, we consider the median filter, because it is an alternative to linear filtering which has been successfully applied to many problems, including ultrasound speckle.

## 3. MEDIAN FILTERS IN IMAGE PROCESSING

The median filter is a widely used non-linear technique, often applied to images with "salt and pepper" or impulsive noise [7]. It operates by replacing each pixel with a median value computed over a local area. The median filter is a special case of a more general class of order-statistic filters [8, 9] that has been applied to image restoration problems. Order statistic filters are particularly effective in reducing noise whose probability density function has significant tails [10].

Several researchers have experimented with adaptive median and order statistic filters [11, 12, 13, 14, 15]. In partic-

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ular, Loupas *et al.* [16] have defined an adaptive weighted median filter which uses the ratio of mean to variance as a measure of how nearly uniform in value the pixels in an area are. A small mean to variance ratio causes the filter to give additional weight to centrally located pixels before applying the median operation. This is appropriate if the central pixel is in the vicinity of an image discontinuity. Conversely, a large mean to variance ratio implies that the central pixel is in a region of nearly uniform pixel intensity, in which case more distant pixels can be given greater weight under the median operation.

Extra weight is applied to a pixel by counting that pixel's intensity more than once before taking the median operation. The amount of extra weight given to a pixel a distance $d$ from the central pixel in [16] is

$$w = \left[99 - 20d\frac{\sigma^2}{\mu}\right], \tag{1}$$

where $\sigma^2$ is the local variance, $\mu$ is the local mean, $[\cdot]$ represents rounding to the nearest integer, and the constants 99, 20 (and the block size $9 \times 9$, used in the examples given here) are empirically determined in [16].

The Loupas algorithm is capable of applying more or less smoothing depending on local image statistics. This represents an improvement over the block median filter. However the algorithm still uses an operator which is fixed in shape (*i.e.* round: two points an equal distance from the central pixel receive identical weight). This fixed shape can cause difficulties in enhancing image features such as line segments.

## 4. A DIRECTIONAL MEDIAN FILTER

In this paper, we propose a new adaptive median filter, based on the success of the sticks technique as an image enhancement tool sensitive to linear image features. As in the sticks-based procedures discussed in [4, 5, 6], we define a set of short straight lines passing through the center of a square template. At every point of the original image, we compute a set of median values, each corresponding to a stick of different orientation $\theta$, $s_\theta(x,y)$, and computed by taking the median of the pixel intensities that lie along the stick. The enhanced image is formed by selecting the largest median value at each point. Mathematically, this can be written as

$$I_{out}(x,y) = \max_\theta \operatorname{med}_{\xi,\eta}\left[I_{orig}(x-\xi, y-\eta)\, s_\theta(\xi,\eta)\right] \tag{2}$$

in terms of the original image $I_{orig}(x,y)$ and the sticks $s_\theta(x,y)$.

The median filter is applied only along a single line at a time, and thus applies its smoothing only in a single direction. In this fashion, the blurring due to the median filter is reduced, since the median is only taken in the direction with the most significant straight line component.

The directional median filter is related to the Loupas filter in the sense that each orientation filter can be described as a block from which some elements are given unity weight, and the others are given zero weight within the median operation. The optimization is performed by selecting which filter output is retained. In this research we experimented with the ratio of mean to variance as a means of identifying the dominant line segment at each point, but found that the simple max median operation in (2) offered better performance.

## 5. RESULTS

Figure 1 (a) shows an image collected from a pork carcass using a commercial medical ultrasound imaging system. Figure 1 (b) shows the results of processing that image using a $9 \times 9$ block median filter. Figure 1 (c) shows the results of processing the image with a length 9 Loupas filter. Figure 1 (d) shows the result of applying a $9 \times 9$ directional median filter to the image.

The image produced by the block median filter is significantly blurred (Figure 1 (b)). The Loupas filter reduces speckle somewhat, but severely smears the boundaries which separate the subcutaneous fat layers pictured near the top of the image (Figure 1 (c)). In contrast, the directional median filter preserves the sharpness of these boundaries (Figure 1 (d)), resolving them much more distinctly than the Loupas or block median filter.

In practice, one would not use such a large median filter, because the blurring associated with such operators is well known. We have presented Figure 1 (b) to illustrate the point that the directional median filter can be applied on a much larger scale than a block median filter, because its activity is restricted to lines of relatively high amplitude; a block median filter can not be scaled as easily. The Loupas filter is an improvement over the block median filter because it selectively applies greater smoothing only in locations where the image has no significant features. Since it is constrained to an essentially round shape, however, it is unable to match the linear feature enhancement offered by the directional median filter.

The image output from the directional median filter is characterized by a honeycomb appearance in the interior of the muscle. This texture is similar to that observed with the sticks projection methods described in [4, 5], and results from the tendency of sticks-based algorithms to resolve speckle noise into lines. The intensity of this pattern is related to the average gray level of the original image and the stick length used to process the image. The pattern becomes more uniformly gray as stick length is increased, as the speckle tends to be less resolvable into lines of longer lengths.

This pattern can interfere with the detection of features such as the back wall of the muscle pictured in Figure 1 (shown as a relatively broad faint streak in the middle of the image, towards the bottom). The back wall is slightly more visible in the Loupas output than in the directional median filter output because the Loupas algorithm gives superior speckle suppression in this region. However for linear features with high contrast, the directional median filter offers a performance improvement over the Loupas algorithm.

## 6. CONCLUSION

This paper has presented a directional median filter for speckle reduction and feature enhancement in medical ultrasound. Results are given which show the superiority of the directional median filter to block median filtering. In resolving linear features, it is also clearly superior to Loupas' adaptive weighted median filtering. The technique is related to one presented earlier [4, 5], except that in place of the median operation, those papers use a simple sum of pixel intensities. The present paper extends our previously published work by showing that the stick model can be combined with other simple filtering techniques to produce useful image processing and analysis techniques.

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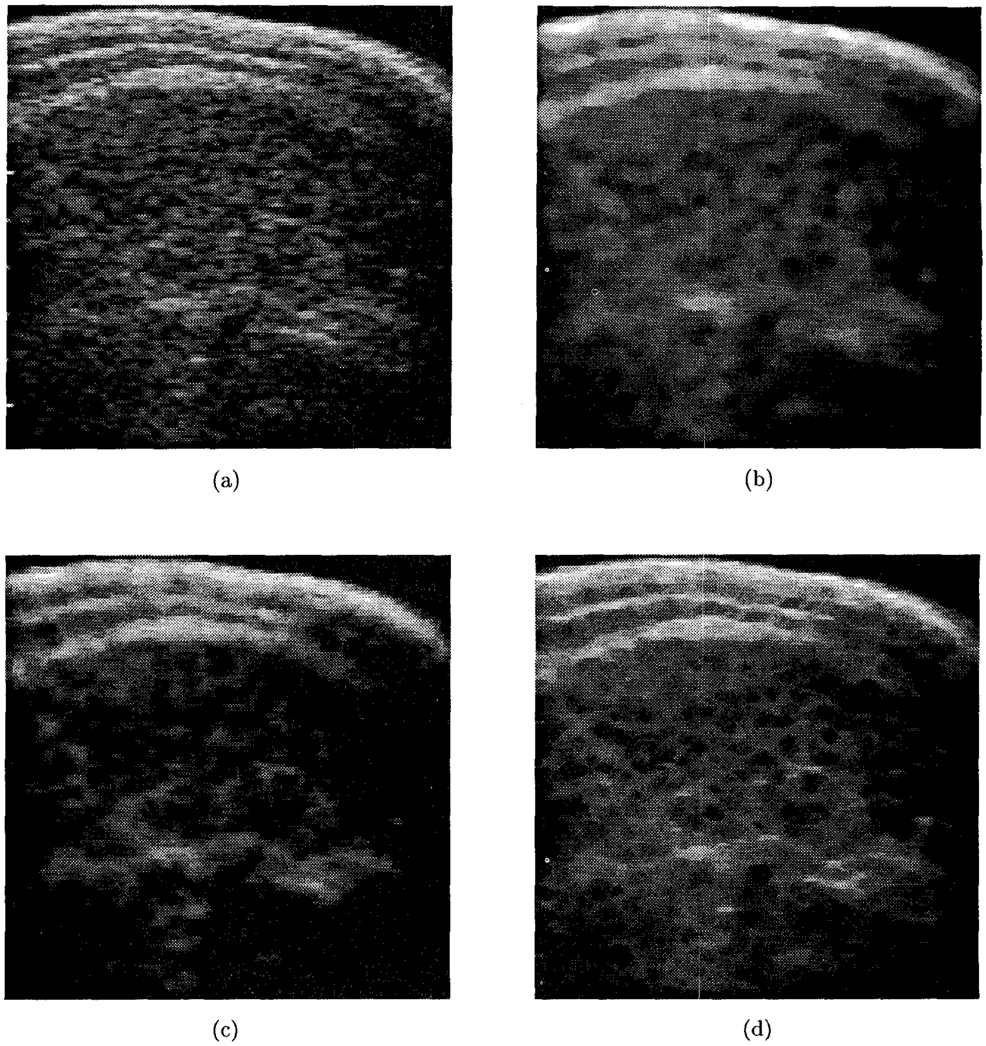

Figure 1. (a) Original image, showing a pig muscle in cross section. (b) Result after filtering with a 9 × 9 median filter. (c) Result after filtering with a 9 × 9 Loupas filter. (d) Result after application of a 9 × 9 directional median filter. The thin boundaries between subcutaneous fat layers shown at the top of the image are much more clearly resolvable in the directional median filtered image than in the Loupas filtered image. In regions without linear image features, however, the Loupas filter shows superior speckle reduction capability.