AN APPROACH TO BOUNDARY DETECTION IN ULTRASOUND IMAGING

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ABSTRACT

Ultrasound imaging systems pose unique challenges for standard edge detection algorithms, because the boundaries between regions of interest in an ultrasonogram are typically bright streaks between similar intensity regions, rather than demarcations between regions of differing contrast. This paper presents an approach to boundary identification in ultrasound images that sidesteps this problem by the use of operators that work parallel to the edges rather than perpendicular, as most edge detection procedures do. These operators, called "sticks," are line segments short enough that they can locally approximate the edges in the image, but long enough that their projections onto background noise are insignificant. The algorithm produces a new image by plotting at every point the local projection of the original image onto the stick whose orientation relative to the image maximizes the projected value. The result is an image with reduced speckle noise and enhanced edges in which boundaries between different regions can be more easily detected. This approach has been applied to real-world distance estimation research; processed images indicate distances which correlate highly with physical measurements of the actual tissue.

1. INTRODUCTION

The problem of edge detection is fundamental to many image processing systems. Often, a computer vision system will first identify edges before it attempts to segment an image and identify objects. Indeed, even to human observers, an image composed solely of edges maintains a high degree of recognizability, even without the shades of gray which make up the original image.

Most edge detection schemes assume that the edges are defined by step discontinuities in pixel intensity. In other words, the edge detector looks for regions of sharply differing intensity and identifies boundaries between them as the edges. For many classes of images, such as photographs, this edge model works well. However, the boundaries in an ultrasound image are different, often appearing as bright streaks between regions of similar intensity. Thus it is appropriate to use an edge detector which takes advantage of the special appearance of ultrasound edges.

In this paper, we propose a new image enhancement algorithm which emphasizes thin edges while rejecting a noisy background. This approach works by modeling the edges as thin lines of unknown orientation. In implementation, this technique is similar to the Hough transform[1], which is often used in computer identification of complicated objects.

The result is an enhancement algorithm which displays even very thin edges clearly, is robust in the face of discontinuous lines, and enables accurate detection of the position of ultrasonogram boundaries in a practical research project.

2. CONVENTIONAL EDGE DETECTION OPERATORS

A typical edge detection algorithm uses a global search on the image to find locations where pixel intensity changes sharply. This is equivalent to looking for large values of the derivative of the image. Since the image is essentially a two-dimensional discrete-indexed function, for which no exact derivative exists, a two-dimensional differencing operator is used to approximate the differentials. Two popular such operators are the Roberts and Sobel operators [2]. Since edges can occur in most images at any orientation, no single differencing operator can be effective when used alone. Usually a family of operators are used, each sensitive to edges of a particular orientation, and a point is identified as an edge if any of the differences are greater than some threshold. Such techniques are often used in detecting edges in additive noise.

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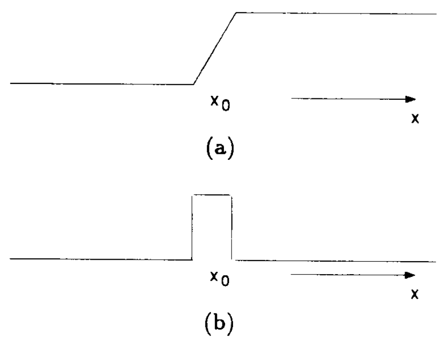


Figure 1: (a) A one-dimensional signal with a step discontinuity. (b) The ratio of averages operator returns a small value except near x_0, where the discontinuity is clearly indicated.

2.1. EDGE DETECTION IN MULTIPLICATIVE NOISE

Speckle noise is a chaotic phenomenon caused when a coherent imaging system such as ultrasound is used to image a surface which is rough on the scale of the wavelength used. The surface produces many reflections in each resolution cell which add coherently to produce the speckle pattern. The speckle noise is often modeled as being at least weakly multiplicative, since the intensity of the speckle pattern at each point is directly related to the intensity of the reflection at that point. As a result, the performance of an edge detector searching simply for a large derivative magnitude will depend on the image intensity at each point, and will vary from location to location.

In the presence of multiplicative noise, a better approach to detecting step discontinuities involves a *ratio of averages* (RoA) operator [3], which looks for large relative jumps in image intensity instead of large absolute jumps. This technique can be considered as the two-dimensional generalization of the following technique for finding discontinuities in a one dimensional signal. Consider a one-dimensional cross section of an image as shown in Figure 1(a).

The edge detected image cross section shown in Figure 1(b) is obtained by applying the following operator at each point:

$$s(x) = \left| \frac{u(x+1)}{u(x-1)} \right|, \qquad (1)$$

where $u(n)$ is the unprocessed original line. Note that since image pixel intensities are assumed to range from 1 to 255, division by zero is not of concern in evaluating (1).

The generalization of (1) to the case of a two-dimensional image lies in generalizing the RoA operator to work in all directions of interest. As in the additive noise case, typically a family of operators are used, each sensitive to discontinuities in a particular direction, and an edge is detected whenever any of the filters returns a value greater than some threshold.

The RoA technique requires the user to make a performance trade-off: a large operator will find edges reliably with few false detections, but will show them as broad stripes, not thin lines. A smaller RoA operator can produce thinner edges, but may also detect spurious edges in the background speckle. Thus, the size of the operator must be selected with care for each application.

2.2. BOVIK EDGE DETECTION

An important result in Bovik [4] combines a RoA edge detector with another technique (known in [4] as a LoG operator) involving the Laplacian of a Gaussian filter. The image is first filtered with a point-spread function obtained by taking the Laplacian of a two-dimensional Gaussian function. The zero crossings of the resulting image represent an edge map in the noise free case, where the edges appear as lines usually a single pixel wide. The speckle also produces many other zero crossings, but they have a low probability of occurrence near the true edges of the image. By taking the intersection of the LoG edge map with the RoA edge map, an edge map is produced which corresponds well to the desired edges in examples drawn from synthetic aperture radar applications. This technique appears to represent the state of the art in detecting step discontinuities in speckle noise.

3. LINE DETECTION USING STICKS

The approaches described above are not appropriate for use in ultrasound images because the character of the edges is fundamentally different. Since ultrasound images are generated from acoustic waves reflected from tissue discontinuities, the edges in a typical image often appear as lines in an apparently constant-intensity background, rather than as boundaries between different regions in an image corrupted with simple additive noise. We propose to search for ultrasound edges using operators which work parallel to the boundaries, rather than perpendicular. The key to this scheme discussed is an operator called a "stick."

A stick is a constant-length line segment of variable orientation, which we use at every point of the image to determine the strength of the most significant line passing through that point (if any). At each pixel, we

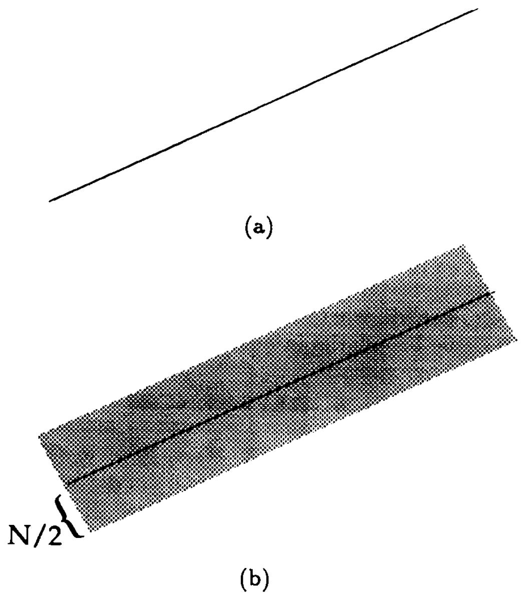


Figure 2: (a) Sample image, containing a single line in a background of zero-mean noise. (b) Stick detection of the line in (a) using a stick of length N. The enhanced image in (b) shows the line clearly, surrounded by an N-pixel wide region of lower intensity (but not non-zero mean) pixels which result from applying the stick operator to pixels in the vicinity of the line.

project the image onto a family of sticks, differing in orientation, but always centered at and passing through the pixel under study. The greatest total projection of any stick is then plotted as the pixel intensity of the enhanced image at that point. In other words, at each point, we compute the sum of intensities of all the pixels that lie along a straight line segment through the original point, and plot the greatest sum.

This operation can be seen to enhance thin lines in the mean in the case of a background of additive zero-mean noise. For example, consider the case of the long line shown in Figure 2 (let points along the line have unit average value, and background points have zero mean). Using a stick of length N, the original line will appear in the enhanced image with an average intensity of N, since sticks lying exactly along the line will encounter N unit average pixels. All background pixels within $N/2$ pixels of the line will have unit average, since a stick perpendicular to the line will pick up a single pixel from the line. Clearly, the detection of edges in an actual image is a more complicated scenario and this example serves only to illustrate the means by which the approach works.

Strictly speaking, this technique is applicable only to the detection of long, straight lines. We find, however, that by making the stick sufficiently short we can restrict attention at each point to a scale at which the edges look like straight lines.

Finite-length lines introduce some other effects that can mislead this algorithm. Specifically, sharp corners and abrupt ends of line segments are represented badly by this approach. The lines tend to blur out towards their end or corner, and appear to continue beyond their termination. This is because at pixels beyond the corner or termination sticks can still align with the original line, picking up and displaying intensity at points where the image contains no lines. Fortunately, in ultrasound imaging, we can restrict attention to edges defining essentially convex shapes; sharp corners and lines that simply terminate will not generally occur.

The result of the algorithm is an enhanced image in which tissue boundaries are more plainly visible than before processing, and in which the position of the boundaries can be more easily estimated.

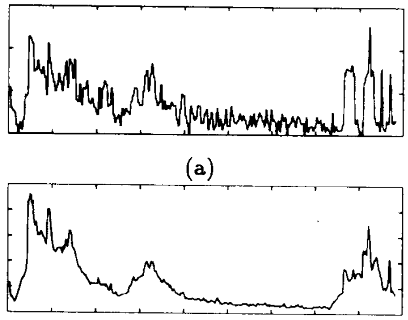
4. STATISTICAL BEHAVIOR OF THE STICKS EDGE DETECTOR

It can be shown that the technique described here is the optimal detector for straight lines in additive white Gaussian noise. While a Gaussian noise model is not very characteristic of speckle noise, optimal detection in speckle is an unsolved problem requiring the use of quadratic or higher order detectors with greater computational complexity. Issues of this sort will be treated in [5].

5. SIMILARITY TO THE HOUGH TRANSFORM

The Hough transform (HT) is a technique often used in computer vision to enable the machine detection of complicated shapes. To locate instances of a shape in an image, the HT requires the computation of a parameter space, the coordinates of which uniquely describe all translations and orientations of the shape that are of interest. For example, a circle would be fully parameterized by an ordered triplet (x, y, r), where (x, y) are the coordinates of the center of the circle, and r is the radius.

Each pixel in the edge map of the image is mapped to a locus of points in the parameter space identifying all possible occurrences of the shape in question that cause its boundary to pass through the original pixel. This becomes a costly operation when the shape becomes complicated. When the mapping from image to



(a)

(b)

Figure 3: A vertical cross-section of the image in Figure 4, (a) before and (b) after processing with stick operators. The processed cross section is much smoother, and its peaks are much more likely to correspond to true image features than the unprocessed cross-section.

parameter space is complete, the points in the parameter space where many loci intersect correspond to likely occurrences of the shape.

The use of stick operators for line detection is essentially the HT, where the shape in question is a short line segment. This special case can be very important, because the simplicity of the short line segments allows for relatively easy computation of the transform. More importantly, many complicated objects can be considered to be made up of short line segments, and this transform provides a good enhancement technique for those cases.

6. APPLICATION TO DISTANCE ESTIMATION RESEARCH

Figure 4 shows a typical image (a) before and (b) after processing. Note that lines in the original image preserve their directionality in the processed image. Even thin boundaries are clearly visible above the background in the output image.

Figure 3 shows a vertical cross section of this image taken 50 pixels from the left edge, both before and after processing. In the project that inspired this work, the important image features are the distances between tissue boundaries, represented by the bright lines this processing enhances. Figure 3 shows that the significant peaks *i.e.* those that correspond to true image features remain sharp, while the non-significant peaks corresponding to background noise are attenuated and smoothed. The result is that cross-sections of processed images are much easier to use than sections of unprocessed images for this type of distance estimation research.

7. CONCLUSIONS

We have presented an algorithm for image enhancement which emphasizes bright lines in a dark background, and which we propose for ultrasound image enhancement. The algorithm makes use of a new model for an edge processes which is better suited to the underlying physics of an ultrasound image. The technique is also shown to be useful in real-world distance estimation research, where it greatly facilitates the detection of tissue boundaries in an automated setting.

8. REFERENCES

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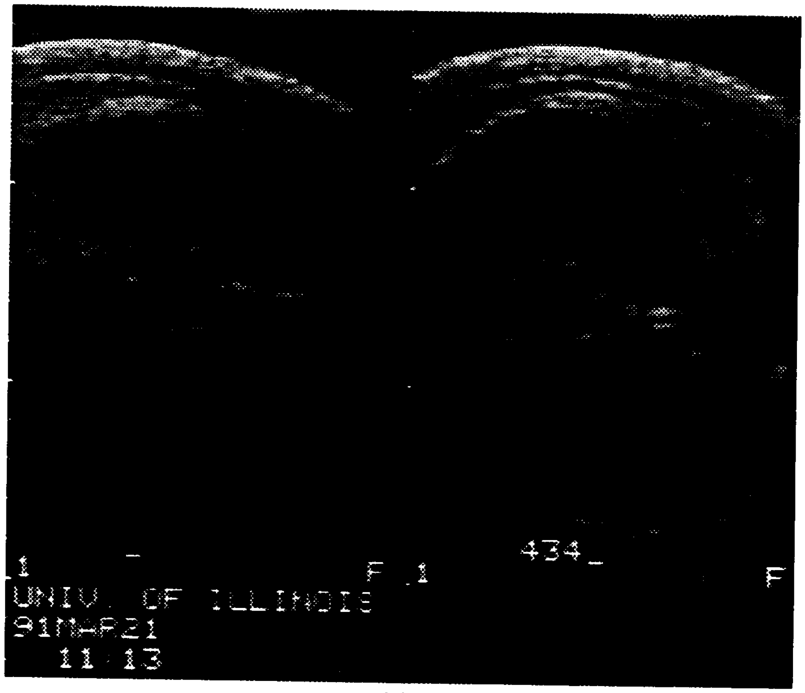
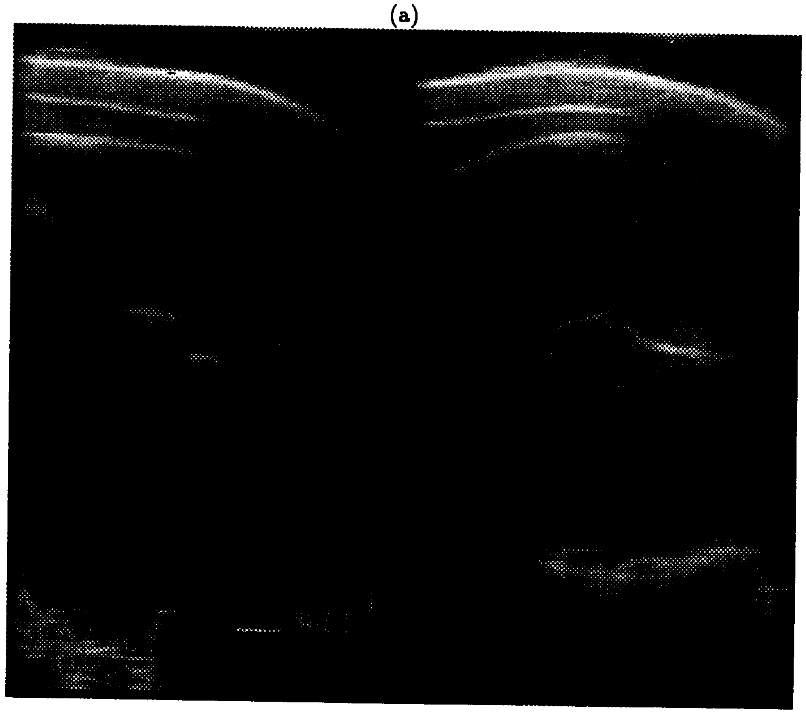


(a)



(b)

Figure 4: A typical image (a) before and (b) after processing with stick operators. The processed image is clearly enhanced, showing even thin lines without smearing, and rejecting background speckle, which typically appears as spots rather than lines.