LINEAR FEATURE ENHANCEMENT BY FALSE COLOR

Richard N. Czerwinski *Douglas L. Jones* *William D. O'Brien, Jr.*

Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois, 61801, USA
rnc@uiuc.edu *

ABSTRACT

This paper presents a technique of enhancing linear features in ultrasonic imagery by use of a false color. Color is used to indicate the direction of the most prominent line segment at each point, as determined by a detection algorithm. The resulting enhanced images contain additional information which is not directly available in the unprocessed image. Because the direction and original gray scale intensity are presented in orthogonal color components – hue and intensity, respectively, in (H, S, I) color space – the color information can be quickly removed to restore the original image for conventional diagnosis.

1. INTRODUCTION

B-mode ultrasound images are formed by interrogating tissue with high frequency sound which reflects off internal structures and propagates back toward the transducer. The reflections are non-coherently received and their intensity is displayed as a gray scale. Bright image points arise from specular reflections from large scatterers oriented nearly perpendicular to the interrogating beam, such as the boundaries between tissue layers. These tissue boundaries are three-dimensional surfaces being observed in two-dimensional cross section, and thus appear as bright curving lines against a dark background. Because the boundaries are smooth on the scale of the scan line spacing, they appear as straight lines if viewed in a sufficiently small neighborhood about each point.

In previous papers [1, 2, 3, 4, 5], we have approached the problem of boundary detection as a composite hypothesis testing problem. We have designed and analyzed the performance of algorithms to determine which, if any, of a number of "sticks," line segments of varying orientation, are present through each pixel. Ideally, a detection algorithm will produce large numerical values in the vicinity of boundaries, and smaller values away from boundaries. By applying a threshold, a binary edge map can be produced showing only those points most likely to contain edges.

We have found that, though not intended for this purpose, our detection algorithms can be used to produce useful *enhancements* of the original image. The algorithms tend to suppress speckle noise because the noise is generally uncorrelated over the length of the stick operator, while the boundaries are highly correlated.

To improve the enhancement ability of these detection algorithms, in this paper, we introduce a false color at each point to indicate the direction of the most prominent line at that point. This information has heretofore not been included in a direct fashion, but shows great potential to improve the visibility of subtle image features. The direction is displayed as the hue component of an (H, S, I) color space, the perceived color which varies with angle in the "color circle" which is used by computer drawing or image processing programs to show the relationships between available colors. Since the direction is coded in a component orthogonal to that used for the original gray scale intensity, the color can be easily removed to restore the original gray scale image for conventional diagnosis.

2. DETECTION OF LINES AND BOUNDARIES IN SPECKLE

In [1] and [6], we described a variety of techniques for detecting linear features in imagery corrupted by speckle noise. A simple projection-based image processing technique was shown to be effective at enhancing lines for detection by thresholding. The technique involves computing average pixel values along straight line-shaped image regions, and retaining the maximum value over all possible orientations of the line.

The result of this procedure is shown in Figure 1. Part a) of that figure shows an unprocessed ultrasound scan of the lower back of a live pig. The large region in the center of each half of the image is the longissimus muscle, which is situated beneath two clearly defined layers of subcutaneous fat, the boundaries between which are visible as strong bright streaks near the top of each half of the image.

Figure 1 b) is an image formed by plotting a gray scale intensity at each point proportional to the maximum stick projection at that point. In this image, the boundaries between fat layers and the longissimus muscle are more sharply defined. Furthermore, the speckle

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noise in the darker regions of the image is suppressed so that subtle boundaries, such as the back wall of the muscle, can be more clearly seen.

3. IMAGE ENHANCEMENT WITH FALSE COLOR

The Sticks technique is equivalent to the generalized likelihood ratio test for lines in additive white Gaussian noise. As such, it is suboptimal even if the noise model is correct. Nevertheless, we have found that the technique is effective not only for detection but also for subjective visual enhancement of images. Because the technique was developed in the detection context, we have considered it of lesser importance to indicate the specific orientation which produced the maximum value at each point. In the context of image enhancement, however, it may be of value to include this information, if the resulting images are more easily interpretable. This can be accomplished by assigning each pixel an orientation-dependent hue in addition to the intensity value proportional to the detector output.

The idea of applying false color to an ultrasound image is in widespread use to display motion information in Doppler ultrasound. We feel the notion has even broader applicability in ultrasound image enhancement. Recently, Momenan et al. [7] illustrated the use of false color to display statistical properties of the backscatter at each point of an image, leading to more successful detection of diseased tissue. That work raises interesting questions about which image statistics should be encoded onto false color. We believe that color based on the orientation of the most prominent line segment at each point has potential to significantly improve the detectability of weak linear features.

The problem of displaying angle and intensity as a color is one of displaying a hue, saturation and intensity (HSI) color space. This is complicated, because while HSI is a natural space for describing perceptible colors, not every HSI triplet can be made up out of the red, green and blue (RGB) components which compose standard computer displays. Thus, the mapping from HSI to RGB space is not exact or unique. Figure 2 was produced using the procedure shown in Table 1.

Example images resulting from enhancement with false color are shown in Figure 2 and Figure 3. These figures show the original image and the Sticks output image in false color obtained by coding the orientation of length 15, thickness 1 sticks as a hue. Note that the uncolored images can be obtained from the colored ones by summing red, green and blue components and normalizing to suit the display's dynamic range. In clinical applications, the ability to display additional information without "corrupting" the original image is important because the expertise of the ultrasound sonographer is highly specialized in analyzing images with a standard appearance.

Figure 2 (a) and Figure 3 (a) show the raw false color images, where hue is equally distributed over all angles. Figure 2 (b) and Figure 3 (b) show the same images, but with a color map which has been modified to show almost a full spectrum of color in the range of angles which describe the fat boundaries near the top of the image. In both images, the colored circle visible in the image was superimposed on the raw image and processed along with the image. The color at each point of the circle indicates the hue assigned to boundaries oriented parallel to a line tangent to the circle at that point.

The colored images, especially the (b) images, show clearly that the outermost fat boundary is in actuality two separate boundaries, a fact which is much more visually apparent than in the corresponding gray scale images. Thus, a more precise characterization is possible with the colored images. Because of this revealing demonstration, we believe that the use of false color is a very promising technique with potential to significantly improve the capability of diagnostic imaging devices.

False color allows two additional degrees of freedom in the display (only one of which is used here), which can be used to supply additional information to the user. More importantly, the additional information can be introduced into the display or switched off without qualitatively changing the appearance of the scan. Further research is required to determine the best quantities to encode using false color.

4. CONCLUSION

We have presented an image enhancement technique for ultrasound imagery which works by estimating the direction of the most prominent linear image feature at each point, and applying a hue characteristic of that orientation. We have also demonstrated an angle estimation technique, and the means of mapping a range of angles into hues. Finally, we have shown an example of this processing applied to a real image. The technique shows great promise at improving the visual detectability of linear features.

```
function (h, s, i) → (r, g, b)

h = h / 60

f = h - floor(h)

p = i*(1 - s)

q = i*(1 - s*f)

t = i*(1 - s*(1 - f))

case i of

        0: (r, g, b) = (i, t, p)

        1: (r, g, b) = (q, i, p)

        2: (r, g, b) = (p, i, t)

        3: (r, g, b) = (p, q, i)

        4: (r, g, b) = (t, p, i)

        5: (r, g, b) = (i, p, q)

end
```

Notes:

h is an angle between 0° and 360°

s is the saturation value set to some constant between 0 and 1 (unused in this application)

value is normalized to lie between 0 and 1

outputs, r, g and b all fall between 0 and 1.

Table 1. Conversion from (H,S,V) to (R,G,B) color space. Adapted from [8].

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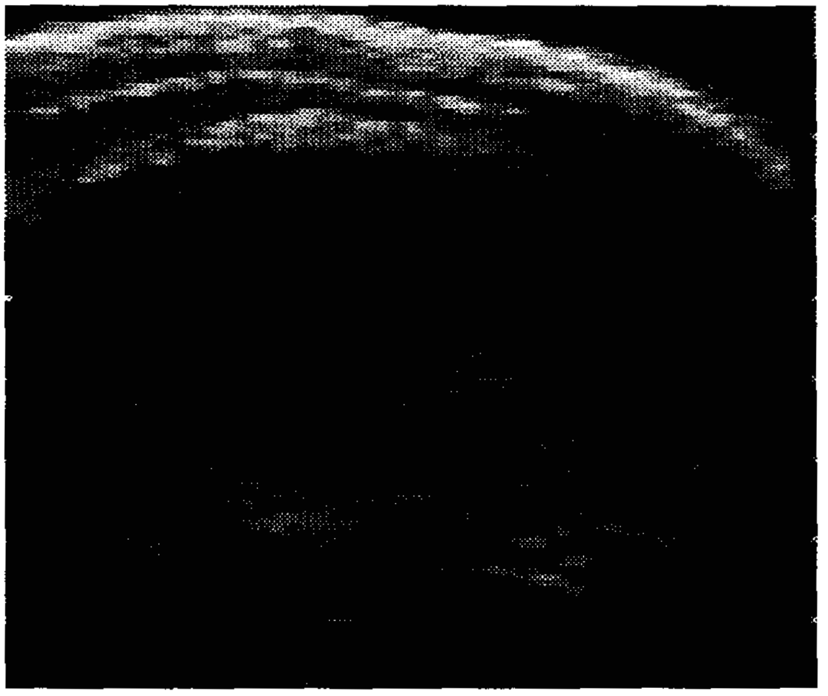
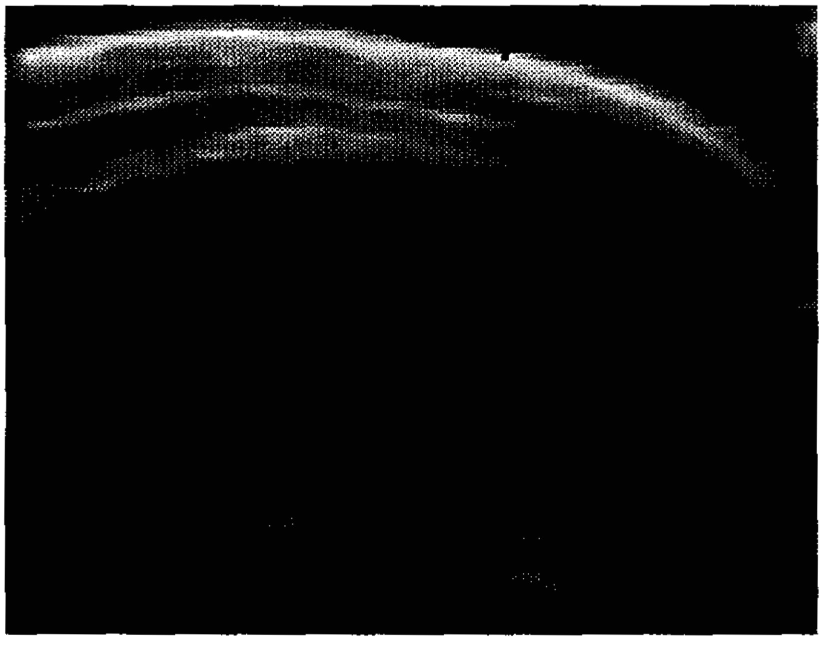


(a)



(b)

Figure 1. (a) Original image showing a cross-sectional view of the longissimus muscle and nearby fat layers in a live pig. (b) Image resulting from processing with a length 15 operator to detect and enhance linear image features.

Color figures not available in printed proceedings. Please visit `http://what.csl.uiuc.edu/~rnc` to download a postscript file containing Figure 2.

Figure 2. Original image with false color applied to indicate the direction of the most prominent stick at each point. The hue applied is obtained from the direction of the most prominent length 15, thickness 1 sticks at each point. The colored circle visible in the image was superimposed on the raw image and processed along with the rest of the image; its color at various points on its diameter indicates the hue assigned to boundaries at corresponding orientations. Part (a) shows color image with hues equally distributed over all angles; Part (b) shows image with colormap warped to better distinguish angles within a narrow range typical of this image.

Color figures not available in printed proceedings. Please visit `http://what.csl.uiuc.edu/~rnc` to download a postscript file containing Figure 3.

Figure 3. Sticks image with false color applied to indicate the direction of the most prominent stick at each point. The hue applied is obtained from the direction of the most prominent length 15, thickness 1 sticks at each point. The colored circle visible in the image was superimposed on the raw image and processed along with the rest of the image; its color at various points on its diameter indicates the hue assigned to boundaries at corresponding orientations. Part (a) shows color image with hues equally distributed over all angles; Part (b) shows image with colormap warped to better distinguish angles within a narrow range typical of this image.