

Speckle Reduction Imaging

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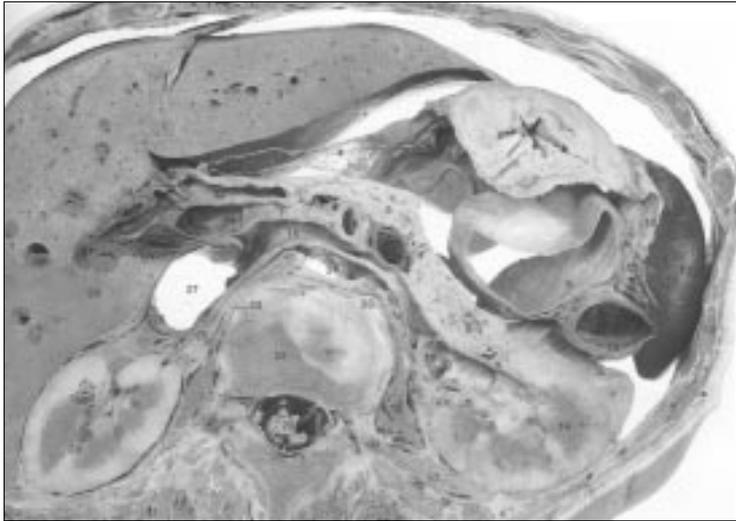


Figure 1.
Sectional view of the
upper abdominal viscera²

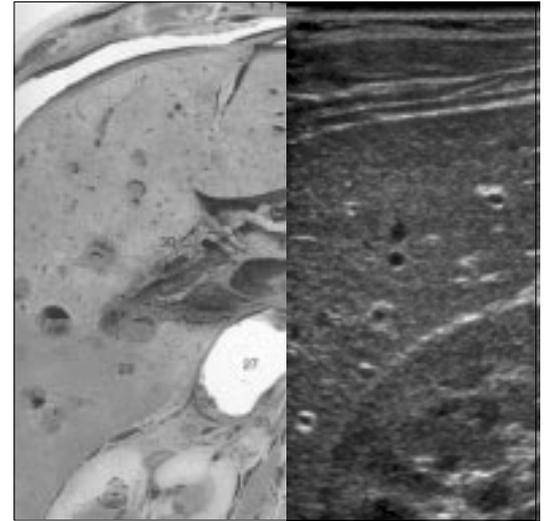


Figure 2.
An optical and ultrasound
image illustrating
approximately the same
liver and kidney anatomy

Abstract

Diagnostic usage for ultrasound has greatly expanded over the past couple of decades because it offers many advantages as an imaging modality. Ultrasound, however, suffers from an inherent imaging artifact called speckle. Speckle is the random granular texture that obscures anatomy in ultrasound images and is usually described as “noise”. Speckle is created by a complex interference of ultrasound echoes made by reflectors spaced closer together than the ultrasound system’s resolution limit. Considerable work has been done to reduce speckle in ultrasound systems but with marginal results. Leveraging the computational power of the TruScan Architecture on the LOGIQ 9, GE recently introduced a breakthrough in speckle reduction called SRI (Speckle Reduction Imaging). Initial clinical trials demonstrate that SRI improves the contrast resolution as well as overall clarity with no perceptible loss of frame rate or detail resolution.

Introduction

Ultrasound is an indispensable diagnostic tool because of its non-invasive, non-ionizing, real-time, portable and low-cost nature. However, ultrasound images suffer from an intrinsic artifact called speckle¹. Speckle degrades spatial and contrast resolution and obscures the underlying anatomy. It makes human interpretation and computer-assisted detection techniques difficult and inconsistent. Since speckle is a major shortcoming of ultrasound, reducing or eliminating speckle is of great interest to system designers.

Speckle and a Gross Anatomy Image

One of the objectives of an imaging modality is to display an image that closely represents anatomy. An optical image of anatomy, such as the cross-sectional view of the abdomen shown in Figure 1, has many characteristics desired in an imaging modality such as excellent detail and contrast resolution.



Figure 3. Magnification of optical and ultrasound images illustrate that speckle seen in an ultrasound image is not directly related to physical structure such as a liver cell

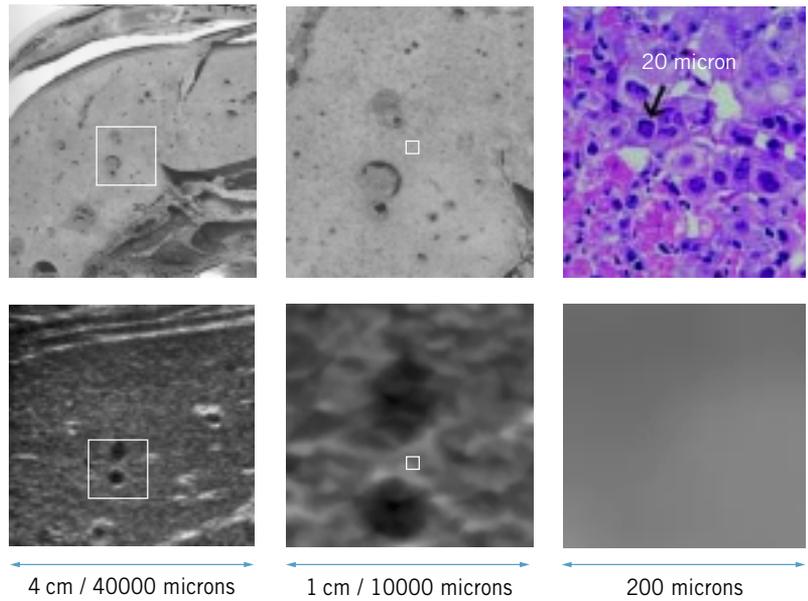


Figure 2 provides a direct comparison of this optical image to an ultrasound image of approximately the same cross-sectional view. A striking difference between the two images is the “noise” or speckle present in the ultrasound image. This noise arguably contributes to difficulty in differentiating structure.

By magnifying both the optical and ultrasound image, as in Figure 3, it is clear that the speckle does not directly represent the cellular structure in the liver.

Origins of Speckle

Since speckle cannot be directly correlated with specific reflectors, or cells, in the body, it is necessary to analyze an ultrasound system to understand the origins of speckle.

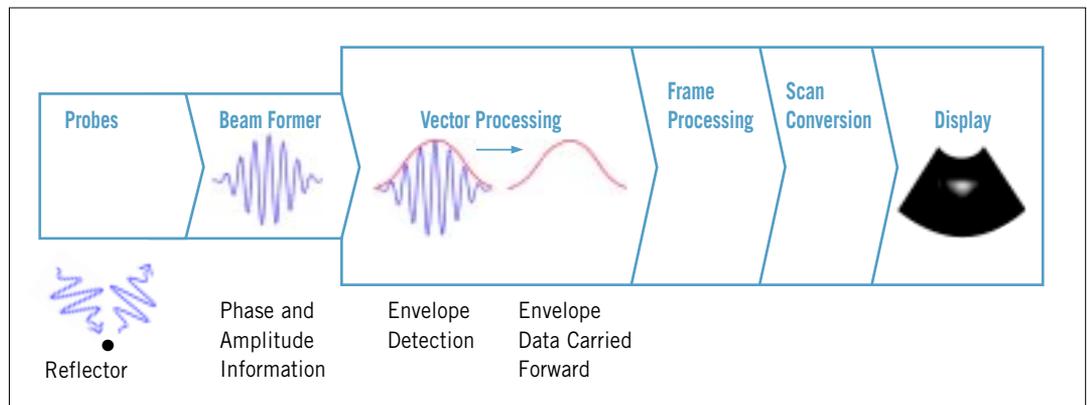
Resolution Limit

Figure 4 illustrates a basic, conceptual diagram

of an ultrasound system. The diagram illustrates the process of an ultrasound echo being transmitted, received and converted into an image on a display.

An ultrasound system forms an image by transmitting, receiving and then processing ultrasonic echoes. This processing includes envelope detection which captures amplitude information from sinusoidal signals. The amplitude information is further processed to produce an ultrasound image. Note that the displayed size of the reflector is determined by the length of the ultrasound pulse and does not represent the actual size of the reflector. The length of the ultrasound pulse determines the resolution of the system and is determined by factors such as frequency and bandwidth. For example, a 20 micron reflector would be imaged as approximately 400 microns at 8MHz.

Figure 4. Diagram illustrating operation of ultrasound system imaging of a point reflector



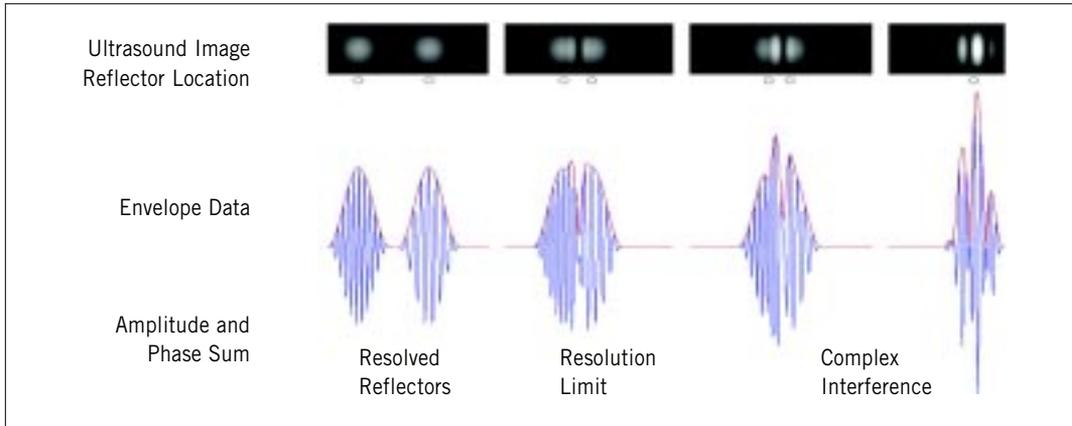


Figure 5. Illustrations showing the results of complex interference as two reflectors are moved together

Complex Interference

Imaging reflectors spaced closely together create additional problems. Variation in tissue attenuation, propagation and scattering properties make ultrasound echoes interfere in complex ways. For example, echoes from reflectors spaced closer than the resolution limit will interfere creating either artificially large (constructive interference) or small (destructive interference) signals. Figure 5 shows that as two reflectors move closer together, there is a point at which the two reflectors are not able to be resolved as distinct echoes but may appear as multiple reflectors.

Figure 6 extends the concept from two reflectors to 400 randomly-spaced reflectors in a line. To illustrate a grayscale image without complex interference, an “Amplitude-Only Sum” line illustrates pure summation of the reflectors assuming a given resolution. The “Average Local Intensity Image” bar simulates a grayscale image

that would be seen on a system with this type “Amplitude-Only Sum” or phase insensitive processing. It is seen that when reflectors are close together they consistently generate a strong amplitude signal, while reflectors spaced further apart generate a weak signal.

The “Phase and Amplitude Sum” line in Figure 6 illustrates the effect of complex interference between closely spaced reflectors. There are a couple differences between this and the previous example. First, the “Simulated Ultrasound Image” has characteristic light and dark areas that are not related to the actual reflector density as seen in “Average Local Intensity Image”. Notice the difference in grayscale between these images called out by the ellipses. Secondly, it is seen that the “Simulated Ultrasound Image” has a large number of light and dark areas that give the false impression of higher detail resolution.

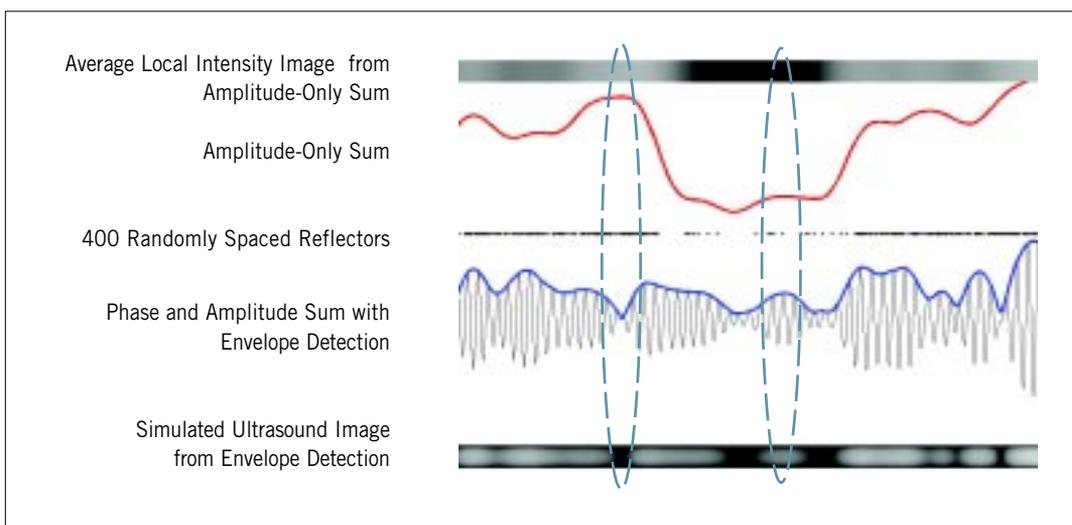


Figure 6. Four-hundred randomly spaced reflectors along a line illustrating the effect complex interference has on an “Simulated Ultrasound Image” by comparing it to an Average Local Intensity Image”

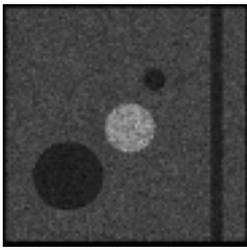


Figure 7.
One million reflectors randomly distributed with varying strengths

Complex interference effects are further discussed by distributing reflectors over two dimensions, as shown in Figure 7. “Amplitude-Only” and “Phase and Amplitude” comparative images are generated for comparison in Figure 8. The “Amplitude-Only” image represents the original reflector distribution accurately, and demonstrates only a slight loss of detail resolution. The loss of detail resolution being from a given resolution limit. The “Phase and Amplitude” image is dominated by speckle and shows a significant reduction in contrast resolution.

Figure 8 presents the “Optical Image” as comparable to the “Distributed Reflector Image” and the “Ultrasound Image” as comparable to the simulated image generated by “Phase and Amplitude” processing. It follows that “Speckle-free” ultrasound image would be comparable to the “Amplitude-Only” simulated image – representing the original anatomy with structural details limited only by the system resolution.

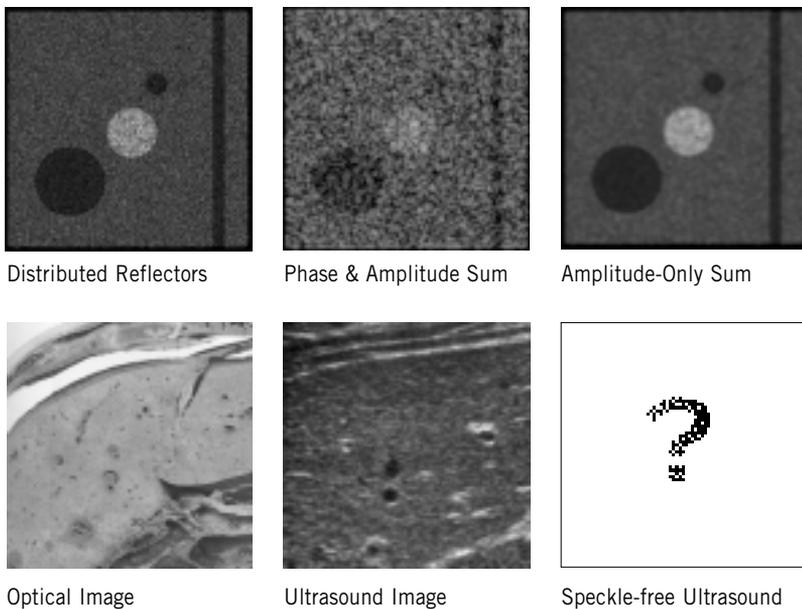


Figure 8.
Illustration showing a comparison between Distributed Reflectors with Phase & Amplitude Sum and Amplitude-Only Sum modifications to the comparable Optical and Ultrasound images of the liver

From the above series of simulations, it is clear that amplitude-only ultrasound images would be speckle free and more clearly represent anatomy. However, phase information is inherent in ultrasound beam propagation and beam formation. Speckle will always be present if reflectors are spaced closer than the system resolution limit. System designers, therefore, have worked on various methods to reduce or eliminate speckle.

Speckle Reduction Approaches

There have been many attempts to reduce or eliminate speckle. Current approaches fall into three broad categories including Resolution Enhancement Approaches, Averaging Approaches, and Post-Processing Approaches.

Resolution Enhancement Approaches

Previous sections describe how speckle is a result of interference between ultrasound pulses from closely spaced reflectors. It follows that if the resolution of ultrasound systems is increased, speckle would be reduced. Techniques for improving system resolution include: Higher frequency operation, Coded-excitation, Matrix-array transducers, and harmonics. Figure 9 illustrates how a higher operating frequency shortens the pulse length and avoids complex interference due to closely spaced reflectors. Higher operating frequency would progressively reduce speckle, but the pulse would have to be short enough to resolve the 20 micron cellular structure to completely eliminate speckle. This would require an operating frequency of 100 MHz, resulting in prohibitively high attenuation, and therefore not be practical.

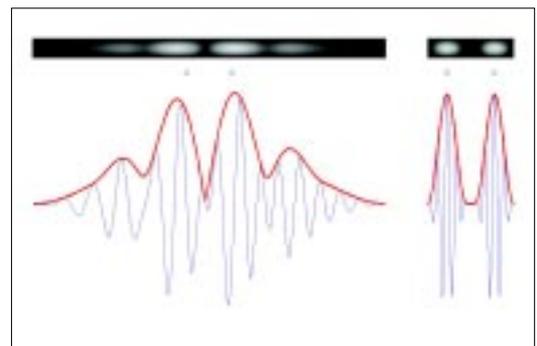


Figure 9.
Illustrates how higher frequency imaging would avoid complex interference caused by imaging objects closer than the resolution limit

Averaging Approaches

A number of averaging techniques have been used to reduce speckle. These methods include temporal averaging, spatial compounding and frequency compounding. These methods all average multiple decorrelated frames³. Decorrelation is obtained through tissue or probe motion in temporal averaging, beam transmitting and receiving at different angles in spatial compounding, and image formation at different frequencies in frequency compounding. Decorrelated frames have different speckle patterns, but the same feature information, so speckle gets reduced and feature information is comparatively strengthened. Averaging techniques suffer from limited speckle reduction effects – speckle is reduced by $1/\sqrt{n}$, where n is the number of frames. Additionally, the multiple frames in averaging techniques reduce the frame rate, making the techniques of limited practical use.

Post-Processing Approaches

Many different post-processing, or advanced image processing, approaches have been proposed for speckle reduction. The most common categories of approaches are: median filters⁴, Weiner filters⁵, diffusion filters⁶ and wavelet filters⁷. There are also some proprietary techniques that are commercially available, most notably are Philips' XRES⁸ and ContextVision⁹. All of these techniques have suffered from a loss of detail resolution or other shortcomings.

Methods – SRI

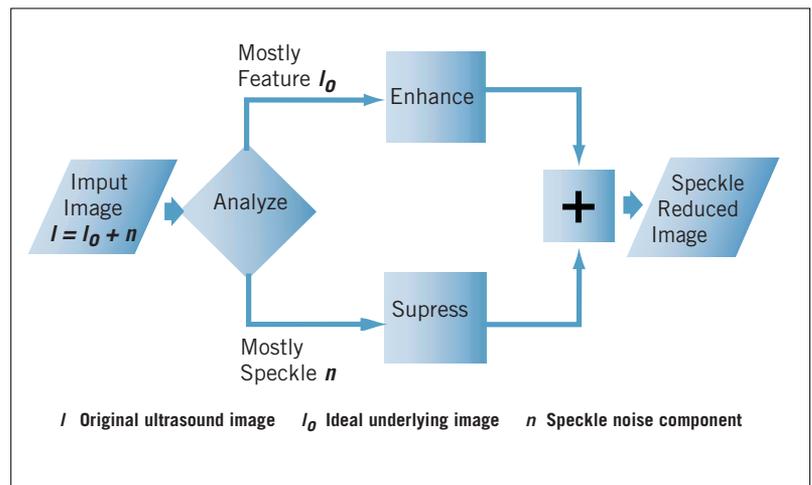
SRI, Speckle Reduction Imaging, is an advanced image processing technique to remove speckle recently implemented on GE's LOGIQ 9 Ultrasound system. SRI is based on the most recent advances in real-time adaptive image processing and is enabled by the computational power of GE Ultrasound's TruScan Architecture.

Algorithm

Figure 10 illustrates a block diagram of the SRI algorithm. In the Analyze phase, the image is examined pixel-by-pixel and classified as "Mostly Speckle" or "Mostly Feature". This classification is performed by examining the relative difference between neighboring pixel values and determining whether the grayscale variations have a sharp difference, follow a trend, or are random in nature.

Random variations are classified as "Mostly Speckle" and the SRI algorithm suppresses this variation while maintaining the local intensity. In the "Mostly Feature" region, the SRI algorithm preserves trends and enhances edges.

Processed image data from both regions are then combined to reconstruct the entire image.



Results

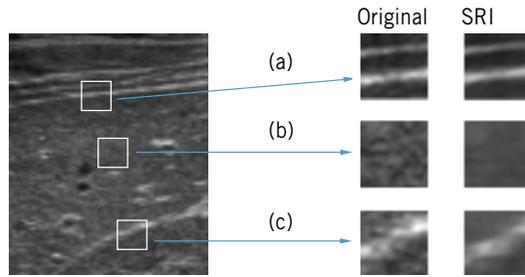
It is instructive to analyze the application of the SRI algorithm to a typical image. An example of such an analysis is shown in Figure 11. The image shows three distinct areas. The first selected area illustrates a bright and distinctive edge. The SRI algorithm recognizes this as a feature, thus enhances the edge – notice the tiny breaks along the edge caused by speckle variations are connected by SRI, giving a more consistent border definition. The middle region is an area that is mostly speckle and without any feature. The SRI Analyze stage determines that there is no feature in this area applies a suppress function, and gives a very uniform grayscale. The bottom portion has some speckle content, however it also has some feature, SRI correctly recognizes the existence of both speckle and feature, and applies suppress and enhancement to each of them. The result is an image that preserves the original image feature, while suppressing the speckle contents.

Figure 10. Block diagram illustrating Analyze, Supress and Enhance operations of SRI algorithm

Table 1. (below)
Table showing the dramatic decrease in variation and increase in SNR with using SRI

Image	Background Std Dev	Signal to Noise Ratio (SNR)
Original	16.9	.95
SRI	6.4 (-62%)	2.4 (+153%)

Figure 11.
SRI algorithm on typical liver showing:
(a) edge enhancement
(b) speckle suppression
(c) feature preservation



The implementation of the SRI algorithm allows the user to select various levels of speckle reduction. Different levels of speckle suppression on the same image is shown in Figure 12. Note that no loss of image detail is observed irrespective of the speckle suppression level.

SRI was also applied on a phantom image for a quantitative analysis of speckle reduction in Figure 13. A graph plotting grayscale intensity across the phantom shows two items. First, the spatial resolution is maintained with SRI. This is easily seen on the bright pin and the dark contrast lesion – both the Original and SRI lines are located on top of one another. Second,

random variation is reduced suggesting that speckle has been suppressed while the average local grayscale level has been maintained. Table 1 shows that SRI reduces variation by approximately 62% and increases in the signal to noise ratio (SNR) by 153%. The SNR was calculated as the difference between the mean pixel values between the lesion and background, divided by the standard deviation of the background.

SRI image quality improvements may be similar to image quality improvements achieved through methods such as CrossBeam, GE's innovative implementation of spatial compounding. However, as discussed previously, the approaches are very different. CrossBeam interrogates tissue at multiple angles and thereby introduces new tissue information and averages out speckle. SRI, on the other hand, aggressively removes speckle artifact from an image with no frame rate impact. Figure 14 graphically illustrates how CrossBeam and SRI combine to offer complementary and additive benefits to achieve an ideal image.

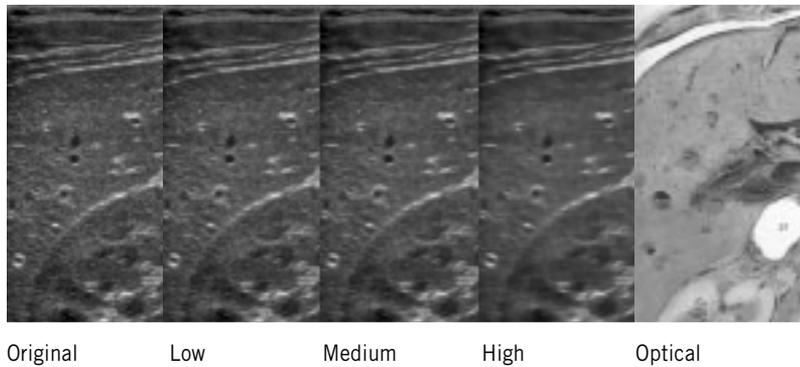


Figure 12.
Illustration showing the original ultrasound scan of the liver with low, median and high SRI settings versus an optical image



Figure 13.
A grayscale intensity plot illustrating that SRI maintains detail resolution while reducing speckle variation

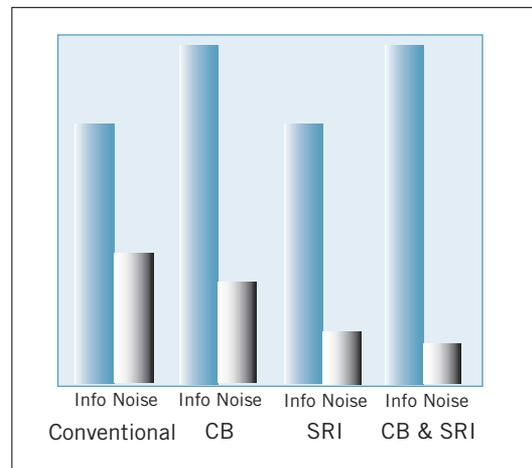


Figure 14.
Chart illustrating the benefits that CrossBeam (CB) and SRI bring to the information and noise content of an image



Figure 15.
A live split screen image illustrating excellent tissue differentiation and speckle reduction brought by CrossBeam and SRI on an adult kidney



Figure 16.
Illustration showing Long Axis Projection of a traumatic Scrotal Hematoma

Early Clinical Observations

The best way to determine the impact of SRI is through clinical evaluation. Several images plus some early clinical observations follow:

Figure 15 illustrates a long axis view of the mid and inferior pole of the right kidney. The image on the left is obtained with fundamental frequency imaging. The image on the right is same view of the kidney using SRI and CrossBeam. Note the appearance of the hyperechoic cortico-medullary junction. Clearly seen in cortico-medullary junction are vertically positioned interlobular arteries. In the lower pole, dorsal aspect, are several hypoechoic structures. Improvements in contrast resolution provided by SRI allow the user to easily pick these structures from the cortical parenchyma. The hypoechoic structures apparent in the fundamental image on the left are difficult to visualize due to the speckle artifact.

Figure 16 shows a high frequency image of a traumatic scrotal hematoma in live side-by-side format. SRI, CrossBeam and Harmonics are applied to the right hand image. Note that the right hand image does not have speckle artifact between the septated area in the hematoma. Additionally, the “salt and pepper” artifact in the image on the left is eliminated to provide clear border depiction of the hematoma.

Lastly, Figure 17 shows a long axis projection of the Right kidney and Liver with a fundamental image on the left and a SRI image on the right. Ventral to mid portion of the right kidney is a complex mass. The margins of the liver lesion are clearly visualized from the surrounding liver parenchyma due to improved contrast resolution

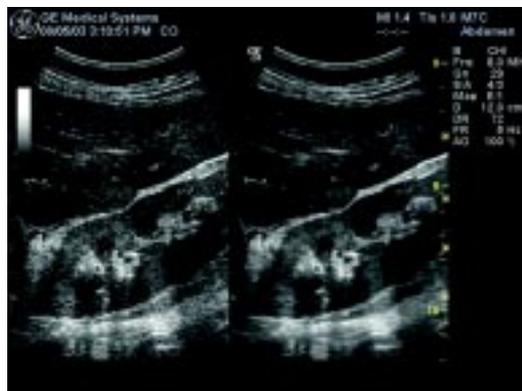


Figure 17.
Illustration showing long axis projection of the right kidney and liver

provided by SRI. Additionally note the improvement in renal capsular appearance. The margins are free of speckle artifact and are presented with an anatomically correct continuous border.

Discussion and Conclusions

SRI, or Speckle Reduction Imaging, is the first real-time algorithm that provides a significant reduction in speckle without the disadvantages that have plagued implementations to date. The adaptive nature of the SRI algorithm allows it to smooth regions where no feature, or edges, appear and maintain or enhance edges and borders. It has been shown that SRI increases contrast resolution by increasing the signal to noise ratio. Lastly, the algorithm does not eliminate any information, so diagnostic criteria is preserved.

These image quality improvements will help to improve consistency in diagnosis, reduce patient and operator dependence and may ultimately improve diagnostic accuracy and confidence and increase patient throughput. SRI methods may also enable computer aided diagnostic techniques.

Sources

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